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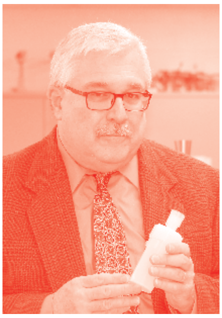



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Meet the editor

Prof. Dr. Sándor Kukovics spent 40 years at the Research Institute for Animal Breeding and Nutrition, Hungary, where he was responsible for the small ruminants sector. He has edited 30 books, published more than 1000 articles, and obtained licenses for 4 products. Since 1996, Dr. Kukovics has been the president of the Hungarian Sheep and Goat Dairying Public Utility Association. Since 2010, he has been the executive manager of the Sheep and Goat Products' Board, in Hungary. Between 2015 and 2019, he served as vice president of the EU COPA-COGECA Working Party on Sheep and Goats. He is a member of the board of directors of the International Goat Association.

Contents

Preface

The future of the goat sector is influenced by several factors, perhaps the most important of which is the growing demand for meat, milk, and other dairy products. Co-products such as hair (mohair, cashmere) and leather (pelt, fur) are also involved in meat production and, in some places, milk production.

The number of goats

There has been a huge change in the number of goats in the world in the last 60 years. The number of goats worldwide almost quadrupled between 1961 and 2019, and in the last three decades this number has doubled. According to the Food and Agriculture Organization of the United Nations (FAO) Statistical Database 2019 (2021), the number of goats kept in 2019 approached 1.1 billion (1,093,732,777 heads).

The importance of goat meat

World meat consumption is diverse and has undergone profound changes in recent decades. According to the FAO Statistical Database 2019 (2021), chicken and pork are the most consumed meats in the world, with beef ranking third. The order of the ten most consumed types of meat in the world is as follows: chicken - 118 million tons; pork - 110 million tons; beef - 68 million tons; sheep meat (lamb) - 9.9 million tons; goat meat - 6.2 million tons; turkey - 5.9 million tons; ducks - 4.8 million tons; buffalo - 4.2 million tons; geese - 2.7 million tons; rabbit - 0.883 million tons.

Although this “ranking” of the types of meat consumed shows an order of importance, there is a considerable difference between the consumption of developed and developing countries. Thus, the consumption of goat meat can be evaluated accordingly.

The most goat meat producing regions

World goat meat production reached 6,252,564 tons in 2019, with Asia playing a key role. According to the FAO Statistical Database 2019 (2021), the production of goat meat is distributed among countries as follows: Asia - 4,529,027 tons (73.05%); Africa - 1,467,207 tons (23.66%); America - 137,407 tons (2.21%); Europe - 96,310 tons (1.55%); Oceania - 22,613 tons (0.36%).

Among the top ten goat meat producing countries, China’s leadership is clear, followed by Asian and African countries: China - 2,357,205 tons; India - 553,380 tons; Pakistan - 491,000 tons; Nigeria - 266,638 tons; Bangladesh - 226,338 tons; Myanmar - 128,701 tons; Chad - 125,789 tons; Sudan - 120,000 tons; Mali - 110,764 tons; Ethiopia - 96,190 tons.

The importance of goat milk

Milk production and consumption mainly involve only a few species. There are large differences in the consumption of the five most popular dairy species, according to the FAO Statistical Database 2019 (2021). The most widely consumed milk is cow's milk (715 million tons), followed by buffalo milk (133 million tons), goat milk (19 million tons), sheep's milk (10.5 million tons), and camel's milk (3.1 million tons).

The most goat milk-producing regions

Goat's milk is the third most popular type of milk, but its volume is negligible compared to that of buffalo milk.

There are considerable differences in the production of goat's milk from country to country. The top ten goat milk-producing countries according to the FAO Statistical Database 2019 (2021) are: India - 5.4 million tons; Bangladesh - 2.7 million tons; Sudan - 1.1 million tons; Pakistan - 0.940 million tons; France - 0.656 million tons; Turkey - 0.577 million tons; Spain - 0.525 million tons; South Sudan - 0.460 million tons; Niger - 0.391 million tons; the Netherlands - 0.386 million tons.

The book is divided in 12 sections

1. **Future of Goats**

The future of goat keeping and farming is dependent on recent changes in meat and milk production and the environmental impact of goat farming, including its role in the production of greenhouse gases (GHGs). In contrast to its negative impact on the environment, goat farming can help to eradicate rural poverty in many parts of the world. Chapter 1 of this book addresses this dichotomy.

2. **Breeding and Selection**

It is challenging to determine which breeding methods can be used to significantly increase the yield of livestock in semi-arid and recently desertified areas and regions. In a large part of the world, in areas where there is a lack of feed and nutrients and a lack of drinking water, the choice of breeding methods and selection of species (local or exotic) is up to the farmers. Chapter 2 summarizes knowledge on breeding and selection. The authors analyze the different yields of various breeds and the effect of genes determining the protein content of goat's milk (based on the different protein fractions of the milk). They also demonstrate the applicability of nucleotide polymorphisms in culture programs.

In the Eastern Democratic Republic of the Congo, goat keeping and breeding are influenced not only by the alternation of dry and rainy seasons and the availability of nutrients and drinking water, but also by metal mining in the area. Chapter 3 evaluates this relationship and analyses the environmental conditions in the Katanga Copper Belt.

3. **Male Goat Reproduction**

There are two basic "halves" of all animal husbandry, including goat breeding: the quality and reproductive capacity of both males and females are essential for successful breeding. There are two main forms of preservation. "In situ conservation" means the conservation with utilisation of the existing stocks. There are two possible ways to preserve "ex-situ". In the "in vivo" version, the representatives of the given breeds are preserved in the zoo or part of the herd of a given breed is kept under protected conditions. "In-vitro preservation" means the "storage" of genetic/reproductive material of a given species in a frozen state. These determinant properties, as well as their test methods, were systematized by the authors in Chapter 4.

4. Goat Nutrition

Chapter 5 describes procedures and methods developed in recent years for feeding and nutrition of goats. Feed products for goats include, but are not limited to, additives, pre- and probiotics, enzymes, antioxidants, secondary plant metabolites, and so on. These can be used to increase animal yields and reduce the use of artificially produced antimicrobials.

On the other hand, in addition to modifying/optimizing the utilization of the area, programmed grazing, reducing the number of herds, and applying for political support programs, additional tools can provide solutions. The authors of Chapter 6 look for solutions to this increasingly pressing issue.

5. Production Systems

Goat farming plays a particular role in the South African region, where animal husbandry is hampered by feed shortages and quality problems, drinking water quality and shortages, low training of animal handlers, limited flock sizes, lack of administration and planned breeding programs, and the presence of several diseases, lower than expected reproductive property of the animals, and so on. These disadvantages were summarized by the authors in Chapter 7, where the number, breeds, and background of production and breeding of goats in 10 South African countries are assessed. The proportion of goats above 90% is limited to small herds, although there are also some large farms with breeding and production programs. The adaptability of the goat, which tolerates heat, feed deficiencies, intermittent drinking water shortages - or quality disadvantages - as well as diseases, is maximized.

The information summarized in Chapter 7 makes it easier to understand the old classification of a goat as a "poor man cow" and how much effort the governments of the countries in the region need to make to maintain goat farmers, the environment and the economy, and how much education, training and further education of the goat farmers are needed to get in this region.

"Backyard goat farming" is quite common, with the greatest numbers of goat keepers farming in this type of system. Chapter 8 examines this farming system in Nigeria.

The importance of goat farming in economically disadvantaged areas cannot be overstressed. It is becoming increasingly important because the keeping and farming of goats require low initial investment. Chapter 9 discusses goat farming in the Eastern Democratic Republic of Congo, where during the country's long civil war most of its cattle was killed for food, leaving goats as the dominant ruminant.

6. Heat Stress

In parallel with global warming, resistance to heat stress is becoming increasingly important in animal husbandry, including goat farming and product production. The goat is excellent at adapting to environmental differences because of a combination of behavioral, morphological, physiological, biochemical, metabolic, and hormonal characteristics as well as molecular changes at the gene level. The effects of heat and moisture tolerance are well traceable in some morphological properties. Chapter 10 examines heat stress in goats.

7. Gender and Climate Change

The increase in both the human and goat population in the sub-Saharan region, where feed and drinking water are scarce, has led to the development of special goat breeds.

Gender inequality is an important factor at the family level, as women tend to do the shopping and decide which products to consume. Care of small animals (goats and sheep) also tends to fall on women. Chapter 11 discusses the important roles that women play in the family unit and the need for gender recognition, which plays a key role not only in the maintenance and upkeep of the family but also in the rural population.

8. Use of By-products

Goats produce two main products (milk and meat), two coproducts (hair and pelt), and one byproduct (manure). Unlike the main product and coproducts, goat manure is yet to be efficiently utilized. Chapter 12 discusses the potential utilization of goat manure in the hydroponic farming of vegetable plants.

9. Animal Health

Goat keeping is also affected by several microbial factors that are fundamentally related to the health status of the animal. Bacteria and viruses can cause serious problems for animal keepers. Chapter 13 examines several bacterial diseases that can affect goats, including anthrax, brucellosis, tetanus, enterotoxemia, pasteurellosis, caseous lymphadenitis, contagious caprine pleuropneumonia, and dermatitis stinking lameness (foot rot). The chapter discusses the etiology, epizootiology, transmission, clinical signs, diagnosis, treatment, preventive measures, and public health significance of these diseases.

There are sixteen known members of the *Eimeria* genus, four of which have been shown to have pathogenic effects and do not occur on all continents, although there are overlaps in their distribution. Chapter 14 provides a comprehensive overview of the genus, including information on the geographical appearance of each variant, its life cycle, pathogenesis, pathology, clinical signs, diagnosis, prevention and control, and economic effects.

Numerous external parasites and the diseases they spread must be considered by all animal keepers. Tickborne illnesses are of particular importance. As such, Chapter 15 summarizes the types of ticks and the diseases they cause and the types of plants that can be used against them.

10. Goat Milk and Human Health

Knowledge of the role of goat's milk in human nutrition is constantly expanding. According to some research, goat's milk, more precisely the peptides formed during the breakdown of milk proteins, may play an important role in the treatment and prevention of hypertension, a condition that is a risk factor for cardiovascular disease.

Angiotensin converting enzyme inhibitory (ACE-I) peptides are some of the most widely used bioactive peptides in medicine and food processing. These inhibitors are applied to regulate blood pressure and prevent hypertension. While synthetic peptides may have several side effects, naturally occurring peptides that replace them do not. The breakdown of both groups of proteins in goat's milk (caseins and whey proteins) produces peptides that can trigger the synthetic drugs. Chapter 16 investigates the health benefits of goat's milk on the cardiovascular system.

Goat milk has a special role to play in feeding babies and the elderly. The reason for this is multifaceted: in part, casein differs from cow's milk in its protein composition and milk fatty acid composition. This difference allows for easier digestion. Moreover, peptides formed during the breakdown of goat's milk proteins can help prevent and treat diseases in infants such as obesity and epilepsy. Chapter 17 explains the beneficial qualities of goat's milk, including its use as a substitute for cow's milk in allergy sufferers and for treating infants with epilepsy and metabolic disease.

Goat's milk has long been known to have robust health properties and has been used as a medicinal food in lung sanatoriums for many decades. Chapter 18 evaluates the properties of goat's milk, including its protein, fat, lactose, vitamins, and minerals.

11. Goat Meat as a Protein Source

The protein content of goat meat is about the same as that of other types of red meat (sheep, beef, etc.), but its fat content, especially saturated fatty acid and cholesterol content, is significantly lower. In addition to reducing the potential negative impact of goat meat consumption on human health, there is little consumer awareness of the biological benefits of goat meat consumption. Chapter 19 highlights these advantageous properties.

12. Economy of Goat Production

One important element of the economics of goat farming is related to animal health. According to Czech researchers, udder health and one of its indicators, somatic cell count, plays an important role in the economic value of goat keeping. The main source of income for goat farming is the sale of dairy products, so the loss of animals from milk production, the cost of veterinary treatment, and a reduction in the amount of milk that can be sold can affect up to one-third of the income of goat keepers. Chapter 20 presents the results of the Czech study.

The economics and profitability of keeping goats as farm animals are important factors in all regions, yet their quality varies considerably. Understanding, analyzing, and outputting this depends on several factors within which clean and known market processes are essential. In addition to production, this includes regulated and known details of slaughtering and sales of meat, but also details of sales of milk and dairy products. The whole process also has significant social and employment implications, which are also part of the assessment of the economy and profitability.

The Maghreb region is not one of the fertile regions of Africa, thus the economic activity of the people and communities living there depends to a large extent on animal husbandry. Chapter 21 examines the role and economic significance of goat keeping in this region.

So-called household goat farmers are an existing category in goat farming and make up a crucial proportion of the number of goat farms in developing countries. Chapter 22 discusses household goat farming in South Africa.

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Section 1

Future of Goats

Chapter 1

Future Prospects on the Goat Activities for the Coming Decades in the Context of a World in Transition

Jean-Paul Dubeuf

Abstract

This article explores the evolution of the goat sector in the world between 2000 and 2020 and its prospects. We base it mainly on the statistics available as well as on the author's observations and his involvement in various projects. It also updates a study carried out on the same subject on the last decades of the 20th century. We observed a constant development and growth of the goat sector during this period. The trend has been the same between 2000 and 2020 but less strong and more localized in Asia and Africa. Several scenarios on our global future lead to consider the absolute need to preserve environment and biodiversity but above all to reduce the emission of GHGs for all productive sectors on the planet. In this case, we will face a dramatic progress and adevelopment paradigm shift. Although goat systems emit less GHGs than other ruminants, we can also observe an overall increase in net emissions by the goat sector between 2000 and 2020. So, they contribute significantly and their net emission has to be reduced, which will disadvantage the most intensive systems. However, while animal production and the consumption of its products are increasingly ostracized, goat farming (as pastoral farming in general) could have a bright future in this context. Goats, particularly those of local populations and breeds, have more than any other ruminant significant capacities to valorize spontaneous absorbing GHGs forage resources (grass, shrubs, crop or feed residues) and without other uses. In addition, goats are easy to integrate in small farms and strengthen the complementarity between agriculture and animal production, largely abandoned in favor of specialization. The strengthening of localized and interdisciplinary scientific research will also be necessary to strengthen the role of goat farming and innovation and the author proposes the establishment of "living labs" associating all the actors involved for this purpose.

Keywords: prospective, innovation- research, ecological transition, goat sectors

1. Introduction

For centuries, humans have used goats for many purposes under various conditions but until recently, goats were less supported publicly and academically than other animal production sectors. Since the 80's, we have observed a renewed interest for goats and goat's breeding and the creation of several institutions and associations dedicated to the development of goat production for milk, meat and fibers. In addition, the creation of the International Goat Association in 1982 has contributed significantly to develop an international network of professionals and scientist to favor innovation and research on goats and organize frequent events to discuss and debate on the more recent knowledge and trends about goats.

At the beginning of the 21st Century, several studies have described the situation of the goat sectors (and small ruminants in general) all over the world as well as their contribution for the development of rural zones and what could be the future of these activities [1–4]. The objective of this article is to up-date these initial perspectives to consider the on-going changes and their consequences for the goat sector and its future.

Since this period, the world has faced radical challenges that have changed in the visions of Science and our Society regarding livestock production. We studied the main trends of global and climate changing and their consequences on the livestock sector including the goat sector. After having reminded the suggestions and recommendations stated at the beginning of the 2000's, we updated data on goat stocks and productions and main observed tendencies.

The implications of global change and ongoing transitions on the evolution of goat production but also on goat science and the type of scientific knowledge requested are explored. In a last part, several possible scenarios are proposed and discussed.

2. Methodology: a prospective approach based on existing statistics and personal experiences

To update the horizon of goats, we first provided a retrospective view of the changes in the goat activities between 2000 and 2020. We compared the present statistics with the trends observed at the beginning of the 2000s. From an analysis of some inflections in these trends, we have developed a prospective analysis of the present changes at work. The prevalence of documented climate issues has been considered as one of the main levers for designing scenarios for the evolution of the goat sector for the next 30 years. The main hypothesis explored here is that the world has to manage a major structural mutation, which will change in depths our way to organize our activities.

Foresight approaches and prospective are necessary to imagine these possible futures whether at local and global levels. Prospective are methods to try to face what could happen and how to be up to the identified challenges. They are neither forecast nor anticipation but a reflection on the future and its possible orientations for stakeholders [5]. Foresight produces scenarios on the strategies they could implement and challenges they could face. To develop a prospective approach, strictly speaking, it is necessary to organize a device with a prospective group of experts and several actors mobilizing documentation and proposing a diagnosis on the present and some scenarios for the future. Consequently, it would imply giving up top-down approaches, still too often the most common ones. Prospective procedures take into account the diversity of local expectations and visions and combine them to formulate realistic scenarios. Until now, the goat sector implemented poorly such foresight visions. For instance, nevertheless, a group of regional partners has organized recently a workshop on pastoral goats and pastoralism in Corsica, a mountainous Mediterranean French Island. The group has built innovative strategic orientations on pastoral breeding and goat farming in this Island for the coming decades [6]. From these scenarios, the stakeholders could discuss what priority actions they should implement. The next step will be to build operational action plans.

In this article, such a device could not be organized art a world extent for obvious reasons of lack of funding and logistics. Nevertheless, to bypass this difficulty, we applied some principles of foresight methods by crossing recent data with our observations on the expectations of goat in several situation and the results of an already published global prospective for agriculture [7]. We are aware that we will need to formalize the proposed scenarios and to validate them locally in the several types of goat systems and situations in the several continents.

3. Results

3.1 The situation of the goat sector as it was presented at the beginning of the 2000s, its prospects and priorities

After a fall of goat stocks at the end of the 19th and the first part of the 20th centuries due to industrialization of animal production and the development of intensive cow and sheep farming, the trend has been reversed during the second part of the 20th century. Statistics on the goat sector [8] showed clearly its growth in all regions of the world. The number of heads increased significantly of nearly 60% in 20 years from 1980 to 2000 and was still constant during the first two decades of the 21st century. Between 2000 and 2010, the total stock of ruminants grew 24% (3.31 billion heads) but the part of goats was higher from 22 to 26% of the total heads.

This global growth has been still more significant in countries with Low Individual Family Incomes (+ 75%) but is general and concerns all continents [4]. The presence of goats in rural areas with a subsistence economy and rising demography explains partly the increasing number of goats. The relative improvement in living conditions among these populations can also explain their ability to increase their herds, which nevertheless generally remained very small (2 to 4 mother goats). Even if the share of goat production in organized markets tended to increase, it remained very small compared to the informal sector, which underlines the social importance of goat farming [3]. At this time, the main issues and challenges for the goat sector in the early 2000's were, moreover, to promote training and technical support for goat keepers with a crucial need for technology transfer and collective governance of the local projects. Another key point was the acceptance of goats in the forest areas with an improvement of the herd management.

In developed countries, the goat sector initially relied on niche markets for the dairy and cheese sector. In this situation, the strategy for development was over all, improving, through technique and investment, the efficiency and performance of production factors (labor, capital, animals) and by reducing production costs. Although, it enhanced the peculiar role of goats, the intensive goat systems followed the same logics than all animal industrial production and in particular that of the dairy cattle sector. For instance, In Europe (France, Spain, Netherlands mainly) the progresses made possible to achieve very high performances equal to or even superior to that of bovine dairy genetics (+ 1000 l of milk/goat/lactation) with a strong specialization of breeding. This success has also often been a model for many projects in Southern countries even if local conditions did not allow the same technologies to be implemented what led to many failures. The development of goat farming was here an alternative to the industrialization of animal production but by proposing to mobilize the same techniques and the same logics.

The prospects for the 21st century were considered favorable, so far as developments led to the modernization of goat farming being increasingly integrated into the economic life of rural populations. The improvement of the health and dietetic quality of the products should make it possible to meet the needs of consumers and improve the image of the goat and its products. Everywhere THE solution proposed was integration into the market economy and scientific research had to produce knowledge to meet these challenges.

3.2 Between 2000 and 2020, the trends on the goat sector confirm the previous prospects and do not take into account new challenges

Between 2000 and 2020, we observe the main trends than previously but with slight inflections. Regarding the goat world stocks, the number of heads has kept on growing dramatically of +44% between 2000 and 2019 (**Table 1**). More precisely, it nearly doubled in Africa but more slowly in Asia and America. Simultaneously, we observed a decrease of the goat herd in Europe (−15%), in Northern America and in China (−8%). These date confirm the increasing importance of goats for small holders in low- income countries.

During this period, the production of goat milk increased in all continents (**Table 2**). These data confirm that intensification remained the main trend in Europe for milk where the goat milk industry is rather strong (+42% milk yield

	2000	2010	2019
World	758	918	1094 (+44%)
Africa	243	348	459 (+89%)
America			
North	2.3	3.06	2.65 (+15%)
South	20.1	21.1	23.1 (+15%)
Europe	19	17.5	16.5 (−15%)
Asia	458	510	575 (+12,6%)
Chine	*148*	*142*	*137 (−8%)*
India	*123*	*137*	*149 (+21%)*
The data are in 10^6 heads – [8].			

Table 1.
Goat heads from 2000 to 2019.

	2000	2010	2019
World	13	17.6	19,9 (+53%)
Africa	3.1	4.3	4.35 (+40%)
America			
North	0.025	0.033	0.026 (+1%)
South	0.31	0.31	0.34 (+10%)
Europe	2.5	2.7	3.07 (+22%)
Asia	7	9.8	11.7 (+64%)
Chine	*0.23*	*0.28*	*0.24 (+4%)*
India	*3.3*	*4.6*	*5.4 (+63%)*
Data in 10^6 tons – [8].			

Table 2.
Goat milk production from 2000 to 2019.

per animal from 2000 to 2019). At reverse in Africa, the dairy performance has decreased of an average of 27%. Although these data meet a high diversity of systems we can consider that the recommendations to invest and control more efficiently have not been applied successfully. In spite of many development projects implemented to support the role goats in small-scale farms by international institutions and Not Governmental Organizations, we have shown that market issues and the governance of the projects limited their impact [9]. Nevertheless, In Asia the dairy collection contributed to the milk supply of rural population with an increase of the dairy performances of goats (+13%). This growth is for instance significant in India.

Goat meat production has also grown steadily during the period, confirming the trend and prospects suggested previously (**Table 3**). Although it keeps minority, the world market of goat meat increased significantly during the period. China followed by India area the two main goat meat producers. China developed export of goat meat between 2000 and 2010, which doubled between these two dates to reach 6700 t but kept at a relatively low level comparatively to production.

Regarding the fibers, several projects in Central Asia promoted the quality of cashmere and the organization of the market although China increased its leader ship on the sector with an identified environmental negative impact on the desertification of Inner Mongolia highlands due to overgrazing [10, 11].

This quick outlook of the goat sectors around the world between 2000 and 2010 confirmed at a large extent the trends proposed previously. In spite a steady growth of these sectors goats remain a minority sector comparatively to other animal production sectors like for instance the dairy cow milk and cattle sector in a ratio of 1 to 10 for meat and 1 to 35 for goat milk although this ratio should be significantly higher on informal markets [8]. However, it appears that the goat sector like other animal production sectors has followed the same paradigms than during the previous period. People consider often progress only through the prisms of the growth and the improved efficiency of production factors.

3.3 The general context has dramatically changed between 2000 and today

Sustainable Development Goals are the global goals adopted by the UN system in 2015 (previously the Millennial Development Goals) as universal call to action to end poverty and ensure that all people enjoy peace and prosperity by 2030. 17 SDGs have been integrated that is, they recognize that action in one area will affect

	2000	2004	2010	2019
World	3879	4500	5200	6250 (+61%)
Africa	886	1030	1230	1470 (+65%)
America				
North	9.7	11.5	11.5	9.9 (+2%)
South	71	71	71	74 (+4%)
Europe	139	140	135	96 (−31%)
Asia	2710	3200	3600	4500 (+66%)
Chine	*1290*	*1630*	*2000*	*2350 (+82%)*
India	*470*	*480*	*520*	*550 (+17%)*

The data are in 10^3 tons – [8].

Table 3.
Goat meat production from 2000 to 2019.

outcomes in others, and that development must balance social, economic and environmental sustainability" [12]. Beyond the formula and the slogan, the development of goats could be an important lever among others to reach these goals and improve human condition in many areas.

But simultaneously, in 2015, under the pressure and dissemination of the reports of the International Panel of experts on Climate Change (IPCC, [13]) and the concrete observation of the present effects of the climate change (higher prevalence of hurricanes, floods, drought, big fires, heat waves), a large number of countries firmed the COP 21 Paris agreement. By this agreement, the world realized the dramatic possible incidence of global changing on the humanity's living conditions at short and middle term. The COP 21 and the following COP fixed goals to keep the increase in global average temperature to well below 2°C (3.6°F) above pre-industrial levels; and to pursue efforts to limit the increase to 1.5°C (2.7°F), recognizing that this would substantially reduce the risks and impacts of climate change.

In spite of the denial on the realty and future impact of this climate changing by some countries (USA until 2020, Brazil…) and some experts, they were a minority. The awareness of the danger is now nearly universal and the discussions and debates are more today to the intensity of the measures to take for the mitigation of the increase in Green House Gas (GHG) emissions. CH4 and N2O emissions from manure management, deposition on pasture with enteric fermentation make livestock the main agricultural source. The total emission of GHG at the world level and their sharing is on **Table 4**. From these data, we see that agriculture and food systems are responsible of nearly 30% of GHG emissions, the main responsible in climate changing and animal production of 15% (+ 12% from deforestation for Animal production). Some studies have estimated that Agriculture, animal production and forests could provide 1/3 of the total potential mitigation of GHG emissions.

The total livestock numbers has kept on growing dramatically in all major categories from 80 to 210% between 1990 and 2018. As animal production is a major responsible of climate changing for many institutions and environmental organizations, the need for the mitigation of the GHG emissions would lead to limit significantly animal production and reduce milk products and meat! There is a real trend to substitute animal for plants in the food systems.

Nevertheless, we have to relativize these drastic orientations. Firstly, the growth in animal numbers, milk and meat production is mainly due to industrial production systems that still increase their level of intensification and are very dependent on not renewable resources. Secondly, the data are global which simplifies the issue; we have to differentiate the characteristics of each production systems and the contribution of each system for climate warning could vary significantly.

	Annual GHG emission	%
Total	37	100
Agriculture and food systems	11	30
Total Animal Production	5.35	14.5
Enteric Fermentation –Animal production	2.1	5.4
Deforestation due to Animal production	4.44	12

The emissions are in Billions tons equivalent CO2 – [8, 13].

Table 4.
Total emission of GHG at the world level.

Secondly, the recommendations of the experts on climate changing have always insisted that integrated responses should be imagined to link mitigation of GHG and addressing poverty eradication and rural employment while positively contributing to fiber and food security. Other issues have to be taken in account and measures for reducing loss and waste could be very positive.

3.4 A focus on the role of goats towards a climate-friendly and resilient livestock development

There is a global consensus to consider that the challenges we are all facing concern all sectors of activity. **Table 5** logically shows that the impact of goats on CO2 and CH4 emissions is relatively low compared to, for example, that of dairy cows. 3% and 10% of the total emissions are due respectively to the enteric fermentation of goats and cows respectively. However, ignoring these emissions is impossible and for instance, there is an increase in these emissions in Africa and Asia, whereas they tend to decrease in Europe.

In this logic, intensive goat farming wherever it is must really control its emissions such as for dairy cow. In most other situations, goat farming is rather characteristic and emblematic of integrated small-scale farming in domestic economies and agriculture and small herds are often associated. This often involves either extensive systems, based on the use of grassy or shrubby rangelands either small family farms of 2 to 4 heads that consume family residues or fodder resources at the edges of plots. In all cases, we speak of resources that would have no other valuation than through animal production.

In addition, family breeding helps to fertilize crops without mineral fertilizers; we know also that one ha of natural meadow absorbs 1 t of Co2 and one ha of forest 3 t which brings an additional benefit. These systems, often associated with transhumance, also make it possible to depend less on supplementation based on creatures and proteins such as soya.

	2000	2010	2018
Dairy Cow World			
CH4	0.16	0.18	0.18
CO2	3,4	3.79	3.76
Goat World			
CH4	0.038	0.046	0.052
CO2	0.79	0,94	1,09
Africa			
CH4	0,012	0,017	0,022
CO2	0,26	0,37	0,46
America			
CH4	0,0017	0,039	0,002
CO2	0,036	0,37	0,04
Europe			
CH4	0,009	0,0087	0.0084
CO2	0,020	0,018	0,0176
Asia			
CH4	0,027	0,025	0,023
CO2	0,48	0,54	0,47

The emissions are in billions tons per year – [8].

Table 5.
Enteric fermentation from goats from 2000 to 2019.

A simplistic but a more and more widespread view today tends to ban animal production from agricultural and food systems and their future. This militant and extreme vision does not take into account the diversity and complexity of the situations present in particular in the Southern regions and may even have a negative balance in GHG emissions. The few elements we have developed above encourage us to reconsider animal production and a majority of goat systems not as a sector of activity, as an "industry", but as a component of complex and diversified agro-food systems.

Reconsidering goat farming also implies moving away from the analysis of life cycles based only on the efficiency of each production factor taken individually. These perspectives open up new and numerous fields of research and production of knowledge. We had already underlined the importance of simultaneously mobilizing and combining the contribution of several disciplines [14]. In Human Sciences, we have to understand the conditions for a constructive dialog between the various stakeholders and promote the local organization of activities, the quality of production and the marketing of products.

The analysis of the interactions between animal system and agricultural system should lead to redesigning new technical itineraries. The hybridization of local knowledge with generic science could allow goat activities to be primarily based on human capacities. By favoring an intensification, not of production factors, but of skilled labor, we will favor innovative design systems that will give the goat its full place in these systems [15, 16]. We will also support local policies to generate positive externalities and respond to the challenges of global change and agro ecological transition. Thus, the orientation of goat research must be redefined in a more open and systemic perspective. We know that science, with all society, often remains ideologically locked up to the point that it is almost impossible to question our representations and our paradigms. The ever-present and rather totalitarian processes of cognitive locking in often unconsciously lead to the stifling of all critical thinking [17, 18].

3.5 What scenarios for goat farming in the next 30 years?

We have enlighten above the path of the futures of goat farming by looking at the present and its challenges, but also by looking back on the past. From these elements, it is thus possible and necessary to envisage in a lucid way what could happen at short and mid-term. We have showed previously that at a large extent, the future of goat farming will depend on the local dynamics of the territories where it is present. It is the strong implication and the broad participation of all the involved actors, which through their dialog will be able to build futures, which are not yet pre-determined today.

But, at a more global level, the future of goat farming will be decided upstream by the future trends of human societies and the main scenarios of change at work with regards to the global change mentioned above. Of course, it would be neither coherent nor legitimate to propose a general foresight on goat farming in the world. Nevertheless, the possible evolution of the place of goats and their role in the dynamics of many rural areas can be explored from the main global trends and policies in the world on one side on the diversity of the goat production systems on the other side [9]. We use for this the global foresight Agrimonde project to explore the possible futures of the world's agricultural and food systems up to 2050, and too face its key fundamental challenges [7]. The scenarios of the Millennium Ecosystem Assessment (MEA) are the bases of the hypothesis formulated by Agrimonde. The MEA scenarios differ according to the geopolitical configuration (globalization versus regionalization), and the management of environmental issues (proactive versus reactive).

The first hypothesis proposed by Agrimonde is that the world will collectively succeed and decide to face the challenges of climate changing, environmental control and apply the principles of sustainable development. This hypothesis leads to a scenario for feeding the planet by preserving eco-systems, reducing GHG emissions and use of fossil energy. We see major changes in how losses will be managed, in dietary habits and in organization of production systems: It will thus mean a substantial change in current habits and trends. This hypothesis asks new questions about how research is tackling the changes in yields and in the areas used for agricultural production, and their extent and their technical, economic, social and environmental consequences. By linking the technical and land-related aspects of the yield-area pairing, it establishes ecological intensification as a major issue. With this hypothesis, agricultural development could become again a driving force of global economic development and poverty alleviation. Rural areas could create many jobs to absorb underemployment caused by automating many functions in administration, finance, travel, etc. In this world, animal production and consumption will significantly decrease globally, but this hypothesis could be a chance for goat farming and more widely pastoral systems. This scenario will be favorable to the development of systems combining agriculture and animal production. Family farming will be more efficient and more integrated. Research would orient its priorities in favor of agro ecological transition with reinforced financial resources. Agriculture will be more attractive to many young people and goat farming will benefit from a positive image; pluri - activity will replace previous trends towards specialization. Efficient extension services will relay the knowledge produced and new technologies; simultaneously, a better control of the management of pastoral herds (goats and other species), particularly in terms of valuing spontaneous resources and fodder could limit overgrazing and erosion. Conversely, we will see the reduction of the most intensive systems, as for other livestock sectors.

The second hypothesis will make still global economic growth a priority to feed the human population. Technological development will allow for a more intensive farming, as well as for an extended use of fertilizers and plant material, much of them genetically modified to prevent environmental impacts. The vast majority of farms, both small and large, will be highly mechanized and industrial. Local know - how will be often replaced by standardized industrial methods and the variety of agricultural species will keep on decreasing. Multinational firms are a predominant feature of this scenario; they will increase their control over plant and animal production, primarily through the development of new genetic strains. In this second hypothesis, awareness of global issues is slower and more controversial but environment and climate changing are also a priority. The general opinion is that technological innovation is the solution face these challenges. New digital technologies will better manage and control the management of herds and their environmental impact. The divide between the most favorable areas for agriculture and livestock farming and the marginal areas would remain predominant. The search for productivity will continue to be the engine of change in areas with the highest potential with a concentration of capital, land and equipment. This trend will favor goat farming with large, high-performance herds in dairy production, but also meat and cashmere; but they will benefit a relatively small number of breeders and social or equity issues will be few integrated in the implemented strategies. In addition, the growth of goat heads will continue in marginal areas under the effect of demographic pressure. Goat farming will thus contribute to the subsistence economy of many populations without benefiting from the support necessary to improve their living conditions. In this scenario, the effects induced by climate change will probably also still impact negatively the poor rural populations.

4. Discussion and conclusion

Between 2000 and today, throughout the world, numerous projects involving goats and in favor of poor rural populations have been implemented with the support of international NGOs, International institutions or private actors. The comparative study carried out in 2013 for IFAD identified success indicators to scale up these projects [9]. It also showed that many of them failed because poor anticipation of the real market for goat products, their bad governance and inadequate funding (often too large for a too short period). The organization of a goat industry consolidated in Europe, America and Asia for milk meat and fibers but the share of the goat stocks and farmers in the informal not profit sector is still dominant.

Given the economic and social climatic challenges that the world will have to meet, goat farming can play an important role in the restructuring of the agricultural systems of many regions. We are indeed in a situation of paradigm change. In terms of research and production of knowledge, we will have to understand better the practices of farmers, and integrate crops and goat farming, to control diseases without antibiotics and to identify what social economic technical performances they need. The organization and development of training will be another important issue.

This conclusion opens up new perspectives for scientific research and interdisciplinary research. Less than ever, there will be a single model of goat development. For each region, it will be necessary to identify the potential of existing production systems, breeds, available food resources, value chains. This will involve new ways of doing research. For example, living labs are a methodology where all the actors involved in a problem participate fully in the research and innovation process [19]. For the goat sector, the implementation of "living labs" type devices could allow the design and full-scale testing of innovative goat systems for new uses for the products and services necessary for them to develop.

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Section 2

Breeding and Selection

Chapter 2

Goat Type Selection and Molecular Markers; a Solution for Milk Production in Recently Desertified Zones

Erwin Strahsburger and Juan Scopinich-Cisternas

Abstract

Goat farming has been severely affected by Desertification, limiting their water and food resources and inducing physiological heat stress that reduces the doe milk yield. Does well adapted to heat stress would be a possible solution, but creole or indigenous goats from desert or arid areas produce between 0.5 to 1.5 L of milk per day, which is lower than the 3 L of milk per day produced by dairy goats like the Saanen breed. Nevertheless, in this chapter, we will discuss the disadvantages of introducing common dairy goats in dry places. Instead, we propose the introduction of desert goats from the Middle East or India, because they produce high-quality milk with low feed intake, making a profitable goat farming activity, and an opportunity to include crossbreeding strategies to improve the herd milk yield. Creole goats, on other hand, has been an underestimated livestock animal with a rich and unveil genetic patrimony that migth improve the herd milk yield. The effect of improved diets and extensive husbandry conditions remains unexplored in desert creole goats, and the use of advanced knowledge in goat genomics, genetic expression, and a wide variety of molecular markers can improve the studies on creole goats for crossbreeding strategies identifying the best traits involved in high-quality milk production and adaptation to dry environments. In this way, the synergy between goat type selection and molecular markers should boost goat farming in recently new desert or arid zones, counteracting the detrimental effects produced by the desertification.

Keywords: goat type, lactation, mating, Creole, molecular markers, crossbreeding, desert, arid, genomics

1. Introduction

The current climate change is a consequence of the increased content of atmospheric CO_2, CH_4, N_2O, and particulate matter, which raised in 1.2°C (2018) the surface air temperature [1]. This warming climate change has impacted the hydrological cycle inducing a Hadley cell expansion and poleward movements of the jet stream, making dry areas becoming drier and wet areas became wetter [1]. This effect has been observed mainly in countries situated between 30 degrees latitude south and 30-degree latitude north (Hardly cell) and correspond very well with the reported literature by these countries to counteracts or diminish the drought effect on farming activities [2–5]. Among these detrimental effects, desertification is defined as the effects of constant dry or persistent drought on fertile lands, making them desert and unsuitable for agricultural activities.

Farming land is a limited resource and climate change is reducing it, due to the desertification of rural areas usually used for agricultural purposes [6]. This devastating impact requires mitigation actions to prevent the advance of poverty in farming communities, the food shortage, and the loss of farming land [5, 6]. In this sense, is necessary to take action and start goat breeding plans in places with advanced desertification conditions that threaten the goat farming activity and their rural communities. One of these actions has been the migration of Pastoral activities to livestock production to sustain the goat farming in lands hardly affected by desertification [5]. This adaptation involves changes in the feed resources, the growth of forage resistance to desert or arid conditions but with good nourish properties, and the improvements in goat management to reduce the heat stress and sustain the goat milk and milk derivatives such as Cheese, and Yogurt [2, 5, 7].

Fortunately, the solution to sustaining goat farming activities is the goat itself. Among livestock animals, the goat is the best candidate to sustain farming activities in desert or arid zones [3, 8]. This is because domestic goat (*C. hircus*) is originally from the middle east and then was diversifying and habitat diverse places in Europe, Asia, and North Africa, to finally arrives in America and Australia by the European conquers [9–11]. *C. hircus* species has three genetic lineages. The first lineage A is present in diverse goat types across many continents and started at >200,000 years ago (YA), a long period before the beginning of goat domestication estimated around 9,000–13,000 YA according to fossil evidence [12]. While the lineage B and C started immediately after goat domestication and expanded around 10,000 YA to South and West Asia [12]. Regarding the descendant of lineage A, there is a weak cluster geographically marked (around 10%), suggesting that most of them have been widespread across the globe due to their natural migration with the human population across human history [10, 13]. That suggests domestic goat has a genetic diversity across the globe, being a huge source of diverse goat types with different adaptation traits to improve milk production in different local environments and resist climate change in rural places with limited resources [3, 14].

This chapter will discuss goat diversity and its potential in developing high milk production in desert zones. The unsuccessful experiences of not-desert dairy goats introduced in desert zones will be commented on, and the advantage of desert goats as well. Besides, the unexplored creole goats will be commented as an unexplored goat type with a valuable genetic patrimony to adapt to harsher conditions. Finally, taking advantage of all advances in genomics and molecular markers to follow goat milk production, will be discussed how these tools have been used and which are their potential to assist crossbreeding plan to improve goat milk production in areas affected by desertification.

2. Methodology

The literature analysis was done using google scholar and keywords such as; dry, desert, milk production, goat, farming, casein among other related words. Those studies performed on countries with hot, arid, or desert zones were considered for analysis and others studies from other countries that not belong to dry or desert areas were added to enrich the discussion.

2.1 Comparison of Milk Yield in Diverse Goat Types

Table 1 is a comparative and normalized analysis of milk yield per day for diverse goat species that inhabit hot, desert, or arid zones was performed. Not all these studies have reported the same milk yield parameter in terms of kg of milk per day. For those studies with a reported total lactation yield, the total milk yield was divided by the lactation period to obtain the milk yield in kg/day. In cases of total or daily milk, the yield was reported in liters, the conversion to kg was performed using the goat milk density of 1,11285 kg/l. That value comes as the average of the milk density considered in a range of 0.9917 to 1.2324 kg/l according to the report by Gabas et al. [29].

Goat type	Habitat or country	Milk production (kg milk/day)	References
Black Bedouin	Desert of Negev, Israel	0.9–1.5	Shkolnik et al. [15]
Saanen	Italy	2.78	Serradilla [16]
Saanen	Tanzania	1.5	Nziku et al. [17]
Ardi	Saudi Arabia	0.9	Kim et al. [18]
Ardi x Damascus	Saudi Arabia	2.1	Kim et al. [18]
Damascus	Egypt	1.3	Kahilo et al. [19]
Barki	Egypt	0.7	Kahilo et al. [19]
Zarabi	Egypt	1.0	Kahilo et al. [19]
Zarabi x Barki	Egypt	1.0	Kahilo et al. [19]
Damascus x Barki	Egypt	1.2	Kahilo et al. [19]
Beetal	India	1.2–1.3	Kumar et al. [20]
Barbari	India	0.8	EI Gadir et al. [21]
Beetal x Barbari	India	1.0	EI Gadir et al. [21]
Beetal x Saanen	India	1.3	Shelton et al. [22]
Beetal x Alpine	India	1.2	Shelton et al. [22]
Saanen x Nubian	Sudan	1.3	Gol [23]
Sahelian	Mali	0.7	Hosseini et al. [24]
Sahelian x Anglo-Nubian	Mali	1.5	Hosseini et al. [24]
Mamasani	Iran	0.67	Kume et al. [25]
Mamasani x Saanen	Iran	1.3	Kume et al. [25]
Chilean Creole	Chile	0.2–0.9	Egwu et al. [26]
Saanen	Chile	1.0–2.3	Egwu et al. [26]
Chilean Creole x Saanen	Chile	0.5–1.6	Egwu et al. [26]
Sahel	Nigeria	0.3–0.5	Marletta et al. [27]
Red Sokoto	Nigeria	0.3–0.42	Marletta et al. [27]
West African Dwarf	Nigeria	0.32–0.36	Marletta et al. [27]
Mexican Creole Goat	Mexico	0.65–1.1	Turkmen [28]

Table 1.
Goat breeds milk production.

3. The dairy goat type for desertify zones

3.1 Milk production by dairy goat naturally not adapted for arid or drought zones

Dairy goats like Saanen (Sweden), Toggenburg (Sweden), Alpine (France), and Anglo-Nubian (England) have a remarkable high milk yield under extensive breeding conditions producing between 600 to 1000 kg of milk per lactation period and extraordinarily exception until 3000 kg of milk as described for a Toggenburg goat animal in 1997 [16, 30]. Therefore, seems common sense to introduce any of these dairy goats in arid zones to promote goat milk production. However, this naive approach does not always have succeed. Common dairy goats are naturally adapted to live in moistening and cold environments with plenty of food and water covering all their metabolic demands. While in dry or arid zones they have a limited food resources and dry conditions that do not satisfy their metabolic demand for high milk production [31].

Common dairy goats introduced in tropical or desert environments have a low milk yield barely producing. 200 L and 80 L, respectively [16, 22, 32, 33], as a consequence of the heat stress condition and changes in their cellular metabolism and immune response [22, 33–37]. Dairy goats under heat stress conditions reduce their food intake between 22 and 35% and their milk production between 3 and 10% with a reduced content of lipids, proteins, and lactose [35]. In Trinidad and Tobago, Saanen goats were introduced to improve local goat milk production but this initiative never prospered because the animals never were able to adapt to their arid conditions, manifesting detrimental thermoregulation, reduced prolificacy, and low kidding interval [38]. In a similar situation, local farmers from Tanzania imported Saanen, Toggenburg, and Norwegian goats to start dairy goat farming, and they reached a maximum milk yield of 1.2 kg per day, which was three times less than the expected 3.5 kg per day for Saanen and Toggenburg and the half of expected 2.3 kg for Norwegian goats [17]. These authors also noted that dairy goats had a low birth rate of 64%, while in a cool and moist environment the Saanen goat has an 81% of birth rate (**Figure 1**) [39], concluding that new breeding schemes must be planned to support a more productive goat farming activity [17].

Another interesting experience was took place in the Atacama Desert in Northern Chile. This place is one of the driest deserts in the world with less than 5 mm of rainwater per year, and comprise the Pampa of Tamarugal as an agricultural area with a protected forest placed at its core [40–42]. Underground of this Pampa of Tamarugal there is a water basin that sustains these agricultural activities and its forest, which have trees with deep roots to reach this water source [43, 44]. However, even with this water and food supplies available, the high temperatures and low moisture may induce heat stress on dairy goats affecting their milk yield (**Figure 1**). That explains the low milk yield observed in Saanen goats introduced in this Pampa in 2008–2009 by local ranchers within a regional strategy to improve goat milk production in local communities [33]. They include a low number of animals and in consequence, their statistics is not strong enough, but still this study worth its analysis.

They perform a crossbreeding between Saanen goat using one male and ten females, and another crossbreeding with one creole male and six Saanen females. In the first crossbreeding group they had seven pregnant goats and one of them had a spontaneous abortus, while the second crossbreeding group had four pregnant goats and any spontaneous abortus. Unexpectedly, all pregnant goats of the first group ended their gestation period delivering twins of the same gender or different genders. While the second group had only one pregnant goat that delivered twins of the same gender [33]. Usually, Saanen has a 22–45% of goat's twins birth

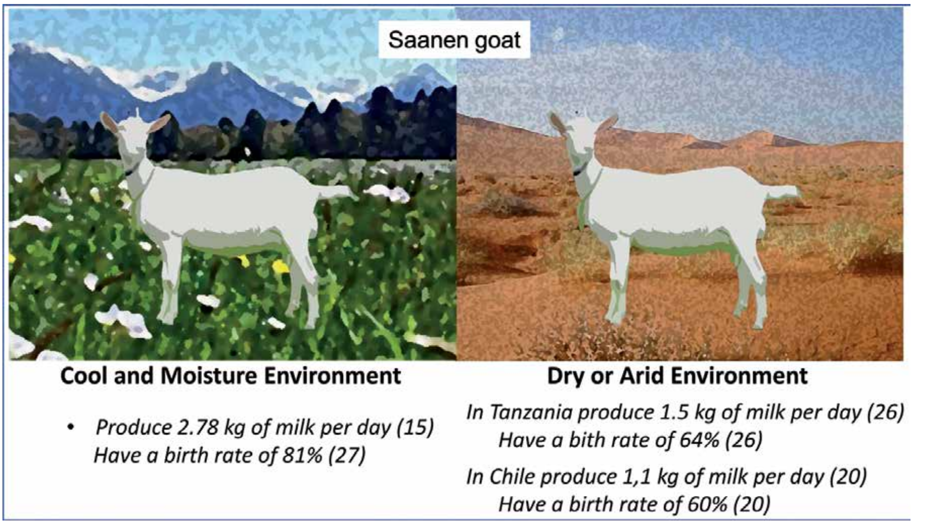

Figure 1.
Milk production of Saanen goat in different environments. Source: The final version of ***Figure 1*** *was developed be the authors.*

rates according to the doe age [39], so these unexpected results might be linked to some genetic traits present in the male Saanen [45], although this observation was unexplored by the authors [33].

The litter size observation is relevant because could be considered as a predictive value for milk yield. In Alpine goats with twins or triplets offspring produced on average 32 kg more milk than singletons goats [46]. Similarly, a study performed in the United Kingdom demonstrated that Saanen goat with single birth, during its first, second, and third lactation period produced at the 50 days a total of 143, 150, and 91 kg of milk, respectively. While twin birth goats produced 156, 205, and 216 kg of milk in the same period [47]. That constitutes an increment of 37% and 137% regarding the singleton milk yield during the second and third lactation periods.

From that perspective, for Olave et al., the high amount of twin birth observed in their study would auspice a high milk yield in that study group. However, they reported an opposite result. The maximum milk yield was 1,8 L of milk at day 10, decreasing the milk production at 1 L at 50 days and then 0.5 L until 100 days of lactation. Although the authors [17] did not determine the average total milk yield per goat, their graphic suggests a total milk production of around 60 L at day 50. Considering a milk density of 1.112 kg per mm^3 [29], the authors probably produced around 66.7 kg of total milk at day 50, which is around 46% less than the expected for a Saanen goat only the 32% of the expected production for a mother goat with twin birth rate at the second lactation period [47].

In summary, the study of Olave et al. [33] is interesting because demonstrates that the introduction of common dairy goats in desert zones, even under a controlled condition with plenty of food and water, finally is hardly affected by the low moisture and high temperatures reducing their milk yield. Therefore, seems do not recommendable to introduce common dairy goats in desert zones, unless a high investment in technology would be endorsed to adapt the desert environment for a more moisture and cool husbandry. Although this investment could be afforded by developed countries, for smallholder from developing countries [48, 49] cheaper alternatives are needed, being important to explore new crossbreeding programs with native and dairy goats without major changes in goat farming.

3.2 Milk production by dairy goat adapted to arid or drought zones

In arid or desert zones, native goats have been well adapted to produce high-quality milk under limited supply conditions. In Israel, the black Bedouin goat that habitat at the desert of Negev (**Figure 2**), can produce between 0.95 to 1.561 kg of milk per day during the first lactation period in goats of 1–2 biological years (**Table 1**), and until 1.640 kg per day in older goats of 3–7 biological years [50]. This goat produces quality milk with a stable content of protein, fat, and lactose in 3.5%, 5.5%, and 5%, respectively, until the fourth lactation period [15]. Therefore, this goat is a highly efficient livestock animal that produces high-quality milk under desert conditions [51].

Black Bedouin goat has a better adapted physiological response for dryness conditions than Saanen goat. The Bedouin goat can adapt its feed intake from 63.9 g/kg to 52.0 g/kg after 3 days of dehydration, while for the Saanen goat the same adaptation involves a more extensive feed intake reduction from 95.0 to 55.3 g/kg in the same period [52]. In other words, Bedouin goat is already adapated for goat farming under low consumption of nutrients and waters in heat stress envirnments, reaching a basal physiological condition without stress. Meanwhile, for Saanen goats, there is a higher gap between the standard food and water demands under milk farming production, and a basal physiological state under heat stress conditions, being more physiologically stressfull for this dairy goat. Curiously, both Bedouin and Saanen goats were able of reaches the same water and food intake rate after three days of dryness [52]. In consequence, the black Bedouin goat tolerates much better the heat stress and constitutes a better race option for goat farming in arid and desert zones [53].

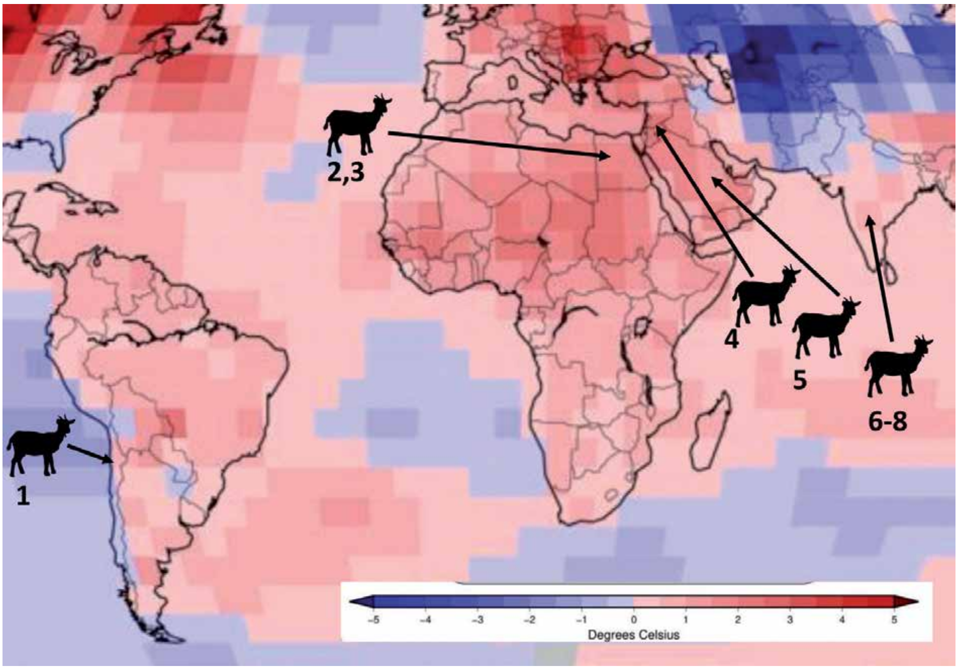

Figure 2.
Distribution of desert and creole goats with the potential to boost milk production in desertified areas. The map represents the land and ocean temperatures departures for average Dec 2020 with respect to a 1981–2010 base period (map from National Center for environmental information, GHCNM v4 0.1.20210105.qfe). The maps shows the habitat of selected goat breed that habitat to hot area in the Middle East, India and northern Chile. The goat breeds are: 1, northern Chilean Creole goat; 2, Barki goat; 3, Zarabi goat; 4, black Bedouin goat; 5, Ardi goat; 6, Kutchi goat; 7, Beetal goat; 8, Jamunapari goat. Source: The final version of ***Figure 2*** *was developed be the authors.*

Black Bedouin (Dhaiwi), Sahrawi (Desert) and Jordanian Damascus (Shami) goats are from Jordan (**Figure 2**), and like many other goats of the middle east have a common genetic origin [54]. Black Bedouin, Sharawi and Ardi goats belong to the same phylogenetic cluster according to genetic studies based on the polymorphisms of 17 microsatellite [54]. Curiously, the Ardi goat does not belong to the Jordan Country but to the Kingdom of Saudi Arabia (KSA), the nearby country (**Figure 2**). This goat is capable of regulating its hearth beat, corporal temperature, and diverse hormones like cortisol, triiodothyronine, and thyroxin according to the season (winter or summer), showing its evolutionary adaptation traits to live in hot and dry environments [55]. Consequently, the Ardi goat is considered the best animal for goat farming across all KAS, supporting harsher conditions, limited feed nutrition, and still give enough meat and milk to sustain economically to local farmers [56]. For that reason has been included in a national breeding program to spread its genetic trait on the herd of goat farmers across the KAS to increase the meat and milk productivity and decrease the national poverty rate [56]. The Ardi goat has a milk yield production of around 225 kg for milk yield [57], and within a crossbreeding plan with Damascus goat, they have produced a hybrid offspring capable of produce until 514.19 kg for milk yield and better milk quality in term of fats and proteins content than the Ardi and Damascus goats by itself, suggesting a good opportunity to improve the herd genetic background and increase the milk production among goat ranchers [57].

Egypt is another country of the middle east, and its coast harbor the Barki goat (**Figure 2**), which has evolved to live in arid zones [18]. Its genome possesses genes related to thermotolerance, body size, energy metabolism, digestive and nervous system, and immune response [18]. In a study with a lactation period of 16 weeks, the Barki and Zarabi goats have a low milk yield of around 0.7 kg/day of milk and 1.0 kg/day, in comparison with the 1.3 kg/day produced by Damascus Breed (**Table 1**) [58]. The crossbreeding between Zaraibi or Damascus male with Barki Dam produced an offspring that increased the milk yield to an equal or similar value of Zarabi and Damascus parental goats (**Table 1**) [58]. This improvement may be related to the polymorphism of the β-lactoglobulin gene [57], a molecular marker for milk production [19]. In this genotype the alleles most related to milk production in decreasing order are; A > B > C > D. Therefore, goats with A or B genotypes will produce more milk than those with C or D genotype. For example, in Damascus goat the most frequent polymorphism is AC (33%), BD(25%), BB(17%) and AA(17%), while in Zarabi goat is mainly BD(73%) and a reduced population of AC(27%), and for Barki goats is BD (73%) [59]. Therefore, using molecular markers to select those parents with A or B genotype and then identify in the offspring those with AA, BB or AB genotype, could help to adders crossbreeding strategies between Barki and Zaraibi or Damascus goats to improve the genetic background of the selected herd keeping only those kids with the AA genotype for milk production, shown in **Figure 3**.

Another interesting dairy goat from dryer zones is the Indian Beetal goat (**Figure 2**). Its lactation curve showed a milk yield of 1.2–1.3 kg/day according to the parity and doe age [60], and its milk has been used for yogurt production with good sensory and nutritional characteristics [20]. The Beetal goat, together with Kutchi and Jamunapari breeds are classified among the more productive dairy goats in India (**Figure 2**) [16] and considered a useful multipurpose goat for tropical and dry environments [34, 61]. Regarding the crossbreeding strategies, the crossbreed between Barbari and Beetal goat produced an offspring more productive than their parents [62]. The Barbari goat produced 0.886 kg for milk yield, meanwhile, the Barbari x Beetal crossed goat produced 1,045 kg for milk yield (**Table 1**) [63]. In the same way, a crossbreed between Beetal with Saanen or Alpine goats produced offspring with the same milk yield as Saanen and Alpine goats in tropical

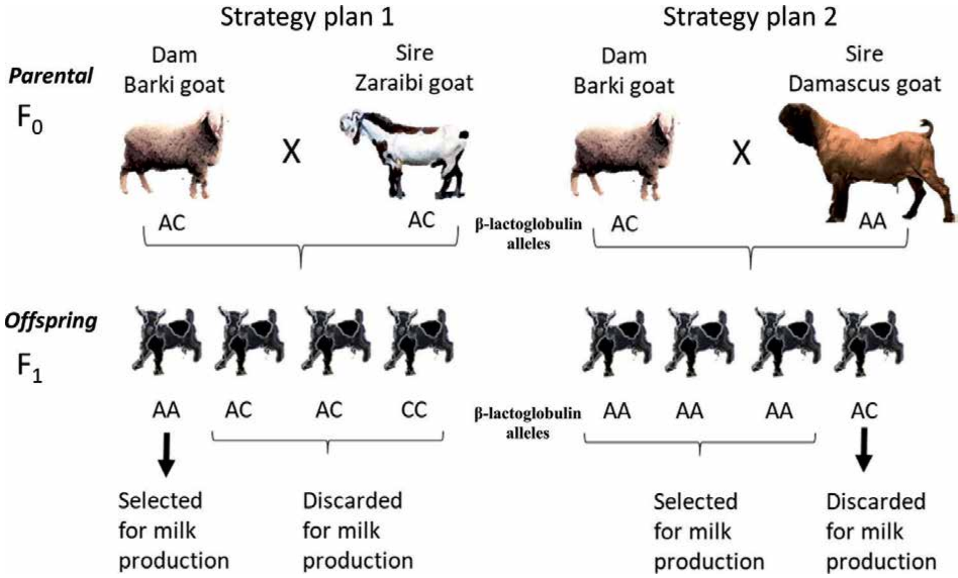

Figure 3.
Example of a crossbreeding strategy assisted by β*-lactoglobulin molecular markers. Source: the figure developed by the authors.*

environments (291.4 kg vs. 303.1 kg), but with a shorter lactation period (230 days vs. 248.2 days) [22] (**Table 1**). That improvement was an advantage for local farmers because involve the same milk production but in a shortened period.

In other desert areas, the crossbreeding experiences using parental desert goat breeds and non-desert dairy goats have given different results. However, these studies have shown inconsistency in the parity, milking frequency per day, feed conditions, lactation stage, and environmental factors, making it difficult to do a fair comparative analysis between them. For example, in Sudan, the crossbred Saanen-Nubian goat produced 1.2 L ($\approx$ 1.3 kg) per day and with only one milking per day (**Table 1**), with limited food, and during the second lactation period [21], while in a similar experience applying the same crossbreeding strategy (Saanen-Nubian) had an offspring able of produced 2.55 kg for daily milk yield during the second lactation period and increasing to 3.37 kg for milk yield in the third lactation period [23]. In this last study, the pure parental Saanen and Nubian breed animals produced 0.67 and 0.73 kg of milk daily, evidencing the detrimental effect of the heat stress on their milk production, and suggesting that the off spring have acquired the best adaptative traits from their Saanen and Namibia goat parental to produce high milk yield in the desert and arid conditions.

Another good experience was reported for a crossbreeding between the Sahelian and Anglo-Nubian goats. The offspring produced 1.37 kg milk per day, while the Sahelian goats only produce 0.74 kg/day, half of the hybrid milk production. Besides, this hybrid crossbred goat increased their milk quality from 4.7% to 5.8% for total lipids concentration and from 3.9% to 4.1% for total protein contents [64]. On the contrary, in Iran, the crossbreeding between local goat Mamasani and Saanen breed had a progeny able to produce 1.31 kg of milk per day, the double volume produced by the local Mamasani goat (0.65 kg per day) (**Table 1**). However, this progeny produced low-quality milk with reduced fat-protein contents, changing the expected 4.8% to 4.1% of fat and protein contents from 3.9% to 3.6%, respectively [24]. In Albania, the crossbreed goat between Alpine and local goats produced 30% more milk than native goats, but still was half of the milk yield of the Alpine breed and the milk quality was not evaluated [25].

In consequence, a great diversity of goat breeds well adapted for arid and desert zones are good candidates for crossbreeding plans addressed to improve the goal milk yield of the herd. However, each crossbreeding plan has to be meticulously planned and executed because diverse experiences have shown different results, some of them very successfully but others barely succeed.

3.3 The creole goats in dairy goat farming; an unexplored type

Creole goats arrives with the colonizers and was adapted to the local environment across the centuries. Genetic studies based on the polymorphism of microsatellite markers were done on goats located across the American continent and their results show that creole goat comes from Iberia and Africa and are geographically clustered [65, 66]. Their origin started in Veracruz (Mexico) and goes in three directions; to the North, to Central America passing through Panama and to the Vice Kingdom of Peru, and then to Argentina [67]. Meanwhile, the Portuguese introduced the goat in Brazil, explaining this particular genetic cluster differentiated from the rest of America [65, 66].

The Creole geographical cluster has a low diversity due to the inbreed tendency among farmers that introduced goats during the 19th century to increase the goat farming production according to European breeding programs [65]. Nevertheless, between geographically groups their different origin and admixture with different parental populations contribute to producing a high significant genetic distance among Creole groups (distance 0.16), compared with the genetic distance observed between Iberian Groups (0.05) and African groups (0.11) [66]. This genetic distance also reflects the differences regarding the adaptation against different geographic environmental conditions such as dry, hot, wet, or moisture places, selecting a goat breed well adapted to local conditions [65, 66]. Therefore, these Creole goats represent an underestimated genetic patrimony that changes according to the geographic distribution and with the threat to be lost due to the transboundary practices that replace the creole goat with common dairy goats in modern goat farming practices [66].

In Northern Chile in desert and arid zones the creole goats (**Figure 2**) were introduced by Spanish conquers during the XVI century and used with multi-purpose uses [68]. Throughout Chilean history, these goats were admixed with others breeds without any record and breeding plan, raising a broad diversity among Chilean creole goats [69]. In desert and arid zones, the Chilean creole goats are a robust animal, resistant to diseases, and adapted to pastoring with longer walks distances until reach the foods [69]. However, they have low milk yield of 0.2–0.9 kg/day in comparison with the milk production by Saanen goat of 1.0–2.3 kg/day under the same husbandry conditions, and the crossbreeding between Saanem and creole goats had an offspring able to produce 0.6–1.6 kg/day improving the genetic background of Chilean creole goats (**Table 1**) [70]. In the same way, the indigenous goats that live in Nigeria such as Sahel, Red Sokoto, and West African Dwarf have low milk yield between 0.3–0.5 kg/day (**Table 1**) being historically breeding for multi-purpose [26, 49]. For that reason, the creole or native goats are usually prejudged as low milk producers but without any serious studies that determine the milk yield under intensive breeding conditions.

In Greece, Italy, and India, genetics studies using molecular markers on casein genes as genetic markers for milk production, found a good potentiality for milk production in creole goats, proposing an affordable alternative for local goat farming [27, 71]. In Mexico, a study demonstrated that the milk yield of creole goats changes from 0.65 kg/day to 1.14 kg/day just moving from pasturing farming to stalled management and improved diet [72]. Thus, the potential of native and creole goats in dry local areas is still an unexplored field, and more studies about their milk yield under intensive husbandry conditions in desert and arid zones is still pending.

4. Goat milk quality

4.1 Benefits of goat Milk

Milk is a supplementary food from livestock animals like cows, goats, donkeys, and other mammals, and also is considered a rich source of carbohydrates, lipids, proteins, vitamins, minerals, and immune defense factors [28]. Cow milk is the most demanded by consumers, but goat milk has better nutritional properties enriched in vitamin A, riboflavin, growth factors, and lipids of short-chain such as; capric, caproic, and caprylic acids [28]. These lipids have better dissolution properties for serum cholesterol preventing coronary disease, cystic fibrosis, and gallstone, and can reduce body weight by promoting lipid oxidation, reducing lipogenesis, and increasing the synthesis of ketonic bodies [73]. Finally, goat milk is easily digested because has more dispersive bulbs and is recommended for milk allergic individuals for their reduced content or even lacks α-casein protein [28, 74].

4.2 Goat Milk quality

The goat milk quality is expressed in terms of sanitary, dietetic, nutritional, and technological properties, and evaluated according to their gustative, rheological, gastronomic, and hedonic features [75]. In general, the milk quality is determined according to the content of protein, lipid, and carbohydrates, among other parameters, and these concentrations are crucial for cheese production. The cheese yield depends on the protein content, while the texture, fineness, flavor, taste, and nutritional value is depending on the content of fatty acids and lipo-vitamins [75]. Environmental stress can affect the goat milk quality that finally affects the cheese quality. Saanen goats exposed to heat stress have low-quality milk with a low content of fat, protein, non-fat dry matter, and lactose [37]. However, with just a few adjustments the milk quality can be improved. The lipid profile can be modified according to the diet contents and management procedures, but protein concentration is more dependable on goat genetic background [46, 75–78]. In a study with Saanen goats, the milk quality was improved after the introduction of a diet based on stoned olive cake silage modified with a lipid profile [79]. Meanwhile, in Creole goat, a new integral diet (1 kg) increases in 6% the protein and lactose content and 200% the milk volume [72]. Alpine goat fed with a diet based on alfalfa hay with different quality plus concentrates pellets did not change the total protein or casein milk concentration but modified the lipids and lactose concentration according to the diet used [80].

These fluctuations in the milk protein and lipid concentration according to diets used may be explained in terms of the relationship between the doe and the kid. In general, proteins are crucial for kid nutrition and their milk concentration remains constant adjusting protein synthesis according to the food intake rate [81]. Meanwhile, lipid content and lipid profile are dependable on gene expression and metabolic activity, and are controlled by metabolic precursors and hormones added to diets or promoted by nutritional factors that modified the rumen microflora activity [82]. In fact, the goat lipids metabolism is more complex than expected.
A recent study about gene expression in mammary gland cells during a diet improvement demonstrated that lipid profiles change according to the gene expression of

the protein associated with goat metabolism and protein transport, instead of genes directly related to lipids synthesis [83]. This observation encourages to do more studies to understand these correlations and the links among lipid metabolism, genetic polymorphism, and diet composition, and how this can affect the milk lipid content.

5. Molecular markers for dairy goats

5.1 General characteristic of domestic goats

The domestic goat is a livestock animal with attractive properties. A comparative genomic study reveals major differences between domestic goat breeds and their ancestor *C. aegagrus*, related to coat color, which is more uniform in domestic goats, and genes linked to the immune system, behavior, and reproduction, which are features related to domestication practices [84]. In another study, the complete genome annotation of a female Yunnan black goat using whole-genome optical mapping methodology found common characteristics with cattle, but more efficiency for milk secretion in goats, due to the presence of genes related to Prolactin hormone and its metabolism. Besides, an expansion in genes related to the olfactory receptor gene subfamilies was observed in goats and linked to the historical selection of a broad spectrum of forage during the expansion of goat farming. Finally, another remarkable fact is that the goat immune system has a Major Histocompatibility Complex (MHC) highly conserved with sheep and humans, suggesting an interesting animal model for immunological studies [85].

Transcriptomics analysis reveals interesting traits in goat breed for goat farming activities. In the Inner Mongolia Cashmere goats, the transcriptomic analysis reveals the expression of genes related to keratin and keratin-associated proteins of the primary and secondary hair follicles tissue that were directly associated with the goat hair phenotype [85]. Later, a gene knockout by CRISP/Cas9 technology produced modified Cashmere goats that express long secondary hair [86]. In Alpine goats, a similar transcriptomic study but using a cow microarray (there was no goat genome array available at that time) identified the gene expression associated with the animal response against food deprivation. Under this food poor condition, the milk yield was reduced to 16%, and the lactose, protein, and lipids concentration was reduced to 10%, 25%, and 45%, respectively [36]. These changes provoke a downregulation of many genes in the mammary gland cells, and some of them corresponded to casein genes, cell proliferation gene, and estrogen receptor gene, among others [36]. In this way, was possible to associate the gene expression with milk production, although still needs to be confirmed with other studies. Currently, there is a wide technology accessible to afford this challenge like those used to produce transgenic goats to synthesize human lysozyme or spider web protein and released through the milk [87, 88]. Therefore, the technology is available for improvements in goat milk production to move forward goat farming activity to produce a high volume of milk with high quality in arid and desert zones.

5.2 αS1, αS2, β, and K-casein polymorphism

The most abundant milk proteins are: αs1(CSN1S1), αs2 (CSN1S2), β (CSN2) and κ-casein (CSN3), β-lactoglobulin (BLG), and α-lactalbumin (LALBA) and they represent 95% of the total protein content in ruminant milk [89]. These proteins are encoded on chromosome 6 in a segment of 250 kbps [90], have different post-translation modification [91], and their milk concentration changes according to the gene expression of these casein genes [92].

These casein genes have a polymorphism within the same breed [93] and among diverse breeds [27, 90], and this biodiversity might impact the goat milk quality and milk properties in term of their role with the immune system, nutritional quality, and as raw material to produce other products derived from milk [91].

The most stronger correlation between casein polymorphism and milk quality has been described for the αS1-casein gene [89, 94, 95]. This gene has 18 alleles (represented as a capital letter) and is phenotypically grouped as "strong" with a milk yield of 3,6 g/L (A, B1, B2, B3, B4, C, H, L, M), "intermediate" with milk yield of 1.6 g/L (E, I), "weak" with milk yield of 0.6 g/L (F, G), and "null" because did not synthesize the αS1-casein protein (N, O1, O2, ON) [94, 95]. In the Sicilian goat breed Girgentana and Argentata dell etna, the "strong" alleles were identified as homozygote or heterozygote with null allele [27]. In Spanish goats, the most predominant alleles were B and E, while other goats showed different heterozygosity; Murciana-Granadina (B, E), Malagueña (E), Payoya (B, E), Canaria-Palmera (A, B), Canaria-Majorera (B, E, D + O), and Canaria-Tinerfeña (B, E, D + O) [96]. In the Malagueña goat breed, the BB genotype produces 6.94 g/L, meanwhile, EE phenotype produces 4.58 g/L [96]. In Girgentana goats, the genotypes AA not only produce more casein protein in milk (43.4 g/day) than FF genotype (25.4 g/day) but also more milk volume (1.419 kg of milk per day) than the FF (1.014 kg of milk per day) after improvements in diet nutrition [97].

Saanen and Alpine goats with the AF genotype produced more αS1-casein protein in milk than the FF genotype (4.26 g/L vs. 1.21 g/L) [98]. Meanwhile, in another study on dairy French Saanen and Alpine goats, the αS1-casein polymorphism predicted the fat and protein content but was influenced by the goat gender [99]. The authors also found that almost 65% of the Saanen goats studied were AA and AE genotypes, being biallelic for the αS1-casein gene [94]. Future studies that apply molecular techniques like PCR to identify αS1-casein polymorphism in Saanen goats, may validate the biallelic tendency, and impulse improvements in milk goat farming through selective crossbreeding strategies [99].

In the West Africa goats such as; Borno, Red Sokoto, and West African Dwarf Cameroon the most frequent alleles found are B and B′, while in the Nigerian Dwarf breed was the A, B, and B′ alleles [100]. Thus, the natural segregation for high milk production by goat farmers has promoted the dominance of certain strong and intermedia alleles in the goat herd.

Polymorphism in αs2-casein have seven alleles with three different gene expression levels: A, B, C, E and F, associated with a high expression of αs2-casein (2.5 kg/l); D allele with moderate expression (1.25 kg/l) and O (null) allele with no expression and undetected αs2-casein content [101, 102], but still inducing an allergic reaction for those people immune sensitive to milk casein proteins [103].

Variations in the β-casein gene (CSN2) locus involves ten alleles with different gene expression. Alleles A, A1, C1, E, O, O′, D, F, C, and B that has been identified from the cDNA analysis, using MS analysis, and from the electrophoretic pattern [104]. The C and F alleles are associated with low concentration or traces of β-casein protein in milk due to mutation that makes an unstable mRNA that finally reduces the protein content [104]. In consequence, this milk with low content of casein is the best option to produce infant milk formula for those kids with restricted acces to milk products due to their cow milk allergies [105].

In the case of the kappa-casein gene (CSN3), up to 21 allelic variants has been described, and according to their isoelectric point they are separated into two groups, AIEF (A, B, B′, B″, C, C′, F, G, H, I, J, L,) and BIEF (D, E, K, M, N, O, P, Q, and R) [106]. This last group shows differences in their milk protein content according to the genotype, and the BB alleles are those with higher content of casein in the goat milk with a 2.98% [107]. In the Murciano-Granadina goat, the BB genotype had an effect on the rennet coagulation time evidencing the important role of K-casein in cheese production [104]. Therefore, these reports evidence the importance in identify the K-casein genotype in the herd to find the best goats for goat cheese production.

5.3 Single nucleotide polymorphism

The genetic polymorphism of genes related to protein content in goat milk is not only limited to casein genes. The molecular technique denominated KAS PCR (Kompetitive Allele Specific PCR) was applied on 40 genes previously identifies as molecular markers and includes; caseins genes, genes related to the immune systems, growth, proliferation, and milk production [108]. The study analyzes 48 single nucleotide polymorphisms (SNP) present across these 40 genes encoded in the genome of Alpine and Saanen goats. The study found 13 polymorphic SNPs and 4 of them were directly associated with the protein, fat, and lactose milk content. These 4 SNPs encode two interleukins receptors (Il1RN, IL15RA), one suppressor of cytokine signaling (SOC3), and a growth hormone-releasing hormone receptor (GHRHR) [108]. In this way, these casein genes and other molecular markers are currently used to study milk yield in dairy goats.

The SNPs technology consists in analyze a single nucleotide change (transition or transversion) present in a small region of selected loci in both chromosomes to identify a genotype classified as homo or heterozygous [109]. The uses of SNPs analysis in conjunction with massive sequencing or arrays technologies allow analyze hundreds or even thousands of polymorphic genes and correlated them with a specific phenotype [109]. The SNPs analysis has been successfully used in collaboration with the International Goat Genome Consortium (www.goatgenome.org) and the data reported by diverse researchers in the field have been able of creating a 52 K SNP CHIP that detects more than 50,000 SNPs in diverse goats breed [110]. The CHIP was constructed using diverse breeds as references, including milk representative types such as Saanen, Alpine, LaMancha, and Toggenburg breed, and as a meat representative to Boer and Rangeland breed, and as milk-meat representative to Nubian goat breed. Thus, the CHIP technology can be applied to diverse goat breeds, including mixed-breed [111, 112]. The CHIP allows the understanding of genetic diversity among goat breeds and their relationship with a specific productive trait [111]. In South Africa for instance, a study used the 52 K CHIP to analyzes genetically the most local representative breeds and correlated them with their adaptation characteristic to different environments. That study identified many SNPs associated with the geographical distribution and physiological adaptation to local environments [113]. A total of 205 pathways were identified after the analysis of 474 adaptive genes with significant SNPs classification. The temperature was a selective environmental factor for the most adaptive animal, and several genes linked to heat stress responses, circadian rhythms, and vascular smooth contraction were involved in this natural selection [114]. That describes a more efficient metabolism to adsorbed nutrients from food with low nutritional value, and efficient use of water sources, reducing the water loss released through the urine and feces [114]. Besides, these goats encoded genes related to better resistance against disease in comparison with other non-desert goats [114]. All these features are consistent with previous physiological studies on the goat that habitat in desert zones [31]. For example, a goat adapted for harsh environments has a small body with a high efficient metabolism rate and a functional rumen adapted to obtain a high amount of nutrients from low-grade nutritional foods [31]. Also, a desert goat can perform a high efficient nitrogen recycling system and water recycling system, allowing survival for long periods with limited sources of water and foods [31, 115]. In consequence, although for a traditional goat farmer a desert goat could look smaller and thinner than a highly efficient dairy goat, they still can produce high-quality milk under restricted diet conditions. This is important because dairy goats well adapted to arid and desert zones will not require expensive investments in farming management to improve their milk yield. The achievement of this goal supported by molecular makers and techniques currently available, would allow to afford the next challenge for goat farming in arid and desert zones, to produce high volume of high-quality milk in a current climate change scenario.

6. Conclusion

In conclusion, goats are extraordinary farming animals capable of being productive under harsher conditions, because the origin of this species comes from the middle east, a place with limited conditions to sustain life. The expansive goat dispersion across the globe associated with human migration along the centuries has generated a genetical richness superior to any other livestock farming animals, allowing its uses as a multi-purpose animal. Taking advantage of this biological diversity and current knowledge about goat physiology and genomic expression, today is possible to create crossbreeding plan that introduces goats bred from the Middle East, India, or even creole goat to produce hybrid offspring well adapted to dry or drought environments and still produce a high volume of high-quality milk. The advances and discovery of new molecular markers associated with milk yield can support breeding plan through the selection of the best parents and offspring to improve the herd genetic background and overcome the nutritional deficiency and heat stress conditions to produce high-quality milk in lands affected by desertification and without major changes in the goat farming management conditions.

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Conflict of interest

The authors declare no conflict of interest.

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Chapter 3

Goat Breeding in the Katanga Copper Belt (KCB): Constraints, Opportunities and Prospects

Innocent M. Tshibangu

Abstract

DR Congo's copper belt is south of the dismembered former province of Katanga. The population has grown over the past twenty years due to the resumption of industrial and artisanal mining. This situation has led to an increase in demand for agricultural products including meat. The majority of these products are imported due to insufficient local production. Goat meat is the most consumed of the ruminants and most of these animals are imported from Zambia. Thousands of the goats are slaughtered daily and its meat sold in all markets and especially next to thousands of drinking establishments as appetizers. Unfortunately, this opportunity does not benefit local breeders because of several factors including the low productivity of the local goat, a stray breeding system, insufficiency and lack of space for breeding, contamination of pastures by heavy metals, insecurity, supremacy of the mining code over agricultural law, the dispossession of agricultural land belonging to peasants for the benefit of private farmers ... In perspective, the establishment of a collaborative structure between breeders, development agents and technicians, researchers and policy makers in sectors related to goat farming and its environment will provide access to information and improve goat production.

Keywords: Katanga, goats, indigenous, breeding, mining, Miombo

1. Introduction

For the CFSVA [1], despite the country's enormous agricultural potential, the majority of the population of the DRC remains largely exposed to poverty, food insecurity, malnutrition and hunger. According to the UNDP_RDC report, more than 71% of Congolese live on less than one US dollar / person / day. In terms of the Human Development Index, the UNDP ranked the country 41st out of 53 in Africa and 176th out of 189 countries in 2018 [2]. For the country as a whole, only one percent of arable land is used, and the country resorts to massive imports of almost all food products such as maize, rice, wheat, sugar, poultry, fish, meat, dairy products and other foodstuffs [3–6]. The majority of the population of the DRC lives on agricultural activities, often associated with animal husbandry [7]. According to Brunneau [8], in Katanga, Kasai, Kivu provinces many villagers have lost their farmland to mining companies. Southern Katanga is one of the populated regions of the DRC. Mining, urbanization, insecurity in some parts of the country and the fluidity of the roads have allowed a rural exodus and an attraction of several populations from other towns and villages of the country. This massive presence of populations constitutes a potential market for agricultural products including milk, meat and vegetables. The same CFSVA report [1] mentions that in the DRC, poultry, goats, pigs, sheep and cattle are common livestock species and are thus among the important sources of income and meat production; they can be used as active savings assets for small farmers. Goat and pork meat is consumed in the HMK region. Goat meat is mainly sold cut in markets or around bars and drinking flow. The majority of goats sold and slaughtered in the Katanga Copper Belt (KCB) are imported from Zambia through the borders of Kasumbalesa, Kipushi, Kasenga, and others. According to the President of the Zambia Cross-Border Traders Association (CBTA), there is a high demand for animals and a huge market for goat meat in DRC. In only Kasumbalesa border on average, more than 4,500 goats are traded monthly [6], not counting sellers not officially registered and other points of entry into the DRC from Zambia. The optimal management of goat breeding and agricultural perimeters: soils, livestock resources, including the production, use, conservation, complementarity of species and the sharing of the resulting benefits, is therefore a necessity for an improvement of living conditions and income for the peasants of the Katanga Mining Hinterland.

Listing the constraints and opportunities of the goat sector in the KCB would serve as support for responsible decision-making at the level of decision-makers and actors involved.

2. Presentation of the environment

The Katanga copper belt area is included in the Hinterland-Minier of the former province of Katanga, which is currently dismembered. This mining area is currently located in the provinces of Lualaba and Haut-Katanga. It was from Kolwezi (Lualaba) to Sakania (Haut-Katanga) (**Figure 1**). These two new provinces are

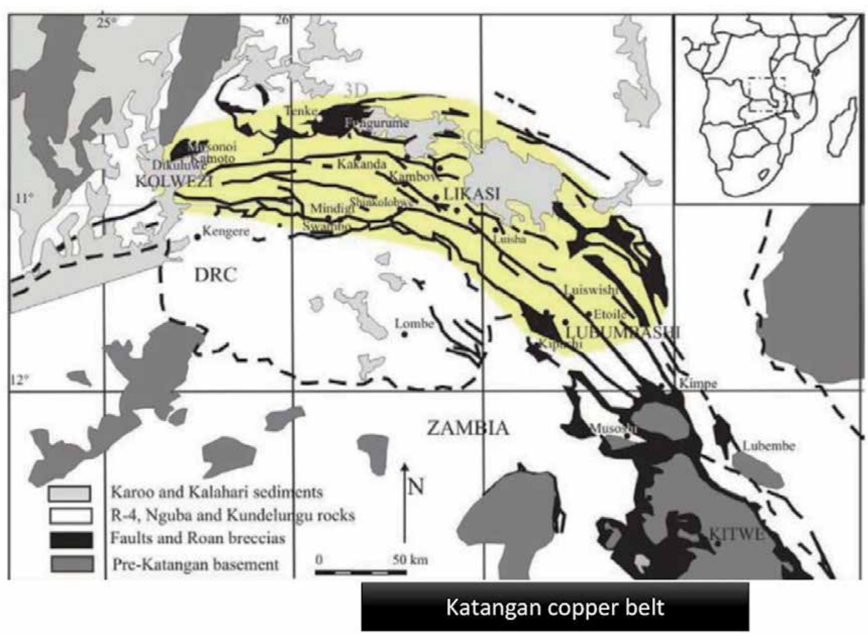

Figure 1.
Katangan copper belt region of Democratic Republic of Congo. (Source: Ref. [9]).

subdivided into five territories for Lualaba, three of which are mining (Lubudi, Mutshasha and Dilolo) and six territories for Haut-Katanga, five of which are mining (Kambove, Kipushi, Sakania, Pweto and Mitwaba). The main minerals mined in this area are copper, cobalt, zinc, manganese, uranium, germanium, gold, cassiterite and silver.

Beyond the mining sector, the copper belt is also an agricultural and livestock area. The main agricultural products are maize, cassava, sweet potatoes, vegetable crops, rice, soya and other.

Animal husbandry is a secondary activity practiced by the majority of farmers and non-farmers. The main livestock species are in order of importance the chickens, the goat, the pig, the rabbits, the ducks…

The vegetation of the mining hinterland of Katanga (**Figure 1**) is characterized by an open forest (Miombo), wooded savannas, swampy meadows and grassy savannas. There is a specific cupricola vegetation installed on soils highly contaminated with copper and other metals characteristic of the region [10].

The different types of soils encountered are ferrisols, arreno-ferrals, hydrokaolisols, recent tropical soils, the tropical black earths on alluvium.

The climate is classified as warm and temperate. Precipitation is heavier in summer than in winter. The Köppen-Geiger classification is of the Cwa type. The annual average temperature is 20.5°C. The average annual precipitation is 1240 mm. The climatological characteristics of the region are presented in **Figure 2**.

The economic activities of the population bordering on mining are based on a subsistence economy, which is an economy chosen or suffered, relatively or totally separate from economic flows, where there is essentially self-consumption. The production of food, movable or immovable goods necessary for existence depends on the family or a small group without there being any trade or in a very limited way. They are mainly based on subsistence farming, the production of embers, small trade, fishing, hunting, breeding, crafts, education and in some urban planning sites, some households live off the property rights of the Earth. Several studies show that 61% of people earn their income from farming. This shows that agriculture remains the main income-generating activity in areas around mines and in general in rural areas [11].

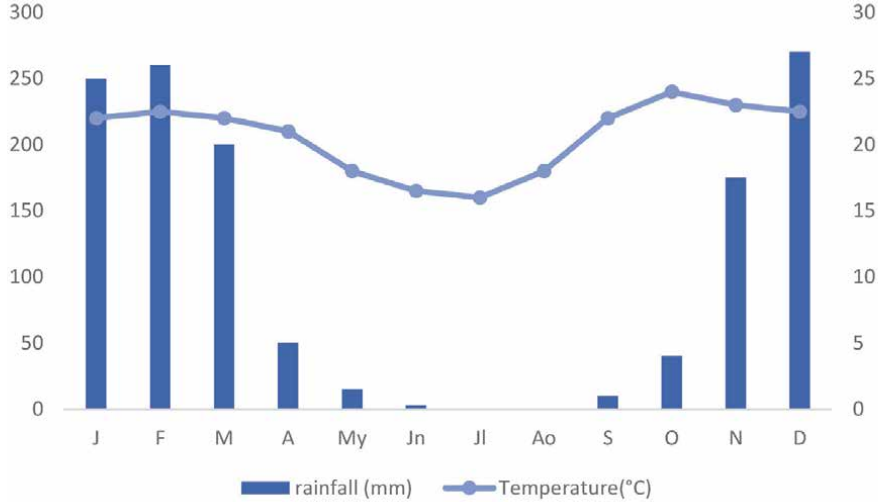

Figure 2.
Ombrothermal diagram of the hinterland-Minier of Katanga region. (source: Climate-data.org, 2021. Climat Lubumbashi (Congo-Kinshasa): https://fr.climate-data.org/afrique/congo-kinshasa/katanga/lubumbashi-503/)

3. Material and methods

This study on goat breeding in KCB was made possible by a compilation of official documents, in particular: reports from state institutions such as national and provincial ministries, provincial inspections of agriculture, fishing and breeding; the national statistics institute. Reports from international organizations. Reports from state institutions and development NGOs, scientific articles, theses and dissertations from higher studies, the laws of the country and archives of the territorial administration, testimonies from village chiefs, reports from cadastral services and mining cadastre, as well as data from our own investigations and professional experience and our discussions with goat breeders.

The protein content was determined by the Digesdahl method (CP = Nx6.25). Contents of parietal fiber (ADF and NDF) were determined by the FibreBag Gerhardt procedure as described by Van Soest et al. [12]. The ether extracts (EE) were determined by the Soxtec System using the method described by Matsler and Siebenmorgen [13]. The organic material was determined by placing the samples in a muffle furnace at 560°C overnight. Crude ash levels were deduced by the difference of dry matter and organic matter. Dry matter concentration was determined after drying leaves and root in an oven at 105°C for 24 h. Soil total concentrations of copper, cobalt, zinc and lead were measured in duplicate, and results reported in mg/kg dry soil. The pH was determined using a pH-meter glass electrode in a soil to distilled water ratio of 1: 2.5. The mineral content of the soil was determined according to the method described by Alsac [14]. Digestion was carried out on 0.5 g soil with 6 ml of hydrochloric acid and 2 ml of nitric acid (aqua regia) at 95°C for 75 min on a heating block. The digest was then adjusted to 50 ml. Mineral content were done using atomic absorption spectrometry, according to the NF EN ISO 17294-1 and 17294–2 French standard method [15]. The minimum detection limit for each of these metals in leaves and roots samples were Cu: 3 ppb, Co: 5 ppb, Pb: 10 ppb and Zn: 1 ppb. For Influence of Washing, Samples of the plant, were collected from the shallows, slopes and trays on each of the sites. Whole plants of were harvested at the same places where soil profiles were dug for soil sampling. Roots were separated directly from the aerial parts of plants, washed and tops sampled into two parts. Fractions were packaged and labeled. In the laboratory, one of two aliquot of each aerial part was washed with deionized water containing Alconox [16].

4. Constraints

4.1 Mining and decline in peasant farming activities

The presence of the mining industry in the KCB has had an impact on agricultural activities in general and goat breeding in particular. Mining companies and artisanal mining activities have resorted to an active local workforce. This practice has had the following consequences [11]: - Food insecurity due to the drop in agricultural production per capita: exodus of young people to the mines and adults and old people who remain in the rural environment must feed everyone who is in the quarries and in the city, – Diversion of agricultural labor: the villages are depopulated by young people who prefer quarries than the village because of the high income provided by mining activity, – Rise in food prices so much both plant and animal origin, – Ecological imbalance which paralyzes certain crops and other rural activities, – Disappearance of certain villages and centers.

The granting of mining squares resulted in the expropriation of agricultural land and even the relocation of local peasant farmers. The acquisition of land by some mining companies to the detriment of communities is a form of land grabbing. The precedence of the mining code over the agricultural law [17] has a lot to do with the dispossession of agricultural land. Land, the precious capital that provided the bare minimum of subsistence to small producers, through agriculture is in alteration. At the provincial level, the study carried out by in 2015 by [11], revealed that out of a total of 496,865 km^2 of land, 356,220 km^2 are occupied by mining companies, or 71.69%. Another study estimates that 85% of the territory of former Katanga is divided into mining squares ceded to third parties, Yan Gorus (2009) cited by [11]. The part of the land that remains unassigned to mining companies is approximately 140.645 km^2, or 28% of the land. It is also necessary to subtract from it all the space occupied by the national parks (17.870 km^2) as well as the water surfaces (lakes: approximately 26.899 km^2) and the 95.932 km^2 remain free for agriculture without considering to what degree they lend themselves to this in terms of fertility without subtracting urban space. According to the same study 87% of farmers have reduced the area of their fields as a result of the pressure exerted by the occupation of land for mining activities. Areas that were once used for agricultural activities are closed to indigenous populations. However, the agricultural activity practiced in rural areas is nothing other than shifting slash-and-burn agriculture with the practice of fallow. For the communities, this leads to the reduction of areas or cultivable land, and as a result, a drastic reduction in subsistence income.

Mining has opened a door to easy but very precarious and unsecured gain for the young people who engage in it. For most of the peasants in this region, mining is a quick and easy way to earn income, to the detriment of farming and goat farming. The breeding time to obtain an adult animal that can be cheap being “long”, the peasants, men, women and even children, prefer to practice artisanal mining and other activities related to it including washing. Minerals, prostitution, petty trade and transport. These activities are not without negative consequences on the health and social life of the population: precarious income, sexually transmitted diseases, debauchery, drugs, banditry, unemployment and teenage delinquency and especially contamination with characteristic metallic trace elements from the cupro-cobalt-bearing region. Exposure and contamination to heavy metals in KCB has been well described by [18, 19].

4.2 Small business

The rush for mining centers and quarries fostered intense commercial activity. As with the artisanal mining mentioned above, the petty trade, especially in foodstuffs from the countries of southern Africa, mainly from neighboring Zambia, has taken a toll on agricultural and livestock activities. This activity also has consequences on the social life of households, including household instability, monetary instability, the advent of COVI-19 which, at certain periods, has forced the confinement of populations, the instability of prices of manufactured products, debts, the eviction of artisanal miners unexpectedly by the politico-administrative authorities… All these acts have repercussions on the life of the peasants: their social and monetary stability which could be guaranteed by an activity agricultural and/or goat breeding.

4.3 Seasonality and nutritional value of forages

The south-eastern region of the former dismembered province of Katanga is characterized by a CWa type climate according to the Koppen classification. Pastures are mainly made up of seasonal grasses and rarely legumes. The rainy season is spread out from November in the first half of April and the dry season is from April to October. During the long dry season, with cold periods (**Figure 2**), the grassy vegetation dries up completely and leaves in place highly lignified straw of poor nutritional quality for ruminants. Likewise, the crop residues of the main food crops are very lignified and do not provide an acceptable quality fodder, especially since the method of rearing straying, without supplementation leaves ruminants no choice but to be satisfied with these quality poor foods.

This situation is to the detriment of the animals with the consequence of a decrease in performance and an economic loss for local breeders.

4.4 Exploitation of the clear forest "Miombo"

Following the flourishing mining activities in the region, the residents exploit natural resources of the clear forest: the Miombo. Among the available resources exploited we find caterpillars, edible mushrooms, game, honey ... and especially wood.

Of all these non-timber and wood resources, the exploitation of wood, firewood and charcoal production is one of the intense activities of farmers. Due to the insufficient supply of electrical energy for domestic needs, charcoal is the primary resource for cooking for all households in the region (**Figure 3**). This activity is preferred by peasants (**Figure 4**) after agriculture. Logging is one of the activities of environmental degradation and imbalance of Miombo ecosystems.

4.5 Other agricultural activities

Some agricultural and livestock activities are adopted by agro-pastoralists because of the short time frame and simplicity. Market gardening activities are preferred by many farmers because of their short duration and market demand. Chicken breeding, mainly broilers, is also preferable to goats rearing, among other things, to the short raising time, the demand and preference of more and more

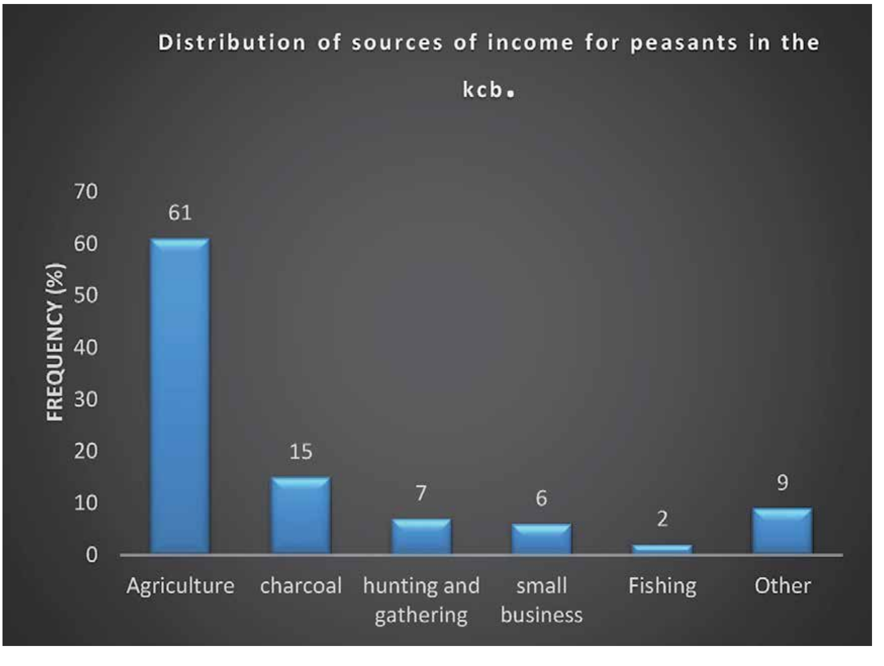

Figure 3.
Distribution of sources of income for peasants in the KCB [9].

Figure 4.
Peasants selling charcoal in KCB. (source: Alexis Huguet, 2019. En RDC, le charbon de bois vital pour les foyers, mortel pour les forêts. Agence France-Presse.)

consumers and the availability of chicks and feed imported completely without difficulty from neighboring Zambia. All these activities are without consequences because market gardening crops face competition with that from Zambia and also they are exposed to rapid degradation in the event of unsold, for lack of techniques and means of conservation and/or processing. The cost of local production of broilers is so far higher than the selling price of imported chicken. This constitutes a huge difficulty for local semi-intensive poultry farmers.

4.6 Insecurity and theft

The insecurity experienced by the DRC following the various wars that have taken place for more than twenty years; have caused negative effects on animal husbandry as a whole. Armed groups have had to constantly resort to farm animals for food in various war zones including the Hinterland-mining region of Katanga. Several villages have been victims of this practice and some agro-pastoralists have abandoned the practice of goat breeding. An example is the incursion of militiamen and the looting in the city of Diambala and Kakokonya, in the territory of Kipushi (Haut-Katanga). During the night of Thursday, January 16, 2014, these attackers took goats, agricultural products and other goods from the population of these localities.

Another constraint linked to insecurity is theft. The wandering breeding system and the precarious housing conditions of the animals are factors that contribute to the loss of animals by theft. The high selling price of goats in urban centers and large towns in the region is the determining factor in this practice. Stray animals are stolen either by some inhabitants of the village or by strangers in the village. This practice is often organized at night during which thieves, coming from urban centers, bring in vehicles and spray insecticides in goat houses to steal animals without agitation or noise. Several villages, some of which have benefited from NGDOs aid, nowadays find themselves without goats because of this practice.

4.7 Poverty and urgent household needs

Several NGOs have contributed to the rebuilding of goat herds in the dismembered province of Katanga after the unfortunate events of the repetitive wars that have raged in the country. Unfortunately, some breeders, having benefited from these donations, have preferred to sell their herd for emergency medical care or children's schooling. Some preferred other activities, mainly petty trading and the sale of charcoal or market gardening which allows them to have permanent access to cash.

4.8 Heavy metal contaminations

Several studies have shown that soils and fodder are contaminated with trace metal elements characteristic of the region (**Tables 1–3**) [16, 20–22]. This situation does not encourage fodder vegetation to spread in certain potentially grazing areas. Goats reared on vegetation in Lubumbashi in its southwest and northwest part had debris and tissues including meat, liver and kidneys containing high levels of Cd and Pb exceeding the recommended standards [18]. And that the feces of these goats had high levels of Cu, Cd, Pb and Zn [18]. This is explained by the presence of the former foundry plant of the state mining company, "Générale des Carrières et des Mines: ***Gécamines***" and of a new plant of the Lubumbashi slag processing company (STL). High concentrations of heavy metal are in soils and vegetation found in the direction of the prevailing wind as found by others authors in the Penga Penga site [20]

Soils	pH_{h2O}	pH_{kci}	COT	Cu	Co	Cd	Pb	Zn
Garden	6.2	5.8	2.2	142	6.7	0.67	15.3	24.9
Penga penga	5.4	5.3	1.1	3524	109	8.59	249	290.4

Source [20].

Table 1.
Physicochemical characteristics of the two soils studied: Contents of pH, TOC (%) and ETM extractable by ammonium acetate-EDTA (mg,kg^{-1}).

Culture	ETM (mg.kg^{1})	SN	TO	C15	M105	CM1
Amaranth	*Cu*	31	—	118	—	121
	Co	—	—	8.8	—	6.5
	Cd	4.1	—	8.6	—	6.1
	Pb	1.2	—	6.5	—	7.1
	Zn	100	—	80	—	113
Swiss chard	*Cu*	49	2601	62	156	121
	Co	1.5	91.2	3.2	84	6.5
	Cd	5	0.9	2.9	6.1	2.3
	Pd	1.7	11.5	2	7.1	3.1
	Zn	192	348	94	113	58

Contaminated soil without amendment (T0), with 15 g of limestone (C15), 105 g of compost (M105) per kg of soil, 15 g of limestone +105 g of compost (CM1) per kg of soil and reference soil of experimental garden (SN).
Source [20].

Table 2.
Contents of ETM extractable by ammonium acetate-EDTA in the harvested plants (mg.Kg^{-1} MS).

		Sites			Topography			Effect (p > F)			
Parameters	**WS**	**KAS**	**KINS**	**LUI**	**S**	**T**	**SI**	**SEM**	**Site**	**top**	**site*top**
Cu	Unwashed	63^{Aa}	42^{Ab}	$I68^{Aa}$	85^{Aa}	98^{Aa}	90^{Aa}	27,8	**	NS	NS
	Washed	20^{Ba}	12^{Aa}	$45^{B'}$	$I8^{BA}$	30^{Ba}	29^{Ba}	9,5	NS	NS	NS
Co	Unwashed	14^{Aa}	10^{Aa}	60^{Ab}	29^{Aa}	25^{Aa}	30^{Aa}	2,7	*	NS	NS
	Washed	10^{Aa}	3^{Ab}	$I3^{Ba}$	8*	11^{Ba}	7^{Ba}	1,3	NS	NS	NS
Zn	Unwashed	185^{Aa}	24^{Ab}	87^{Ab}	38^{Ab}	107^{Aab}	151^{Aa}	33	*	*	NS
	Washed	103^{Aa}	26^{Ab}	39^{Aab}	37^{Aa}	58^{Ab}	$\mathbf{73^{Aa}}$	12,3	*	NS	NS
Pb	Unwashed	107^{Aa}	8^{Ab}	$l36^{Aa}$	78^{Aa}	65^{Aa}	78^{Aa}	21,7	**	NS	NS
	Washed	7^{Ba}	3^{Aa}	7^{Ba}	4^{Ba}	9^{Ba}	4^{Ba}	1,4	NS	NS	NS

*1: **KAS** - Kasombo; **KINS** -Kinsevere; **LUI** - Luiswishi,*
*2: **S** — shallows; **T** — Trays; **SI** — Slopes;*
Values with different uppercase letters in a row arc significantly different at $p < 0{,}05$,
Values with different uppercase capital letters in one column arc significantly different at $p < 0{,}05$,
: *p *< 0,05;* ***:* ***p*** *< 0,01;* p < 0,001; *NS: not significant.*
SEM: standard error of the mean.
Source [16].

Table 3.
Heavy metal concentration in Adenodolichos rhomboideus leaves according to site, topography and washing at Lubumbashi.

(**Table 1**). In the same area hi gh levels were found in the fodder of *Setaria pallidefusca*, in the leaves of amaranths and chard perry [20] (**Table 2**).

High levels of heavy metals were found in different soils and fodder in a few sites near certain mining quarries in Kasombo (Kipushi), MMG (Kinsevere) and Luisuishi (Lubumbashi) [16]. For these authors, the Cu contents were high in all the sites, the Pb contents were read high at Kasombo and Luiswishi; Co levels were high at the Luiswishi sites and moderately at Kasombo, while Zn was higher at Kasombo and Luiswishi (**Table 3**).

As the region is a mining area, there is no policy of choosing pasture with uncontaminated vegetation to practice goat breeding. The consumption of forages containing high levels of heavy metals can have several consequences in animals and in consumers of goat meat. The consumer can, through the food chain, become intoxicated by regularly consuming meat from these farms.

More than 40% of samples of kidneys, livers and muscles from goats reared in the prevailing wind area levels of cadmium, lead, copper and zinc above the recommended standards (**Table 4**). While samples collected from farms indicate values below recommended limits in feces. Samples of offal and meat from goats collected from contaminated sites showed high levels of Pb and Cd in kidneys and liver (**Table 5**) [18].

Samples taken from edible offal in some markets show that only the Pb contents are above the recommended limits in the kidneys and liver (**Table 6**). In view of these results, the regular consumption of goat offal may be the basis of lead poisoning in humans.

4.9 Rearing practices, pathologies and genetic type of goats

4.9.1 Rearing practice

Another constraint is linked to the practice of traditional and rudimentary rearing [25]. The majority of goat keepers resort to straying and tethering [26] (**Figure 5**) without supplementation, prophylaxis or breeding stock selection. The

	Contaminated urban areas		Peri-urban farms	
	Dry season	**Rainy season**	**Dry season**	**Rainy season**
Cd	3.02 ± 1.41	4.39 ± 2.55	2.49 ± 2.28	2.27 ± 1.41
Cu	277.80 ± 304.07	236.83 ± 272.16	87.05 ± 66.71	71.57 ± 28.92
Pb	24.24 ± 24.93	23.99 ± 20.25	4.92 ± 4.94	6.01 ± 3.07
Zn	221.63 ± 124.81	259.59 ± 98.21	106.19 ± 30.02	145.20 ± 33.88
Source [18].				

Table 4.
Average concentrations of Cd, Pb, Cu and Zn in the feces of goats reared in Lubumbashi (mg/kg).

	Kedney	Liver	Muscles	Standard
Cd	1.91 ± 0.69	1.39 ± 0.62	0.36 ± 0.12	0.5[22] (FAO/WHO)
Cu	36.09 ± 12.17	47.84 ± 22.59	24.48 ± 11.87	200[23] (ANZFA)
Pb	4.7 ± 2.55	1.8 ± 0.5	0.96 ± 0.46	1[23] (ANZFA)
Zn	66.06 ± 30.1	106.94 ± 50.21	12.98 ± 5.38	150[23] (ANZFA)
T				
Source: [18].				

Table 5.
Heavy metal concentrations (Cd, Cu, Pb, Zn) found in certain tissues of goats reared in the contaminated zone.

	Kidney	Liver	Muscles	Standard
Cd	0.084 ± 0.037	0.061 ± 0028	0.015 ± 0.006	0.5 [23]
Cu	36.09 ± 12.17	47.84 ± 22.59	24.48 ± 11.87	200 [24]
Pb	4.7 ± 2.55	1.8 ± 0.5	0.96 ± 0.46	1 [24]
Zn	66.06 ± 30.1	106.94 ± 50.21	12.98 ± 5.38	150 [24]
Source [18].				

Table 6.
Heavy metal concentrations (Cd, Cu, Pb, Zn) found in the meat and certain offal of goats sold at the market (ppm).

practice of stake tying is often done during the maize growing period, at the start of the rainy season, to prevent goats from grazing the young plants of this food crop. Animals are satisfied with natural vegetation regardless of its composition. A few rare breeders sporadically bring in crop residues.

Prophylaxis is almost non-existent and goats hardly ever receive veterinary services. These are often limited to inspecting meat and collecting state taxes. The practice of straying, which is the general breeding method for almost all breeders, promotes uncontrolled mating. This practice has harmful consequences such as consanguinity, the transmission of venereal diseases, the increase in genetic defects and abnormalities. This does not promote good animal yields for growth and reproduction.

4.9.2 Genetic type

The average sub-sternal gracefulness index (IGs) of adult animals in this region, all sexes combined, is close to 1, indicating that these goats are mostly brevipedes,

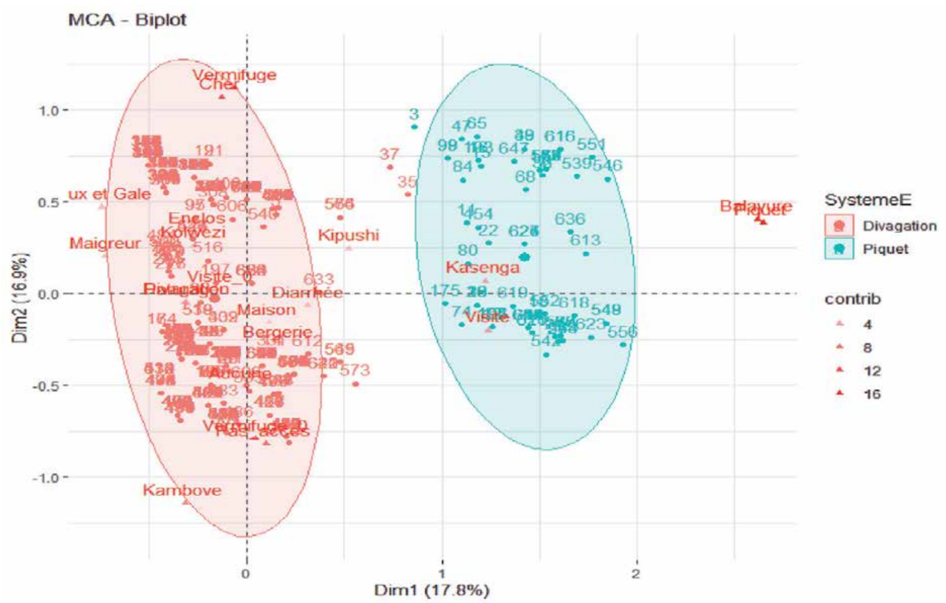

Figure 5.
Grouping of farms based on farming method. SystemeE: Breeding system; divagation: Rambling goats system; piquet: Stakes attachment system. Source [26].

and that considering the average weight and other body measurements, in particular the average height at the withers greater than 50 cm, they belong, like small ruminants of the "Mossi" breed, to the small-format genetic type[7]. However, these authors have found that these goats are very heterogeneous, this does not allow them to be classified into a homogeneous genetic type. This gives rise to a great possibility of selection.

The small size and low weight of these animals may be due to the fact that the grazing in the study area is generally poor. Indeed, soils have a high metal content, acid rain makes phosphorus virtually unavailable, and uncontrolled bushfires destroy huge amounts of organic matter every year and deplete the soil of nitrogen [27].

The poor performance of these goats does not allow them to be marketed within a reasonable time (**Table 7**). The live weight of adult goats ranging from 12.8 to 26.3 kg [29] and some authors found weights of 13.28 and 14.41 kg respectively for females and males at the age of 9 months [28]. The male: female ratio is on average 1: 3. However, 11.4% of herds have a zero ratio with absence of males [29]. And this zero ratio can reach more than 60% for some goat herds in the region [30].

4.9.3 Pathology

Several symptoms related to pathologies have been documented by some authors [26, 29, 31].

In the event of pathologies, breeders resort to pharmacopeia, using some local substances and plants, and the main symptoms encountered in goats are: diarrhea, cough, mange, cachexia [26] (**Figure 6**). An extrapolation of the etiological causes of some of the symptoms of the diseases was carried out on the basis of the diagnoses carried out in the field: - weight loss, usually associated with bloating of the abdomen, poor general condition and a "pricked hair »Is a sign of significant gastrointestinal verminosis; –the causes of abortion are undoubtedly diverse: their etiology has not been specifically studied; –diarrheas are frequently cited, but their

Variable	N	Average	Standard deviation	Minimum	Maximum
P0days: Weight at Birth					
Average herd	245	1.75	0.46	0.5	2.8
Females	119	1.74	0.36	0.6	2.5
Males	126	1.75	0.54	0.5	2.8
P10days					
Average herd	111	2.69	0.59	1.4	5
Females	54	2.62	0.47	1.6	3.9
Males	57	2.77	0.69	1.4	5
P30days					
Average herd	235	4.28	1.04	1.8	8.9
Females	113	4.2	0.96	2	6.1
Males	122	4.34	1.12	1.8	8.9
P90days					
Average herd	228	7.14	2.04	3.2	12.3
Females	111	6.82	2.05	3.2	10.6
Males	117	7.46	1.99	3.7	12.3
P180days					
Average herd	218	10.22	2.15	4.2	14.4
Females	105	9.9	2.13	4.2	14.4
Males	113	10.52	2.09	5.3	13.4
P270days					
Average herd	216	13.37	3.47	5.5	19.4
Females	104	13.28	2.9	5.5	17.1
Males	112	14.41	3.87	6.6	19.4

N: effective, P: Weight.
Source [28].

Table 7.
Weight (kg) of local kids from birth to 270 days.

intensity and frequency vary from one farm to another. This variability could be linked to farming conditions and more specifically to hygienic conditions; - the diarrhea described as “red” by the breeders are in fact bloody diarrhea; – the udder problems, which the breeders clearly dissociate from agalactia, are probably mastitis in the majority of cases: they describe swollen udders, red and painful; –the skin problems revealed by breeders most often result in the presence of scabs and scratching lesions, probably due to the presence of ectoparasites (scabies, lice, ticks, even myiasis); –Cough a sign of an upper and/or lower respiratory disorder. It is more frequent, according to pastoralists, during the rainy season which lasts from October to April [31].

A few cases of reproductive pathologies including physiological (muco-sanguinolent or bloody discharge) and pathological (mucopurulent or purulent discharge) vaginal and/or uterine secretions in 13% and 5% of the 739 non-pregnant goats examined, respectively in farms. And that a number of cases (n = 59) of more specific pathological situations were also observed including eleven cases of hydrosalpinx, eleven cases of paraovarian cysts, two cases of hydrometer and one case of paracervical cyst. Six cases of genital tract abnormalities were observed out of 346 males examined. They mainly concerned the testes (atrophy, cryptorchidism, hydrocele, orchitis) [29].

In addition to reproductive pathologies, a few cases of contagious ecthyma, scabies and estrosis have also been detected [30]. A few cases of caprine brucellosis have also been reported in the killings of goats in the city of Lubumbashi, around 9.8% of cases recorded [30].

Other pathologies are linked to gastrointestinal parasitosis. **Table 8** provides information on the symptoms linked to infestations of these parasitosis.

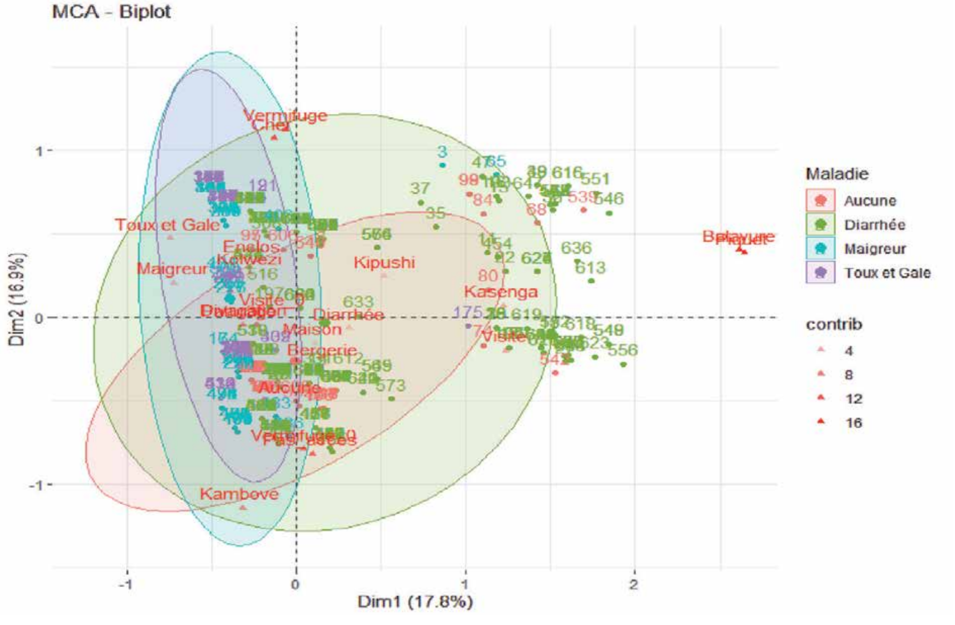

Figure 6.
Grouping of farms in relation to the pathological symptoms encountered. Aucccune: None, Diarhée: Diarrhea, Maigreur: Weight loss, Toux et gale: Cough and scabies. Source [26].

Symptoms and causes of gastrointestinal parasitosis		Frequency
Symptoms:	Weight loss	28/44
	Lack of appetite	28/44
	Hairless hairs	39/44
	Belly bloating	32/44
	Presence of worms in stool	32/44
	Diarrhea	19/44
Causes:	Water	44/44
	Pasture	37/44
	Night kraal	2/44
	Humidity	3/44
Source [32].		

Table 8.
Symptoms and causes related to gastrointestinal parasitic infections.

5. Opportunities for goat breeding in the Katanga copper belt

5.1 Market opportunity

The DR Congo is the world's leading producer of cobalt (the leading strategic mineral in the electric automobile industry with a third of world reserves[31], the leading African producer of copper and the fourth in the world. The mining code [17] of 2002, inspired by the World Bank and designed to attract foreign investment, encouraged the rise of the mining sector. DR Congo's mining industry has been one of the most dynamic in sub-Saharan Africa over the past two decades. There are currently several industrial companies that exploit deposits mainly of copper and cobalt and nearly sixty cooperatives including those working in artisanal mining [11]. There are also several other independents not officially recognized who sell directly to expatriate intermediaries, mainly Chinese and Indo-Pakistani. This situation has encouraged a massive exodus of the Congolese populations to the mining centers and agglomerations of this region. Added to this is the insecurity due to the wars and armed groups that have taken place in certain regions of the Northeast favoring the influx of displaced people from internal wars to the more secure Southeast. The presence of all these populations has constituted a labor force for mining companies and also for artisanal mining which represents about 20% of the mining production of the DRC. Currently more than ten million people depend directly or indirectly on this mining activity [33]. This has fostered a strong demand for primary foodstuffs including meat products.

Goat meat is among the meat products most consumed by the population of Katanga. This meat is the most preferred of ruminant meats, because it is sold in all public markets and especially near the thousands of bars and drinking establishments scattered throughout the KCB, in the form of CABRI commonly called "MITSHOPO", appetizers (pieces of goat meat cooked on a hearth of wood fires). Every day vendors slaughter thousands of goats in large towns, villages and in artisanal mining quarries. Raising domestic animals is generally a savings opportunity for marginalized farming households in the Democratic Republic of Congo. Goats are the second farmed species in this region [26, 27, 29] and in DRC after chicken [25]. It is rustic, easy to breed and easy to handle, with the ability to adapt to harsh and poor grazing areas. Goat droppings are also used as organic manure which serves to amend the acidic soils (ferrisols) which characterize the region. They can also be used to produce biogas in combination with other crop residues. The vegetation of the HMK lends itself well to the rearing of goats.

5.2 Feeding

Some studies on forages have shown interesting results. The studies carried out the supplementation of goats fed on hay of *Imperata cylindrica* and *Setaria palidefusca* supplemented by hay of the legumes *Stylosanthes guianensis, Leucaena leucocephala* and *Adenodolichos rhomboideus* have shown a good opportunity in the rearing of goats in terms of growth performance (**Table 9**), especially in the dry season, if grass and legume hay are used [34]. These legumes showed good nutritional values and were very palatable for indigenous goat [34–36] (**Tables 10** and **11**). They improved the consumption of hay and nutrients (**Figure** 7).

Tests carried out on ten forage species (**Table 12**) have shown the good productive and nutritive capacities of these forage [21]. Some of these species have adapted well despite their first attempts at cultivation in the region. Their use in fodder crops or in association with spontaneous vegetation would be an asset for the

Treatments	WI (kg)	WF (kg)	GWF(g)	ADG(g)
HA	16.85a	17.9a	1050a	17.5a
HAR	16.35a	20ab	3970bc	66bc
HAL	16.7a	21.5b	4820c	80c
HAS	16.6a	19.9ab	3300b	55b
ESM	0.37	0.49	0.42	6.9
P	0.97	0.012	0.000	0.000

Means followed by different letters in the column are different.
SEM: standard error of the mean; *WI:* initial live weighr; WF: final live weight; GWF: liveweight gain; *ADG: average daily gain, HA = hay; HAR = hay and A, rhomboideus; HAL = hay and L, leucocephala; and HAS = hay and S, guianensis,*
Source [34].

Table 9.
Effect on the growth performance of the consumption of hay consisting of a mixture of Setaria palidefusca and Imperata cylindrica, *complemented with the forage from Adenodolichos rhomboideus,* Stylosanthes guianensis *or* Leucaena leucocephala *in local goats at Lubumbashi.*

Fodder	QC (g,DM,Head^{1} day^{1})	Index
Hay	187.5 ± 46.6b	1c
Adenodolichos	83.7 ± 16.9a	1.44 ± 0.5a
Leucaena	268.7 ± 119d	1.7 ± 0.8
Stylosanthes	230 ± 23.7	1.56 ± 0.64ab
Periods		
A	164.4 ± 68.6a	1.6 ± 1.1b
B	208.4 ± 105b	1.3 ± 0.3a
C	208.2 ± 101b	1.4 ± 0.4 ab
D	164.4 ± 68.6a	
P		
Feed	0.00000	0.000000
Periods	0.001	0.016571
Animal	0.272471	0.871944
forage x periods	0	0.778595
periods x animal	0.997815	0.000042
forage x animal	0.919552	0.884571
periods x animal x forage	1	0.996648

*The means followed by different letters in the same column, for each variable, are significantly different from each other ($p < 0,05$), NS: not significant, **: highly significant, ***: very highly significant, QC: Quantities consumed; A: period 1; B: period 2; C: period 3 and D: period 4.*
Source [36].

Table 10.
Average quantities consumed and palatability index of fodder consumed by goats.

improvement of goats and to solve the problems linked to nutritional deficiencies, especially in the dry season. Another opportunity is that some of these forage species have shown good adaptability on soils contaminated with heavy metals characteristic of the HMK region [16, 20, 36].

5.3 Selection and crossbreeding

Studies of indigenous goat crossbreeds have taken place and have shown encouraging results for improved growth and average daily gain. These studies show that crossbreeding has improved the growth rate and average daily gain of hybrids between the indigenous goat and the South African Boer breed [37] (**Tables 13** and **14**).

Forage	*DV-*	OM	CP	ADF	NDF	EE	Asli	UFL	PDLX	PDLE
Hay	977a	959a	30a	503a	709a	11a	40a	0.59a	18a	47a
A rhomboideus	892b	960a	153b	480a	600a	33b	40a	0.71b	96c	76c
L. leucocephala	896b	897b	305.6c	264b	345b	51.5c	100b	1.5c	192d	130d
S. guianesis	910b	947a	104d	492a	560a	17ab	53a	0.68b	65b	66b
Corn	—	—	—	—	—	—	—	1	74	97
SEM	17	24	6.8	10.6	43.8	4.25	24	0.01	1.6	1.1
p	0.002	0.01	0.000	0.001	0.004	0.002	0.01	0.000	0.000	0.000

Means followed by different letters in the row are different ai level p < 0.05.
DM: dry matter, OM: organic matter, CP: crude protein, ÁDF: insoluble fiber in acid detergent, NDF: insoluble fiber in neutral detergent, E: ether extract, UFL: net energy for lactation, PDIN: protein digested in the small intestine when rumen-fermentable nitrogen is limiting, PDIE: protein digested in the small intestine when rumen-fermentable energy is limiting S&M: standard error of the mean.
Source: [36].

Table 11.
Chemical composition (g/kg) of legume forage.

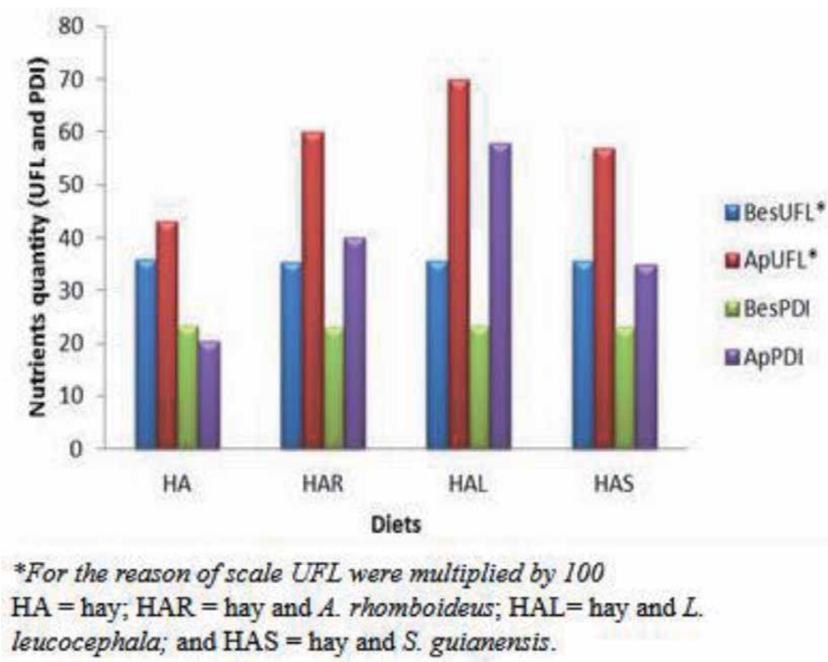

Figure 7.
Comparison between energy and nitrogen, requirement and intake of experimental diets consumed by local goats in Lubumbashi. BesUFL: Requirement net energy for lactatio, ApUFL: Intake net energy for lactation, BesPDI: Requirement protein digested in the small intestine when rumen-fermentable nitrogen is limiting, ApPDI: Intake protein digested in the small intestine when rumen-fermentable nitrogen is limiting. (Source: Ref. [34]).

Species	Production (TDM/ha/year)	CP (%MS)	NDF (%MS)	ADF	CPt/Ha/year	CE
Leucaena leucocephala	7.9	21.38–29.31	48.15–42.41	42.45–29.77	1.8	3340.69–3152.82
Cajanus cajan	10.6	24.51–25.67	50.16–55.89	41.62–50.66	2.7	3444.05–3650.52
Albizia lebbeck	3.8	22.76–24.21	42.13–37.23	24.99–24.45	0.9	3112.35–3053.35
Moringa oleifera	6.3	20.71–26.02	24.68–24.55	16.75–14.07	0.5	3111.54–3251.58
Cynodon dactylon	4.3	7.38	72.94	40.32	0.3	11137,5
Trypsacum laxum	13.9	7.6–9.01	67.40–64.06	39.30–36.28	1.2	2834.27–2661.95
Setaria palidefusca	5.9	3.95	74.47	54.19	0.2	2648.25
Echinochloa pyramidalis	6.5	3.56	65.66	37.50	0.2	2679.64
Panicum maximum	8.7	5.37–6.53	73.13–61.55	48.41–37.36	0.5	2777.22–2485.73
Paspalum dilatatum	13.1	5.66–7.79	71.00–69.77	34.48–44.66	0.8	2631.83–2449.69

TDM: ton dry matter, CP: crude protein, NDF: neutral detergent fiber, ADF: acid detergent fiber, ADL: acid detergent lignin, CE: crude energy.
Source [21].

Table 12.
Productivity and chemical composition of forage species cultivated in Lubumbashi.

Genetic group	Birth	30 days	90 days	180 days	270 days
Boer (n = 62)	2.41 ± 0,38a	6.87 ± 0.38a	14.3 ± 0.38a	17.9 ± 0.38a	24.7 ± 0.38a
F1 (n = 167)	2.18 ± 0,15a	6.87 ± 0.38a	9.53 ± 0.15b	14.4 ± 0.15c	21.4 ± 0.15c
Local (n = 116)	1.75 ± 0,12a	4.27 ± 0.12b	7.11 ± 0.12c	10.2 ± 0.13b	13.8 ± 0.13b
Genetic group * sex					
Boer F	2.29 ± 0.49[a]	6.59 ± 0.49a	13.9 ± 0.49a	17.6 ± 0.49a	24.4 ± 0.49a
F1 F	2.06 ± 0.22a	4.89 ± 0.22b	8.68 ± 0.22b	13.8 ± 0.22c	21.9 ± 0.22b
Local F	1.75 ± 0.17a	4.19 ± 0.18c	6.79 ± 0.18c	9.87 ± 0.18[b]	13.2 ± 0.18d
Boer M	2.52 ± 0.57a	7.14 ± 0.57a	14.5 ± 0.57a	18.3 ± 0.57a	25.1 ± 0.57a
F1 M	2.29 ± 0.20a	5.45 ± 0.20[b]	10.4 ± 0.20d	14.9 ± 0.20d	20.8 ± 0.20c
Local M	1.75 ± 0.17a	4.34 ± 0.17b.c	7.43 ± 0.17e	10.5 ± 0.18e	14.4 ± 0.18e

F1: Hybrid; F: femelle, M: male.
Source [37].

Table 13.
Average weights (kg) of kids in the pre-weaning and post-weaning period of the genetic groups and the genetic group-sex interaction. Means followed by different letters; a, b, c, d and e; in the column are different at level $p < 0.05$.

5.4 Veterinary care and prophylaxis

Studies of the remedies used for the care of goats in this region show that the majority of goat breeders use local plants to care for their animals (**Table 15**). And that for the majority of breeders, this knowledge of herbal remedies is acquired by family transmission; only one of these breeders has enriched his knowledge by

Sources of variation	Days 0–30 ($g.d^{-1}$)	Days 30–90 ($g.d^{-1}$)	Days 90–180 ($g.d^{-1}$)	Days 180–270 ($g.d^{-1}$)
Groupe génétique*sexe				
Boer F	143 ± 9.10^{a}	122 ± 5.91^{a}	41.2 ± 4.44^{a}	75.7 ± 5.53^{a}
F1 F	94.3 ± 4.07^{b}	62.2 ± 2.64^{b}	56.5 ± 1.98^{b}	88.7 ± 2.47^{a}
Local F	81.0 ± 3.30^{c}	43.0 ± 2.16^{d}	33.4 ± 1.68^{a}	37.4 ± 2.10^{b}
Boer M	154 ± 10.6^{a}	124 ± 6.90^{a}	$41.1 \pm 5.18^{a.c}$	75.3 ± 6.45^{a}
F1 M	106 ± 3.74^{b}	82.1 ± 2.43^{c}	$50.8 \pm 1.85c$	65.6 ± 2.31^{a}
Local M	85.7 ± 3.19^{c}	51.0 ± 2.16^{e}	34.4 ± 1.62^{a}	43.0 ± 2.02^{b}

F1 = Hybrid; F = femelles; M = males.
Source [37].

Table 14.
Averages of daily gain (ADG) of different genetic groups. Means followed by different letters; a, b, c and d; in the column are different at level $p<0.05$.

studying botany. Almost a quarter of breeders report having acquired this knowledge esoterically by dreaming, or by communicating with a deceased relative, or even by inspiration. Only one breeder reports acquisition by trial and error [31].

5.5 Reproduction

Like all other ruminants in the tropics, the goat reproduces at any time in the DRC, which makes it economically profitable to have births during all periods of the year. More births are observed in the dry season than in the rainy season [38]. This situation would be due to the fact that the births which arrive in the dry season result from the gestations of the rainy season which is characterized by an abundance of fodder and that the dry season where there is a lack of fodder is characterized by fewer gestations and therefore, fewer births in the rainy season. The mean age of farrowing is 15 months and therefore corresponds to an average age of pregnant matings of around 10 months [30]. While the age of pregnant females ranged from 7 to 108 months [38].

6. Perspectives and recommendations

In view of the constraints and opportunities related to goat breeding in the Katanga Mining Hinterland, it is necessary to list the perspectives and recommendations to overcome the difficulties of breeding and the goat sector in the area.

6.1 Role of politico-administrative authorities and the state

In view of the foregoing, goat breeders are abandoned by the authorities and decision-makers of the Congolese State at all levels. Political leaders should get involved in the organization and supervision of breeders in general, and those in the goat sector in particular, by prohibiting the straying of animals. They should help agro-pastoralists by granting breeding areas chosen according to the quality of pastures and according to safety to help them do their best work in serenity. These pastures must be community-based taking into account the remoteness of the mining and mineral processing areas and also far from urban areas. The breeders should be organized in cooperatives or associations. Each organization must be

Plant used	Vernacular name (in Swahili)	Symptoms treated	Parts of the plant used	Method of preparation of administration remedies	Dosage	Solvent	Number of breeders using this remedy (n = 50)
Allium sativum L. Alliacea	Hayi	Cough	Pods	Pounded and given in syrup (with honey)	1 glass for 2 to 3 days	Honey	27
Carica papaya L. Caricaceae	Kipayi payi	Skin problems (scabs and itching)	Leaves	Fiction on lesions of previously looted leaves	Depending on the surface to be treated	No solvent	42
Carica papaya L. Caricaceae	Kipayi payi	Skin problems (scabs and itching)	latex from unripe fruit	Fiction about lesions	Depending on the surface to be treated	No solvent	43
Carica papaya L. Caricaceae	Kipayi payi	Skin problems (scabs and itching)	Seeds	Maceration	1 to 3 glasses for 2 to 3 days	Water	50
Cucurbitamoschata Duchesne cucurbitaceae	Kibwabwa	Stung belly bloating	Seeds	Maceration	1 to 2 glasses / day for 2 to 3 days	Water	34
Elaeis guineensis arecaceae	Mafuta ya ngaji	Wounds	Paml oil	Local application			21
Euphorbia hirta L. Euphorbiaceae	Kavudji	Belly bloating and prickly hair	whole plant	Maceration	1 to 2 glasses / day for 2 to 4 days	Water	41
Mangifera indica L. Anacardiaceae	Manga	Diarrhea	Trunk bark	Maceration	1 to 2 glasses / day for 3 to 4 days	Water	26
Psidium guajava L. Myrtaceae	Mapela	Diarrhea	Leaves	Decoction	1 to 2 glasses / day for 3 to 4 days	Water	21
Tephrosia vogelii Hook. F. Fabaceae	Buba	Skin problem (scabs and itching)	Leaves	Fiction on lesions	1 to 2 glasses / day for 3 to 4 days	No solvent	23
Tithonia diversifolia (Hemsl.) A. Gray Myrtaceae	Kilulu nkundja	Skin problem (scabs and itching)	Leaves	Fiction on lesions	Depending on the surface to be treated.	No solvent	39
Tithonia diversifolia (Hemsl.) A. Gray Myrtaceae	Kilulu nkundja	Belly bloating and prickly hair	Leaves	Maceration	1 to 2 glasses / day for 3 to 4 days	Water	41

Source [31].

Table 15.
Latin name, vernacular in Swahili and parts of plants identified as constituents of remedies administered to goats, symptoms treated, methods of preparation of herbal remedies, method of administration and dosage. Frequency of use of the remedy is also specified by the number of families out of the 50 questioned.

organized so as to have its own pastures, its own technicians and its organization of the market. This would serve to conduct the feeding well, the improvement and management grazing, prophylaxis, veterinary care, reproduction, selection, other zootechnical operations and the marketing of animals.

6.2 Breeding practice and selection of goats

Poor husbandry practice contributes negatively to the economic profitability of goat rearing in the KCB. Straying like breeding exposes animals to loss, theft, disease, nutritional deficiency and increased rate of inbreeding. It also results in an irrecoverable loss of dejection following straying. In order to compensate for the nutritional deficiency linked to the scarcity of fodder, especially in the dry season, and the low nutritional value of fodder, it is important to resort to the enrichment of pastures with grasses and fodder legumes which have made proof of good growth, good productivity, good palatability and good nutritional value. It should also be noted the valuation of excessive vegetation during the active period as hay for use in cold and dry season where there is a lack of vegetation. Providing decision-makers and breeders with a map of uncontaminated pastures would help guide a good use of the available fodder resources in the region,

The use of a lick block and/or multi-nutritional block, especially in the dry season, could make it possible to compensate for the deficiency in minerals, energy and protein.

The quantification, the study of the nutritional value and the methanogenic potential in combination of the goat droppings of the crop residues of the main crops in the region could also make it possible to increase the productivity per unit of agricultural area and the well-being of households agricultural.

To avoid losses, theft, straying, nutritional deficiencies and allow the welfare of animals, agro-pastoralists must be obliged to build goat barns that meet standards. Good housing for animals would also protect them against diseases and bad weather linked to climatic hazards such as showers, winds, dust and ectoparasites. This practice would also allow the collection of droppings, to be used as organic manure or for methanogenesis, wasted when the animals are straying.

6.3 Promotion of local herbal medicine

The promotion of local medicinal plants is a major asset in the prophylaxis and the fight against common diseases such as parasitoses, bacterial infections and others. This would allow breeders to save the costs associated with the purchase of conventional veterinary drug. A systematic inventory and studies on chemical compounds, biology, cultivation attempts and then the popularization of medicinal plants would be an asset for their conservation and their use for veterinary care and prophylaxis in the region.

6.4 Diversification of goat breeding speculations

The introduction of the goat milk sector which is a stable activity, not depending on the season, providing daily milk, would allow the diversification of sustainable activities and permanent family recipes. This activity would be made possible after studies on livestock purebred goats or crosses of specialized exotic breeds with the indigenous goat. Among these breeds there are some that have proven themselves in sub-Saharan Africa such as Saanen, Nubian, Alpine, Topinambour and others.

7. Conclusion

The goat is the second highest species in the DRC and it is its meat that is consumed the most by ruminants. Too little attention is paid to its breeding; which remains a secondary activity for several peasant families. The goat industry is characterized here by a very low level of inputs in subsistence farms which are made up exclusively of small family farms. The lack of support for its breeding is an obstacle to the development of this sector, which provides meat and financial resources for peasant households. For the Katanga copper belt region, the majority of goats are imported from Zambia, which constitutes a big shortfall for the country and for the local farmers.

The goat sector receives almost no sustainable financial support from the government, unlike the crop production sector. A synergy between researchers, breeders and the political-administrative authorities on improving the goat sector would be a breath of fresh air for the poor farmers and this will save a few masses of currency which are exported for the purchase of meat abroad.

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Section 3

Male Goat Reproduction

Chapter 4

Characterisation of Semen and Phenotypic Parameters in Relation to Male Goat Fertility

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Abstract

The following are aspects were discussed in this chapter: Domestication of goats – checking on when the goats were first domesticated and for what purposes; Current goat industry - looking on the contribution of goats economically; Conservation of domestic animal diversity - looking on the importance of conserving indigenous animals since some of them are under threat of extinction; Male goat fertility – discussing male fertility indicators; Characterisation approaches - different approaches to be followed when characterising indigenous species; and Phenotypic and genetic characterisation of indigenous goats.

Keywords: Phenotypes, characterisation, goat, semen, seminal plasma

1. Introduction

It has been estimated 28% of farm animal breeds became eroded or threatened in the past century and this figure is now expected to be escalating. Therefore, conservation of these goat breeds is important to protect their diversity [1, 2], because once it is lost it cannot be replaced [2]. Conservation of genetic diversity provides protection against diseases, feed shortages, selection errors, unforeseen disastrous actions, social and climatic changes. The main aim of conservation is to keep different genes as pure as possible and to keep special genes of value [3, 4]. For the conservation and improvement of indigenous animals, phenotypic and semen characterisation can be a first step to be undertaken before the use of their genetic material [5–7]. Such characterisation provides information on the reproductive performance and identification of unique characteristics within different populations [8]. In small ruminants, it has been found that there is a positive correlation between phenotypic characteristics and semen parameters. For example: testicular circumference, body weight and condition score of a male goat were positively correlated to high sperm cell concentration [9, 10]. On the other hand, with all the technologies available, there is little information on what parameters can be used as indicators of male fertility [11]. As a result, the search for other male fertility markers such as seminal plasma constituents is needed [12]. Studying of seminal plasma constituents can be another method of evaluating the reproductive system functioning and semen quality in goats [13]. In other species,

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evaluation of seminal plasma constituents such as proteins, sodium, potassium, magnesium, calcium, zinc, glucose, cholesterol, triglycerides, lipids and urea were found to be useful in determining male fertility [14, 15]. These seminal plasma constituents play a major role during sperm cell metabolic processes [16, 17].

2. Materials and methods

2.1 Phenotypic characterisation

Phenotypic quantitative characteristics is assessed with the aid of a flexible tape measure. Individual body weight is determined by using a weighing scale. Rectal body temperature is determined using a thermometer. The phenotypic qualitative characteristics is assessed through visual appraisal. Body condition score is assessed based on standard scale which ranges from 1 to 5 (1 = very thin, 2 = thin, 3 = satisfactory, 4 = fat and 5 = obese). The age of the males is estimated by counting the number of permanent incisors on the lower jaw of the mouth [9].

2.2 Laboratory evaluation

2.2.1 Semen volume

Semen volume is measured by reading the measurements on the collection tube [18].

2.2.2 Semen pH

Semen pH is determined using a pH meter, whereby pH electro-rode is washed with sterile water and wiped with sterile paper towel before being inserted into the tube containing the semen sample for about 30 seconds [18].

2.2.3 Semen colour

Semen colour is observed visually and categorised as clear/watery, cloudy, milky, creamy and thick creamy [19, 20].

2.2.4 Sperm cell motility

Sperm cell motility is determined using a Sperm Class Analyser [21]. Five hundred microliters of Ham's F-10 and 10 μL of semen are mixed in a 1 mL graduated tube and incubated for 5 minutes at 37°C. After incubation, 10 μL of extended semen is placed on a pre-warmed microscopic slide (37°C), mounted with a cover slip and examined (x 10) under a phase contrast microscope [18]. Sperm cell motility is categorised as follows:

2.2.4.1 Progression (%)

Total motility (TM) = is a sum of progressive and non-progressive motility; Progressive motility (PM) = sperm cells that are moving forward; Non-progressive motility (NPM) = sperm cells that are not moving forward [22].

2.2.4.2 Velocity (%)

Rapid = sperm cells moving rapidly (81–180 μm/s), medium = sperm cells moving at an average speed between 51 and 80 μm/s and Slow = sperm cells moving slowly at ≤50 μm/s [22].

2.2.4.3 Average values of velocity parameters

Curvilinear velocity (VCL) = average velocity which measures a sperm cell movement along its actual path (μm/s); Straight-line velocity (VSL) = average velocity which measures a sperm cell movement along a straight line from beginning to the end (μm/s); Average path velocity (VAP) = average velocity of the smoothed cell path (μm/s); Linearity (LIN) = linearity movement is a ratio of VSL/VCL (%); Straightness (STR) = straight line movement is a ratio of VSL/VAP (%) [11, 23] and Wobble (WOB) = wavering movement which is a ratio VAP/VCL (%) [11, 22].

2.2.5 Sperm cell concentration

Sperm cell concentration is determined with a spectrophotometer. A square cuvette is filled with 3 mL of sodium citrate solution and placed in a spectrophotometer for at least 30 seconds. Raw semen (15 μL) is added in a square cuvette containing the sodium citrate solution, again placed in a spectrophotometer in order to read the absorbance. The absorbance read is used to determine the final sperm cell concentration with the aid of a formula (201 X 25.97 X absorbance – 0.3) [21].

2.2.6 Sperm cell viability, morphology and abnormalities

For evaluation of sperm cell viability, morphology and abnormalities, 200 sperm cells per slide are counted in a smear stained with nigrosin-eosin. Nigrosin-eosin stain (60 μL) and 6 μL of semen are mixed, then 5 μL of the mixture is smeared on a slide [23], whereby a dragging slide is placed at an angle of 45° and slowly moved into contact with the semen sample, which runs alongside the edge of the slide until it produces a smear. The smeared slides are dried and evaluated (counting of the sperm cells) under a fluorescent microscope using an oil immersion objective (x 100) on a bright field, with the aid of a laboratory counter. Live sperm cells do not absorb stain (fluorescence) while dead sperm cells do (become purple). Live sperm cells are further evaluated for morphology and abnormalities. Abnormalities are categorised as primary (small, large or swollen head, double heads, abnormal acrosome, elongated and abaxial mid-piece, double and short tail), secondary (detached, loose or damaged acrosomes, bent and protoplasmic droplets of the mid-piece, bent and shoe-hook tail) and tertiary abnormalities (reacted acrosomes and coiled tails) [23].

2.2.7 Sperm cell acrosome integrity

Sperm cell acrosome integrity is determined on the slides smeared and stained with nigrosin-eosin stain, under a fluorescent microscope, oil immersion objective and bright field (x 100). At least 200 sperm cells are counted per slide [24].

2.2.8 Sperm cell membrane integrity

Sperm cell membrane integrity is determined using a hypo-osmotic test. A semen volume of 0.1 mL is mixed with 1 mL hypo-osmotic solution and incubated at 37°C for 1 hour. Following incubation, 7 μL of semen is placed on a glass slide, then smeared and evaluated under a phase contrast microscope (x 40), at least 200 sperm cells per slide are counted. Sperm cells with swollen and coiled tail are considered intact [25].

2.2.9 Determination of seminal plasma constituents

Seminal plasma is collected from semen samples by means of centrifugation [25] at 1500 rpm for 5 minutes. Following centrifugation, seminal plasma is removed using 1 mL disposable plastic pipettes. The seminal plasma is transferred into 5 mL centrifuge tubes and stored at −20°C until analysis. Determination of seminal plasma constituents is done using commercial *kits*. For the determination of sodium, potassium, magnesium, zinc and calcium; seminal plasma is centrifuged at 1500 rpm (4°C) for 20 minutes. Then 1 M sodium hydroxide is added to form a coloured salt complex. The concentration elements in the coloured complex solution is determined spectrophotometrically using a digital fluorescent microscope [26].

Determination of osteopontin, metalloproteinases type-2 tissue inhibitor, fertility associated antigen and urea is carried out by the addition of 100 μL of standards and sample solution into the appropriate wells, shaken gently to mix the contents and then incubated at 37°C for 1 hour. The wells are washed 7 X with 400 μL of wash solution. After the final wash, the wells are firmly tapped on a lint free paper towel to remove any remaining wash buffer. A labelled antibody (100 μL), is pipetted into each well. The plates is sealed and incubated at 4°C for 30 minutes. The plates is emptied of their contents and washed 9 X with 400 μL of wash solution. After the final wash, the plates are emptied and the results are generated by the addition of 100 μL of TMB substrate to each well. The plates are incubated for 30 minutes at 25°C in the dark, the reaction is stopped with 100 μL of stop solution, and the absorbance read at 450 nm [26]. Lactose dehydrogenase is determined by the catalytical oxidation of lactate to pyruvate in the presence of NAD with subsequent reduction to NADH. The rate of NADH formation measured at 340 nm is directly proportional to serum LDH-L activity. The change in absorbance measured at 340 nm is directly proportional to the activity of lactate dehydrogenase in the sample and translated to the concentration of lactose dehydrogenase in the sample. Lactate dehydrogenase reagent 1 (4 X 40 mL) and lactate dehydrogenase reagent 2 (4 X 8 mL) are reacted with the sample and enzyme activity measured spectrophotometrically (Lactic acid + NAD + → pyruvate + NADH) [26].

For the determination of triglycerides, a spectrophotometer is set at a wavelength of 540 nm and the absorbance reading to zero with water as the reference. Free glycerol and triglycerides reagents are prepared and warmed up to assay temperature in the blank, standard and sample cuvettes. Free glycerol and triglycerides reagents (0.8 mL) is pipetted into each cuvette. Then 10 mL of water, glycerol standard and sample are added into the blank, standard and sample cuvettes and mixed by gentle inversion. The cuvettes are then incubated for 5 minutes at 37°C. Initial absorbance reading of blank, standard and sample at 540 nm versus water as the reference is taken. To each cuvette 0.2 mL of the reconstituted triglycerides reagent is added, mixed and incubated for 5 minutes at 37°C [26]. The final absorbance of the cuvettes is read at 540 nm versus water as the reference and the triglycerides concentration is calculated. For the determination of lipocalin-type prostaglandin D synthase, seminal plasma is incubated overnight at 48°C with 30 mg of anti-recombinant bovine lipocalin-type PGD synthase IgG. Samples are washed 3 X with PBS-BSA and re-suspended to 500 mL FC blocking medium. Five microliters (0.5 mg/mL) of fluorescein isothiocyanate-conjugated goat anti-rabbit IgG Fab fragment is added to 500 mL of seminal plasma suspension for 1 hour. After being washed 3 times in PBS-BSA as before, the fluorescence of the samples (concentrations) is measured using a digital fluorescent microscopy. For lipids determination, seminal plasma lipids are extracted with 6 volumes of chloroform-methanol (2/1, V/V), centrifuged at 800 x g for 3 minutes and the resulting lower phase aspirated and dried under a stream of nitrogen. Total lipids are determined enzymatically and their quantities were measured colorimetrically [26].

3. Domestication of goats

Goats were the first ruminants to be domesticated [27] and they have been kept since 6000 BC [28]. They originated from Asia [29]. The main reasons were for the production of milk and meat [27, 30]. Bezoar goats were reported to be the first to be domesticated in Asia before spreading over North Africa and Southern Europe. These goats were raised under very harsh environmental conditions. Goats are active, sure-footedness and have a habit of eating any kind of plant material [28]. This provides motivation for the genetic improvement for this species [31]. Globally, there are about 800 million goats, which represents 12% of global mammalian breeds recorded. About 70% of the world's goats are found in Asia, with the largest number in China, India and Pakistan. Less than 15% are found in Africa [32].

4. Current goat industry

Goats contribute significantly to the livelihoods of poor farmers [5, 27] and they are well preferred due to their natural adaptation, lower maintenance requirements [9] and short reproductive cycle, with a high reproduction rate compared to large ruminants [5]. In South Africa, there are over 6 million goats, and some of the breeds were commercialised and have gained international recognition; for example: Boer, Kalahari Red and Savanna goats. These goat breeds are known for their fast growth rate and good carcass quality [33, 34]. The South African goat industry is dominated by three main products: meat (chevon), milk and fibre. Goat meat production contributed R 3.6 billion to the South African economy between 2001 and 2011 [33].

Worldwide, chevon consumption has increased by 63% over the years as an alternative to beef, pork and chicken because of its high nutritional value, lower fat content, cholesterol composition and its leanness [9, 31, 35]. There is also an increasing trend of socio-economic importance of goats [36, 37] and demand for goat's meat exceeds what is available [31]. Therefore, to keep up with the increasing demand for goat meat, goats' productivity needs to be increased. In South Africa and the other developing countries, most goats are farmed traditionally and a very small proportion is kept commercially [37–39]. The productivity of livestock such as cattle, sheep and goats in South Africa and other African countries is low, due to a low reproductive rate and poor management practices [9, 37, 40].

5. Conservation of domestic animal diversity

Indigenous animals provide necessary genetic diversity to modern agriculture, as a means to ensure stability and improve future breeding programmes. However, indigenous animals are under threat of extinction [5, 41, 42]. Extinction or erosion of farm animal genetic resources is escalating due to environmental conditions, human interference and a combination of genes [4], which is due to an increase in uncontrolled breeding and the introduction of exotic breeds [40]. Factors such as breed dependence, changes in production systems and producer's preference because of socio-economic factors, political unrest, natural disasters (drought), increased disease incidence, single productive trait emphasis and intensive use of biotechnology also contribute to erosion genetic diversity [41, 42]. It is in the interest of the entire community to conserve livestock genetic materials and maintain their biodiversity [4] because once the diversity is lost it cannot be recovered [2].

So far, 22 to 28% of farm animal breeds have been reported to be eroded [32, 42] with one to two breeds disappearing every week [41]. The following threats could be faced due to this erosion: high rate of cross bred animals, development of new genotypes, expansion of intensive agriculture, economy changes, decrease in market demand and food security, disappearance of cultural and historical values, loss of indigenous knowledge [43] and diseases outbreaks [32]. Therefore, conservation of farm animal genetic resources is important to protect their diversity [2]. Conservation of genetic diversity provides protection against climatic change, diseases, food shortages, social changes, selection errors and unforeseen disastrous actions [4]. The main aim of conservation is to keep pure genes and special genes of value [3, 4]. Adequate identification and documentation of animal breeds simplifies conservation of genetic resources. According to Cardellino [41], the Food and Agriculture Organisation requested its members to implement a conservation strategy for the sake of animal genetic resources preservation, which might not be of interest to farmers now. Currently, *in-situ* and *ex-situ* conservation strategies (**Figure 1**) are currently used for the conservation of animal genetic diversity [4, 32].

5.1 In-situ conservation

In-situ conservation refers to the maintenance of endangered or rare live animals in their natural habitat through the enhancement of its production characteristics (conservation with utilisation) [4, 32]. This type of conservation allows the attainment of important information about ecological or historical-cultural value of a breed [32, 42] and it includes performance recording and breeding programmes, with emphasis on the maintenance of genetic diversity within the breed [32].

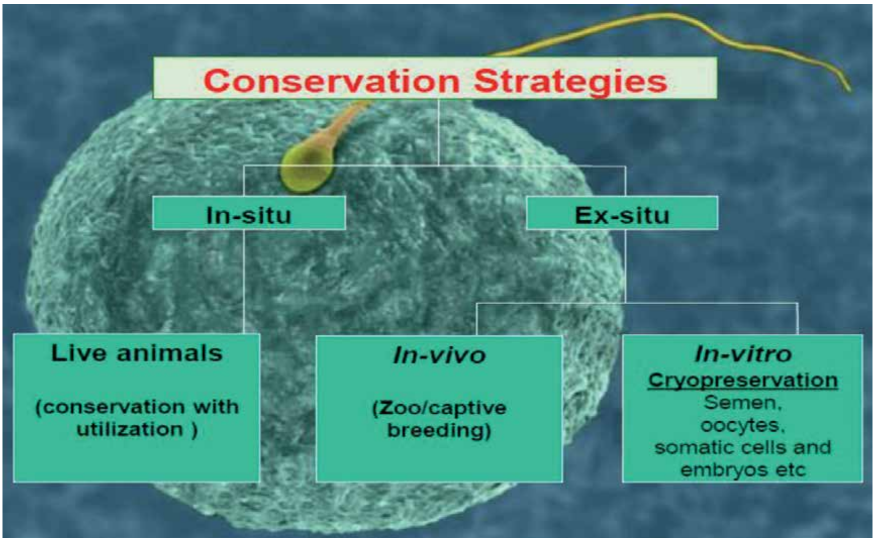

Figure 1.
Schematic representation of conservation strategies [44].

In-situ conservation would be the preferred approach for the short and long term, if there were maintenance and management of farm animal genetic resources (FAnGR). This is because in-situ conservation ensures that a breed is conserved in an active state [32, 43]. With the aid of appropriate genetic improvement techniques, the breed maintains its status to changes in the production, marketing and social environments. In general, conservation of FAnGR as live animals has many advantages compared to the in-vitro approach [43] such as enabling of breed development, adaptation to the environment, maintaining of indigenous knowledge to the keepers, sustainable utilisation in rural areas, contribution to nature management and financial viability [32].

5.2 Ex-situ conservation

Ex-situ conservation refers to the conservation of endangered or rare species in a designated area. This type of conservation strategy also plays a role in strategic breeding programmes [4, 43]. It protects against changes in the production conditions and helps with quick introduction of the breed with the aid of a limited number of recipients [32]. It comprises of in-vivo and in-vitro conservation. In-vivo conservation is the safeguarding of live animals in zoos, wildlife parks, experimental farms or any off-farm maintenance [4, 32, 43]. However, due to the high cost of this type of conservation, animals are usually kept in smaller numbers. It is therefore recommended that in-vivo conservation be complemented with in-vitro conservation. However, in-vivo conservation does not always give assurance of the preservation of the original genetic diversity of a breed, because animals are not preserved in their original habitat [32].

In-vitro conservation involves cryopreservation of genetic materials in haploid (semen, oocytes, somatic cells, testis and ovarian tissues) and diploid form (embryos) [4, 45]. This strategy was introduced because the in-vivo conservation strategy is costly. The cryopreserved genetic materials are used to regenerate a specific population in the future, even after the donors' death or can be used as a back-up [4, 43]. For the establishment of reinforced ex-situ conservation programmes: conservation priorities and goals need to be set, national and regional ex-situ conservation facilities need to be established, the use of genetic materials stored in ex-situ gene banks need to be facilitated, there should be a strict biosecurity measures and procedures must be followed for maintenance of cryo gene banks. Implementation of long-term regional and global conservation strategies is required for saving costs and avoiding duplication of conserved genetic materials [4].

6. Male goat fertility

Fertility is a complex term measured by conception rate [11], number of services, semen parameters, litter size, kidding interval, non-return and kidding rate. Fertility in male animals is an important characteristic that is used to select sires and it is more economically important than other production characteristics [46]. Potential fertility of mature males is a characteristic that has been evaluated based on phenotypic characteristics and it increases the probability of reproductive success during breeding season [39, 47]. Like in any other species, sub-fertile males prolong the kidding season due to delayed pregnancy, which will then lead to culling of does and loss of kids [11, 47, 48]. Male fertility is influenced by development of the testis, seminal plasma quality, libido, physical soundness [11] and the ability of sperm cells to penetrate the zona pellucida of the ova [49]. Therefore, it is important to manage male animals well in order to optimise their breeding performance [48].

6.1 Indicators for male goat fertility

Following physical examination and assessment of males' reproductive organs, semen samples needs to be collected. This is achieved by collecting semen samples with the aid of an approved artificial vagina or electro ejaculation method [50, 51]. Following collection, the semen samples are evaluated for semen volume, pH, sperm cell motility [52], semen colour [53], sperm cell concentration, acrosome and membrane integrity [54], live/dead and morphology [55]. Semen parameters evaluation is an accurate, objective, rapid, inexpensive and standard method of indicating fertility of breeding males, other than directly assessing their ability to make females pregnant [49, 52, 56].

6.1.1 Semen colour

Semen colour is evaluated subjectively by visual observation. It can also be used to predict sperm cell concentration [49]. Clear, cloudy, milky, thin-creamy, creamy and thick-creamy semen colours with average sperm cell concentration of <0.7, 0.7, 2.0, 3.0, 4.0 and 5.0 X 10^9/mL, respectively, are normally observed following semen collection. Semen samples with colour that ranges from milky to thick creamy were found to be good and highly fertile [49, 57]. Sometimes, pink, grey or brown semen colour can be observed because of blood presence, which can be due to injury of the penis or reproductive tract or diseases and infections. If there is urine contamination, the sample will be yellowish in colour, and such semen needs to be discarded, as it will affect sperm cell quality [49].

6.1.2 Semen volume

Semen volume is evaluated by taking the reading on the collecting tube [58] and varies according to the method of semen collection used [49]. Acceptable semen volume of good quality sample ranges from 0.5 to 3 mL, during the natural breeding season [59, 60]. Use of the electro-ejaculator for semen collection resulted in high semen volume when compared to the use of artificial vagina [49]. This was reported to be due to excessive accessory sex gland secretions and urine [61]. A good correlation was observed between animals' age and testicular size; young males produce lower semen volume when compared to old males [62]. Smaller testis produces lower semen volume when compared to bigger testis, and this is attributable to differences in semen production and storage capacity [63].

6.1.3 Sperm cell motility

Sperm cell motility is an essential parameter in the assessment of semen quality and different results have been reported on its effect on male fertility [64, 65]. Sperm cell motility can be determined using two methods, which are subjective and objective assessment [11, 53]. Subjective assessment involves the estimation of sperm cell motility and relies on the training and experience of the observer [53, 66]. Objective assessment mainly involves the use of a computer assisted sperm analyser to analyse sperm cell motility [11, 65]. Goat semen is regarded as good if it has a sperm cell motility of more than 70% [59, 67].

6.1.4 Sperm cell morphology

According to Hashida et al. [56], sperm cell morphology has a number of benefits, as one of the predictive factors in determining the positive outcomes of fertilisation.

A minimum of 70% normal sperm cells are needed for fertilisation to take place [68]. The main sperm cell abnormalities that hinder male fertility in livestock are: small, large or double heads, abnormal, detached, reacted or damaged acrosome, elongated and abaxial mid-piece, double, short, bent, shoe-hook and coiled tail, bent and protoplasmic droplets of the mid-piece [49, 55]. Diseases and stress, as a result of temperature, are the main contributors to high percentages of damaged sperm cells [53]. High ambient temperature and humidity may reduce males' fertility by 6 weeks, and during that period a high rate of abnormal sperm cells appears in the collected ejaculates during the recovery period. During the non-breeding season, abnormalities increase then they decline during the breeding season [49].

6.1.5 Sperm cell viability

Dead sperm cells lead to complete failure of fertilisation. For fertilisation to take place, goat semen samples should have less than 25% dead sperm cells [57, 63]. Temperature levels and infections are the main causes of dead sperm cells in goats [63, 69].

6.1.6 Sperm cell concentration

Males with acceptable semen quality should contain sperm cell concentration of $\geq 2 \times 10^9$ sperm cells/mL [59]. Sperm cell concentration is influenced by different factors such as age, breed, nutrients supply, climatic conditions [36], season, testicle size, semen collection frequency and method [63]. During the breeding season, sperm cell concentration increases [39, 63]. Larger testicles produce more highly concentrated sperm cells due to bigger site of production and capacity compared to smaller testicles [63]. The artificial vagina results in higher sperm cell concentration when compared to the electro-ejaculation method [70]. Excessive application of electric stimuli increases semen volume, due to unwanted secretions, which then leads to lower sperm cell concentration and dead sperm cells [63, 71].

6.1.7 Semen pH

Generally, semen pH of 7.0 to 7.2 has been reported as the best for optimum functioning of most of the enzymes in sperm cells [49], which is in turn favourable for sperm cell motility and viability [72]. Acidic and alkaline semen pH have been observed to be unfavourable for sperm cells to survive and leads to sperm cell damage and low fertilising ability [49, 71, 73]. Ramukhithi [52] also found low semen pH levels of 6.1 and 6.6 to result in total motility of 89.3 ± 1.8 and 76.9 ± 4.7%, respectively.

6.2 Characterisation or breeding soundness evaluation of male goat

Characterisation provides information on the reproductive performance, and identification of unique characteristics of value in different populations [8]. For optimum goat productivity, the farmers should select males that have the ability to serve many females during the breeding season, with the genetic potential for quick and efficient growth [73]. However, the importance of breeding with a highly fertile male is often neglected, especially under the communal set up. This is due to lack of management practices such as breeding soundness evaluation that needs to be done on males before using them for breeding. As a result, the pregnancy rate is compromised [74]. Breeding soundness evaluation is a useful tool to be used during the selection of males for breeding; this eliminates males with lower fertility [11, 30, 36, 73].

Breeding soundness evaluation consists of physical examination of body structure and reproductive organs, semen collection and evaluation, which were found to be the best indicators of breeding potential [30, 47, 73]. Three classes are used to rate breeding soundness, namely: satisfactory potential breeder, unsatisfactory potential breeder and deferred. A satisfactory potential breeder has good physical characteristics: ≥ 17 cm scrotal circumference, ≥ 70% sperm cell motility and normal morphology [11, 59, 73, 75]. Males failing breeding soundness evaluation (deferred breeder) can be rechecked after 1 or 2 months, to see if their fertility has improved [36, 47, 48, 73]. In a herd, about 15% of males kept are of unsatisfactory reproductive breeding quality [48, 73]. Although the method is accepted and highly utilised, it is very subjective and requires a highly trained technician [11].

6.3 Characterisation approaches

6.3.1 Exploratory approach

This approach is undertaken in a situation where there is very little information on the existence of recognised breeds, with the objective to examine the existence of distinct breeds in the study area. It is hypothesised that the target animal genetic resources (AnGR) population is the same and the hypothesis is tested by measuring and analysing the pattern of phenotypic diversity in the study area. This is followed by choosing the study area and sampling frame. For a large area, it is advisable to use stratified sampling based on the following criteria:

i. Geographical isolation of AnGR populations and their movement patterns;

ii. Known patterns of morphological and production characteristics in the AnGR populations;

iii. Indigenous knowledge on the origin of the AnGR

This approach also requires estimation of livestock populations and their keepers in the study area and primary characterisation falls within the exploratory approach [76].

6.3.2 Confirmatory approach

This approach is undertaken in a situation where there is little information on the breed identity. In such a case, the objective is to confirm breed identity and provide descriptions of the breeds, which depends on the national AnGR records, literature and local knowledge. In a situation where there is little information, which is not accurate for phenotypic characterisation, preliminary field data will need to be collected on the identity, geographical distribution, and relative significance of AnGR populations and hence to determine whether an exploratory or confirmatory approach is suitable [76].

7. Phenotypic characterisation (body assessment)

Animal phenotypic characterisation is a practice of documenting the physical appearance or characteristics of an animal. The information provided by phenotypic characterisation studies is crucial for planning management and the use of AnGR at local, national, regional and global levels [5, 76, 77]. This type of characterisation is simple, non-invasive and inexpensive [2]. For the conservation and improvement of indigenous animals, phenotypic characterisation can be a first step to be undertaken before the use of their genetic material [6, 7]. It is necessary to guide decision makers in the development and breeding programmes of livestock [76]. Phenotypic characteristics have important socio-cultural and economic values to African people. As a result, most farmers have specific respect and choices for specific traits. For example: goat coat colours and body sizes are more favourable to the farmers [5]. Phenotypic characteristics are influenced by genetic and environmental factors such as nutrition, health practices and ambient temperature etc. [8]. The phenotypic characterisation tool gathers information on production environment, qualitative, quantitative and adaptive traits [77].

Evaluation of AnGR diversity is difficult because there are many animal populations that are not assigned to any known or registered breed. Even though some of these non-descriptive animals are known to be crosses of existing breeds, some animals may belong to the same population, which is unique from known populations on the basis of identifiable and phenotypic characteristics that need to be identified as separate breeds. Phenotypic characterisation is technically and logistically challenging. In order for it to be implemented in an efficient and cost-effective manner, it requires careful attention. For accurate phenotypic characterisation results, it is advisable to use standard practices and formats for describing animals' characteristics [76]. There are two types of characterisation; the first one is primary characterisation, which refers to the collection of information through single field visits. For example: measurement of animals' morphological features, gathering information from livestock keepers and mapping of geographical features. The second one is advanced characterisation, which refers to activities that require repeated visits. For example: measurement of productive traits such as growth rate, milk production and adaptive traits such as resistance to diseases [76].

7.1 Phenotypic qualitative characteristics

These characteristics include the external physical form, shape, colour and appearance of the animals, and are recorded as categorical variables. Phenotypic qualitative characteristics are based on a small number of genes. Some of the examples of phenotypic qualitative characteristics are coat colour, horn shape and ear length etc. [5, 8, 36]. These characteristics have less direct significance to the production and service functions of an animal. However, they may relate to adaptation to a specific environment. For example: hair coat, size of ears and presence of horns are known to be relevant to the dissipation of excess body heat [5, 76]. Other characteristics that may be relevant to the livestock keepers is hair coat colour. This is normally used in a situation where there is no proper identification of animals; some farmers use hair coat colour as an animal identification tool. As a result, they are as important as the phenotypic quantitative characteristics and hence they need to be included on the phenotypic characterisation studies [5, 76].

7.2 Phenotypic quantitative characteristics

Phenotypic quantitative characteristics are measures of animal body parts [34, 76] and are more directly associated to production characteristics when compared to phenotypic qualitative characteristics. For example; body weight and chest girth are directly associated to body size and production characteristics [5, 9]. These variables have continuous expression, due to numerous genes that influence their expression. Most of the phenotypic quantitative characteristics are dependent on animal age and the environment in which they are kept. Phenotypic quantitative characteristics such as body weight, length and height, are used as an alternative indicator of production traits due to their strong relationship with production traits such as meat and milk [76].

7.3 Phenotypic characteristics correlated to male goat fertility

To evaluate the ability of a male to find, move to and mount a female on heat, a physical inspection is conducted. This includes observation and palpation of the penis, prepuce, sheath, testicles and epididymis, and measuring of the scrotal circumference [9, 73]. The main characteristics that are evaluated are: body condition score and structural soundness of the male. In addition, male history, age, temperature and reviewing the records of past breeding performance need to be done [9, 36].

7.3.1 Body condition score

Body condition scoring is an assessment of body fat, and is determined by feeling the ribs and spine of a male, as well as a visual assessment [9, 36, 73, 76]. The good thing about body condition scoring is that it is fast, simple and cheap, as it does not require special instruments [38]. Animal body condition is influenced by environmental factors, parasites and diseases etc. [78]. Normally, body condition score in males is assessed before mating, while in does it is assessed before mating, kidding and during lactation stage. This method involves allocation of scores to animals in relation to the amount of body fat and muscles. It is a rapid and economical method that shows energy reserves of the animals [38, 79]. A body condition score is assessed based on an arbitrary scale which ranges from 1 to 5, where 1 is very thin and 5 is obese [9, 38]. Body condition score of 3 to 3.5 is recommended for a male during the breeding season [9, 36, 73]. If a male is too thin, its breeding ability is negatively affected. On the other hand, overweight males may lack strength to breed large numbers of does [73]. Body condition monitoring is very important to minimise reproductive and productive losses [79].

7.3.2 Age

The optimum breeding age of a buck ranges from 6 months to 4 years. An increase in spermatogenic activities at a certain age results from a major development of the seminiferous tubules and sertoli cells differentiation [9, 36]. Age has an effect on testicular size. Old age arrives in males at different ages, depending on the health, environment and the use. Most old animals have adequate sperm cells, but most of them are abnormal and dead [49]. The best prediction of how long a male will be productive is to evaluate bloodlines [36].

7.3.3 Body weight

Body weight is an important economic trait in animal [9, 36] and it is influenced by several factors such as breed, age, nutrition and other environmental factors [30]. Body weight and size of a male are influenced by feeding and health care. Body weight can be estimated with the aid of body measurements, especially in the villages where there are no scales. It can also be determined objectively, with the aid of a weighing scale [36] or by visual appraisal [9]. Objective assessment enables farmers to recognise early and late maturing animals of different sizes. Body weight has a close relationship with age, breed and morphological characteristics. Sperm cell concentration has also been shown to be positively correlated with body weight. It can be concluded that age and body condition of a male have a strong influence on body weight and conformation traits [36]. Body weight is also positively correlated to the production of viable sperm cells [9].

7.3.4 Body weight

Body size is an important phenotypic characteristic in meat producing animals [9]. Previously in goats, body size used to be visually assessed with a subjective method. Nowadays, body growth and development are objectively assessed. Delayed growth in body size of an animal leads to reproductive wastage and economic losses [36]. Goats are classified as dwarf (< 50 cm), small (51 to 65 cm) and large-sized animals (> 65 cm) based on their body height at the withers [5]. Large-sized animals are heavier and have bigger testicular measurements than small-sized animals [62]. Even though the body and testicular measurements of animals increase with age, the age at which domestic animals reach puberty in a commercial set up is postponed until they attain a required body size and weight [36].

7.3.5 Scrotal circumference

Scrotal circumference is determined at the widest part of the testis, when the testis is gently massaged and pulled to the bottom of the scrotum [9, 48, 73]. Scrotal circumference is known to be different among different breeds and individuals of the same breed, and it is highly heritable [11, 36]. An average of 17 and 25 cm of scrotal circumference in young and older males, respectively, is recommended to be ideal for breeding [73, 80]. Scrotal circumference varies with the season and body condition, and it is usually larger during the breeding season [39, 73] and can decrease by 2 to 3 cm during the non-breeding season [73]. Goat scrotal circumference also experiences some changes after reaching sexual maturity due to the influence of photoperiod, nutrition and temperature [30, 36].

Measuring of scrotal circumference during breeding soundness evaluation is very important, as it is strongly related to the semen production capacity of a male [9, 49, 73]. Breeders put great selection pressure on larger scrotal circumference [11, 36]. Large scrotal circumference is a reliable indicator of the reproductive maturity, good development of sperm cells and production of semen with greater quality [9, 11, 73]. When artificial insemination is to be conducted, semen samples from superior males with larger scrotal circumference could lead to insemination of many females. Testicular size is also influenced by breed, age, nutrition, genetics and other environmental factors [11, 30, 36]. Large-sized animals are heavier and have larger testicles measurements than small-sized animals [11, 62]. Large scrotal circumference was reported to be correlated with good semen quality and high sperm cell production in males [11].

7.3.6 Skeletal dimensions

Body height, length, depth, width, pelvic width, length hock length, tail length, heart girth and scrotal circumference are some of the characteristics that are measured in goats [34]. These characteristics have a good relationship with each other. For example, heart girth and body height are good indicators of body weight and condition score. Scrotal circumference is an indirect indicator of the testicular mass. It is a major element in breeding soundness evaluation, because it is easy to measure and reliable, as it provides an indication of size and growth [36].

8. Seminal plasma constituents and their relationship to male goat fertility

In many cases, female goats (does) are linked to flock infertility problems than males. Male fertility cannot however be taken for granted as males have a greater influence on a flock performance compared to females. Evaluation of males for breeding purposes is very important in the improvement of goat production as they supply half of the genetics to all the offspring [9, 48].

8.1 Seminal plasma proteins

Seminal plasma proteins have a great effect on the biological quality of semen samples as expressed by sperm cell motility, viability and morphology [81]. Evaluation of seminal plasma proteins were found to be useful in correlating male fertility in other species such as cattle [14], pigs [82] and fish [83]. Seminal plasma proteins are composed of non-protein nitrogen amino acids, peptides albumin, globulin [69] and other inorganic constituents that have effects on sperm cell quality [82]. Utilisation of two-dimensional polyacrylamide gel electrophoresis (2D-PAGE) resulted in the recovery of four proteins in the seminal plasma, which were correlated positively to male fertility [14]. The functions of these proteins are to prolong sperm cell viability measured by its motility, protect sperm cells, supply enzymes of the metabolic processes [69], improve buffering capacity and semen quality [81, 84, 85], capacitation and acrosome reaction [86]. As a result, proteins are regarded as a male fertility marker in conjunction with standard breeding soundness evaluations [14, 47, 85]. However, the accurate mechanisms involved in their actions are not clear [86, 87].

According to Bozkurt et al. [83], protein concentration is normally low in most of the species and it decreases in the second phase of spermiation. Although protein concentration is normally low, it is normally higher in summer or during the breeding season, when compared to the other seasons. Low protein concentration in seminal plasma reduces its buffering capacity and negatively affects sperm cell characteristics [69]. Seminal plasma proteins were firstly associated with male fertility in dairy bulls, followed by beef bulls and horses. The first seminal plasma proteins to be associated with males' fertility in Holstein bulls were: lipocalin-type prostaglandin D synthase (LDH), osteopontin (OPN), albumin, transferrin, fertility associated antigen (FAA) and type-2 tissue inhibitor of metalloproteinases (TIMP-2) [14, 82, 86, 88].

8.1.1 Osteopontin

Osteopontin is an acidic protein and comes from mineralised bone tissue, which is rich in serine, aspartic, and glutamic acid [12, 89]. It is also known as secreted phosphoprotein-1, 2ar and bone sialoprotein [42]. Osteopontin belongs to a family of proteins called small integrin-binding ligand, N linked glycoprotein (SIBLINGS) [12]. Osteopontin (55-kDa) plays an indirect role in increasing fertility by actions in the male reproductive tract, without directly affecting sperm cells [47, 89]. In male animals, it is synthesised by sertoli and germ cells in the seminiferous tubules and expressed in the ampullae, seminal vesicles and epididymis. Its functions are for cell relocation, survival and adhesion, chemotaxis, intra-cellular signalling, macrophage activation and prevention of calcium crystal formation in the kidney [12, 14].

8.1.2 Lipocalin type prostaglandin D-synthase

Lipocalin type prostaglandin D-synthase was firstly identified in the cerebrospinal fluid in the early 1960s. This protein is abundant in compartments beyond blood tissue barriers [90]. It is found in a large and different group of small extracellular proteins identified by their ability to bind hydrophobic molecules (retinoids, steroids, pheromones, odorants and fatty acids) [91]. Lipocalin-type prostaglandin D synthase has been reported to be more dominant in the seminal plasma of highly fertile bulls. It is composed by a series of four spots, which comprise 7.6% of all protein spots. In males with low fertility, they were found to be 2 to 3-folds. Lipocalin-type prostaglandin D synthase is a multifunctional calcium-binding protein, which is responsible for intracellular signalling pathways, interaction of cells, apoptosis [86, 92] and serves as a carrier for blood-derived substances across the blood-testis barrier, which is produced in the seminal plasma [47]. It is also responsible for sperm cell development [90]. Although, these proteins were reported to correlate with sperm cell quality or male fertility in several species, their mechanisms are not clearly understood [86, 92].

8.1.3 Fertility associated antigen

According to Dawson et al. [14], fertility associated antigen is a simple and non-glycosylated yielding a N-terminal 26 amino acid sequence which is 73% similar to human deoxyribonuclease (DNase) I-like protein [47, 82]. In total, fertility associated antigen is composed of 296 amino acids [93]. It is primarily located in the seminal vesicles and prostate glands. It was also labelled as one of fertility markers (26-kDa) for bull semen [47, 82]. For rapid determination of fertility-associated antigen in bulls, a lateral flow cassette has been designed [94]. Bulls that tested positive for fertility-associated antigen resulted in a higher pregnancy rate when compared to those that tested negative [14, 47, 94]. Ax et al. [93], summarised the findings of Bellin (1994, 1996 and 1998) which showed that pregnancy rate was 85 and 66%, when the fertility-associated antigen was present and absent, respectively. Dawson et al. [14], summarised the findings of Bellin (1994, 1996, 1998) and Sprott (2000), which indicated the pregnancy rate was 82.1 and 64.8%, when the fertility-associated antigen was present and absent, respectively. This was believed to be due to a lack of epitope [14, 47].

In South African unimproved indigenous male goats' fertility associated antigen showed a positive relationship with semen volume, sperm cell concentration, TM, NPM, rapid and medium velocity, VCL, VSL, VAP, intact membrane and live sperm cells [89]. Ramukhithi [89] results are in agreement with the literature that has indicated that when the fertility associated antigen is present in semen, the fertility level of that male is high [86, 93]. Contradictory, when South African unimproved indigenous and Tankwa goats' were used, fertility associated antigen did not have a positive relationship with TM and static sperm cells. Due to lack of a relationship, the importance of male fertility associated antigen in the sperm cell motility remains unclear [89].

8.1.4 Type-2 tissue inhibitor of metalloproteinases

Tissue-inhibitor of metalloproteinases are present at the same time as the matrix proteases [95] and it is another 24 kDa protein that has been isolated from accessory sex glands (bulbourethral gland, prostate and seminal vesicles) and found to be positively relevant in correlating bulls' fertility [14, 47]. However, their roles and mechanisms are still not clear, and are under investigation [14, 87]. On the other hand, they were assumed to provide energy and protect sperm cells as a complementary substance [95]. Like with fertility-associated antigen, bulls that tested positive for type-2 tissue inhibitor of metalloproteinases resulted in higher pregnancy rate when compared to bulls that tested negative [14].

8.1.5 Lactate dehydrogenase

Lactate dehydrogenase is an abundant and intracellular enzyme, which displays different kinetic parameters. Its roles are sperm cell metabolism, capacitation and fertilisation [16, 95, 96]. This enzyme penetrates the cell to generate a temporary oxygen in the form of accumulated lactate, which is later removed by the reoxidation of lactate [96]. Increased levels of lactate dehydrogenase in the seminal plasma may be an indication of good quality sperm cell membrane, acrosome integrity [95] and viability [88].

8.2 Other seminal plasma constituents

In addition to seminal proteins, other seminal plasma constituents have a great effect on the biological quality of semen samples as expressed by sperm cell motility, viability and morphology [81]. In other species, evaluation of sodium, potassium, magnesium, calcium, zinc, glucose, cholesterol, triglycerides, lipids and urea were found to be useful in the correlation of male fertility [15, 69]. These seminal plasma constituents play a huge role during sperm cells metabolic processes [16, 17] and ensure that the sperm cells are viable. Evaluation of seminal plasma constituents can be more useful during the preparation of species-specific diluents for short and long-term preservation of semen [81].

8.2.1 Sodium

Sodium is a soft, silver-white coloured and highly reactive metal. It is important for both plants and animals. Sodium is a major cation in the extracellular fluid and a major contributor to osmotic pressure. It is present in seminal plasma at a higher concentration than other seminal plasma constituents [97]. Sodium improves sperm cell motility [15] and it helps with the establishment of sperm cell osmotic balance [83, 95]. Low sodium concentration is associated with low sperm cell motility and may be caused by deficiency in the formation of seminal plasma [64].

8.2.2 Magnesium

Magnesium is the second most common intracellular cation after potassium [98]. It plays a role in enzyme activation [97, 99], energy metabolism, cardiac excitability, muscle contraction, synthesis of nucleic acids and relaxation of male reproductive muscles to delay ejaculation. In humans, a high magnesium concentration was found in the prostate gland and is released into seminal fluid [97]. In a normal situation, seminal magnesium is more than 70 mg/L while in blood serum it is 17–24 mg/L. Low level of magnesium cause premature ejaculation and erectile dysfunction [98]. However, if its concentration is too high it tends to affect sperm cell motility negatively [81]. When it is too low, it leads to disorders in male fertility [97]. There is a good relationship between low concentration of magnesium and human age [98]. In non-identified goat semen, 8.1 mg/dL magnesium with acceptable semen volume, sperm cell motility, concentration and normal morphology were detected [100]. In Granadina goat semen, 1.9 ± 0.3 mg/dL magnesium with unacceptable sperm cell motility, live sperm cells and acceptable semen volume and sperm cell concentration were detected [74].

8.2.3 Glucose

Glucose is a carbohydrate and an important simple sugar in animal metabolism. In humans, its normal concentration in the blood stream is 0.1%. This primary molecule serves as an energy source for plants and animals [101]. Glucose also acts as the main energy source for sperm cell metabolism and provides osmotic balance [81, 84]. In the seminal plasma, glucose has been associated with the high-energy demand of the testis during spermatogenesis and lipids synthesis of sperm cells [81].

8.2.4 Calcium

Calcium is a soft greyish alkaline metal and the, which is fifth most-abundant element by its mass, and it is essential for all living organisms. Calcium contributes significantly to the ionic composition of a seminal plasma [83]. It is also important for sperm cell motility, physiology and acrosome reaction, where by the movement of calcium into and out of the cytoplasm serves as a signal for cellular processes [97, 102]. It is also responsible for muscle contraction of the vas deferens and corpus cavernosum [98]. However, the role of seminal calcium in sperm cell motility is not fully understood, as it inhibits acrosome reaction and at the same time has no effect on sperm cell motility [103]. In non-defined goat semen, 12.1 ± 0.6 mg/dL calcium with acceptable semen volume, sperm cell concentration, motility and normal morphology were detected [100]. On the other hand, in Granadina goat semen, 10.8 ± 1.86 mg/dL calcium with unacceptable sperm cell motility (63.5 ± 18%) and live sperm cells (69.8 ± 14.2%) were detected. However, the semen volume and sperm cell concentration were acceptable [74].

8.2.5 Potassium

Potassium is found in seminal plasma at high concentration when compared to other seminal plasma constituents [81]. It is for osmotic balance [83, 95]. The inhibition of sperm cell motility by potassium can be overcome by increasing the external calcium concentration. Sperm cell motility of *Salmo trutta* macro stigma was reported to increase with calcium and magnesium levels [83].

8.2.6 Zinc

Zinc is an essential mineral for domestic animals and has antioxidative properties [15, 97]. It is responsible for testicular and sperm cell development [15, 101], it stabilises membrane and nuclear chromatin of sperm cells. Shortage of zinc can damage the mechanism of DNA and make the sperm cells susceptible to oxidative damage. Zinc levels in mammalian semen are high and it has been found to be important for the development of sperm cells. When the zinc level decreases, sperm cell quality also decreases, which then leads to reduced chances of fertilisation [97, 103]. In Granadina goat semen, 1.2 ± 0.6 mg/dL of zinc with acceptable semen volume and sperm cell concentration was detected. However, unacceptable sperm motility and live sperm cells were also detected [74].

8.2.7 Cholesterol

Cholesterol is the precursor in the biosynthesis of sex hormones. Thyroid hormones stimulate cholesterol production and hepatic mechanisms that remove cholesterol from circulation. Seminal plasma cholesterol is higher during summer than in the spring season [69]. Like in the lipids, there is little information about the role of cholesterol in the sperm cells, but it has been assumed that it protects the sperm cells during temperature changes [81] and it is responsible for sperm cell capacitation [102]. According to Mellado et al. [74], there is a good relationship between blood cholesterol, body condition and level of nutrition. Blood cholesterol increases with increased levels of nutrition during growth, which also have an effect on seminal plasma cholesterol levels. In rabbits, cholesterol was reported to contribute to infertility during the summer season, which might be due to the changes in biological functions caused by heat stress [69]. In Granadina goat semen, 80.5 ± 12.1 mg/dL cholesterol with unacceptable sperm cell motility (63.5 ± 18%) and live sperm cells (69.8 ± 14.2%) were detected. However, the semen volume and sperm cell concentration were acceptable [74].

8.2.8 Triglycerides

Triglycerides is a chemical compound derived from glycerol and three fatty acids. There are many triglycerides, some are highly unsaturated and some are less saturated. Triglycerides increases membrane fluidity [84] and provides energy to the sperm cells during regeneration after moving. Low levels of triglycerides are indicative of inadequate energy supply, which leads to low sperm cell motility and fertilisation capacity [64, 81].

8.2.9 Lipids

Lipids are naturally occurring molecules such as fats, waxes, sterols, fat-soluble vitamins (vitamin A, D, E and K), monoglycerides, diglycerides, triglycerides and phospholipids. They can be found in the whole cell, plasma membrane and head membrane [104]. There are different classes and levels of lipids in different species [81]. They were found to occur at higher levels in spring than in the summer season [69]. The goat sperm cell plasma membrane was found to be rich in phosphatidylcholine and phosphatidylethanolamine lipids. However, phosphatidylethanolamine lipids decrease during epididymal maturation of sperm cells [104]. Seminal plasma lipids play a role in sperm cell metabolism and capacitation, and it maintains membrane structure [105]. Lipid concentration has a good correlation with sperm cell concentration and motility. A decrease in seminal plasma lipids leads to a reduction in sperm cell concentration and motility [69, 105]. The changes in the lipids quantity and composition of sperm cell plasma membrane during maturation are believed to explain why ejaculated sperm cells are more sensitive to cold shock than testicular sperm cells [104]. In Granadina goat semen, 8.1 U/mL lipids with acceptable semen volume, sperm cell motility, concentration and normal morphology were detected [100].

8.2.10 Urea

Urea is an organic chemical compound, which is produced by the body after protein metabolism. It plays a role in the metabolism of nitrogen-containing compounds by animals. It is also responsible for sperm cell development [15, 101]. In Granadina goat semen, 19.7 ± 4.7 mg/dL urea with unacceptable sperm cell motility (63.5 ± 18%) and live sperm cells (69.8 ± 14.2%) were detected. However, the semen volume and sperm cell concentration were acceptable [74].

9. Conclusion

Collection of reproductive information from different indigenous goats to assist with future breeding plans and maintaining unique phenotypic characteristics and semen parameters of goat breeds is important. Evaluation of semen parameters is reliable and standard method of indicating fertility of breeding males, other than directly assessing their ability to make females pregnant. However, evaluation of seminal plasma constituents and phenotypic characteristics, and their relationship to male fertility is still not well defined in smallstock. As a result, the intensive investigation of male fertility markers such as seminal plasma constituents is needed, as this can be another reliable method of evaluating the reproductive system functioning and semen quality in male goats.

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Section 4

Goat Nutrition

Chapter 5

Recent Advancement in Goat Nutrition

Jacob Matovu and Ahmet Alçiçek

Abstract

Nutrition or feeding is one of the most important components in livestock production and it's associated with high costs. In goat production, it can typically account for 60% or more of total production costs. As a result, there is much new research being conducted on goat feeding and nutrition in a variety of areas regarding production costs, sustainability, and quality of the product produced. Areas of research that are currently receiving much attention include feed additives such as prebiotics, probiotics, enzymes, antioxidants, plant secondary metabolites, etc. Their use in animal feed is expected to increase due to the abolition of synthetic antimicrobials in feed, although there is still limited information on their use and is accompanied by contradictory research reports. This study aims to highlight some of the recent and emerging studies on the different feed resources, feed additives and dietary feed composition for goats.

Keywords: Goat, Nutrition, Recent, Biochar, Glycerin

1. Introduction

Great importance is attached to nutrition in goat husbandry, as it is one of the factors of production on which the farmer can act quickly and easily. Moreover, it has the best known influence on the production cost while as affects the health and reproductive performance of goats [1]. Therefore, more attention should be given to the nutrition and feeding program for the profitability of the farm.

Currently, there is an increase in animal nutrition research carried out under a wide array of topics all over the world. This could be due to the differences in feed ingredients in different continents of the world, hence the wide variety of topics related to feeding and nutrition. The current research topics in feed and feed technology that are being studied are related to product quality, economic/financial perspectives and sustainability. Since there are very many topics currently being investigated in relation to goat feeding and nutrition, this study has reviewed and summarized some of the recently published research from around the world.

2. Methodology

For this study, a comprehensive review of various current scientific, technical and economic literature was used. This review study considered the most recent papers published between 2010 and 2021, with very few older studies published before 2010. Most of the information was obtained from original research articles on goat nutrition published from different regions of the world and very few review articles, books and conference papers were used. The data and results within this study are based on directly reported values in the published literature and derivations from figures and tables.

Various databases from the internet were used to search for papers and different keywords and synonyms were used. In addition, the reference sections of the various papers obtained were scanned for other possible relevant publications. The authors selected the studies included in this review by evaluating the titles and abstracts to match the objectives of the review [2].

3. The different goat feeding resources, the new resources and their utilization

3.1 Fodder shrubs and trees

Goats are natural browsers and feed on shrubs, bushes and trees. This is common in tropical regions, especially in humid zones. Goats feed on these browses and feasibly utilize them more efficiently. Browsing is also common in arid and semi-arid zones, as most browse foliages are drought resistant. Therefore, they are the main forage resource during the long dry periods [3]. During grazing, goats have shown selective behavior towards different plants and plant parts [4]. In a study by Iussig et al., [5], goats showed a high conspicuous desire to consume most of the browse species compared to other plant species.

Browses are considered to have high nutritional value compared to pasture grasses and crop residues. Crude protein content is one of the great attributes of these trees used in ruminant feeding. Mokoboki et al., [6], demonstrated up to 227.9 g/kg (DM) crude protein in Acacia species. They also contain higher concentrations of ash (minerals), less fiber and remain nutritious during the dry season [7].

Despite their nutritional value, there are concerns about antinutritional factors such as tannins, nitrates, oxalates, sinogens, saponins, mimosine that limit their utilization [8]. On the other hand, tannins are said to bind with proteins in the rumen and lead to increased amino acid absorption in the intestine [9], increase nutrient utilization and feed efficiency, thus improving growth performance [10].

Patra and Saxena, [11], found that tannins are associated with stopping bloat, impede methanogenesis and increase the concentrations of certain fatty acids such as conjugated linoleic acid in ruminant products. Matovu et al., [12], in their study showed the potential of ethnomedicinal plants in the treatment of helminths. This could be due to the availability of phytochemicals such as condensed tannins, saponin and flavonoids which have been associated with anthelmintic activities [13].

There is also increasing popularity of a shrub called Cactus (*Opuntia spp*.) as a feed that is best adapted in arid areas [14]. However, it is associated with high fiber and ash content and thus low energy and protein density, which requires specific supplementation when cactus species are used in feeding [15]. The inclusion of cactus species in the diet had no adverse effects on the sensory properties of goat milk or on its lipid composition profile [16].

Eucalyptus leaves are also gaining importance in goat nutrition. Feeding with its leaves has shown antihelminthic activity against gastrointestinal nematodes in goats [17]. Sallam et al., [18], showed that Eucalyptus oil (*Eucalyptus citriodora*) can modify rumen fermentation and has the ability to reduce methane emissions. Further discussion on the importance of plant extracts such as essential oils as anthelmintics and their effects on methane emissions can be found in Section 4.2.

Items	Dietary treatments					
	A	B	C	D	E	SED
Total DMI (g/d)	648.00	696.00	694.00	678.00	723.00	16.35
DMI (g/kgw $^{0.75}$/d)	94.00	99.00	96.00	97.00	101.00	3.34
ME intake (MJ/d)	6.68	7.74	7.39	7.51	7.88	0.50
DCP intake (g/d)	67.90	92.96	92.31	93.41	99.66	3.97
Initial weight (kg)	9.96	9.96	9.97	9.97	9.97	0.55
Final weight (kg)	14.83	16.42	16.60	16.20	16.70	0.76
Daily weight gain (g/d)	40.58	53.83	55.25	51.91	56.08	2.81
FCR	16.50	12.05	11.74	12.20	12.043	0.49

A: Control with no tree forage, B: Erythrina orientalis, C: Leucaena leucocephala, D: Morus alba, and E: Sesbania grandiflora.

Table 1.
Increased performance of goats supplemented with different tree forages (adapted from Rahman et al. [19]).

Due to the high protein content of shrubs/trees, their leaves act as supplements with other roughages and this has shown the increased performance of goats [19], which is seen in **Table 1**. In a study where small East African goats diet consisting of *Chloris gayana* hay which has a low protein content was supplemented with *Maerua angolensis*: *Zizyphus mucronata* foliages led to improved feed intake, digestibility and growth [20].

In the recent developments to further improve the nutritional value and forage tree utilization, they have been developed through the process of pelleting. Pellet products have been developed from these foliages and are seen to be important protein sources during ruminant feeding such as mulberry (*Morus alba*) leaf pellets and *Leucaena leucocephala* leaf pellets [21].

Currently, there are a variety of documented forage trees and shrubs used in goat feeding and these vary in different regions. Based on the above information, these feed types play an important role in the diets of goats in tropical and subtropical regions of the world.

3.2 Pastures, forbs and rangelands

In the humid and subhumid zones, the natural pastures consist of a variety of grasses and form an important food component for goats. One of the characteristics of the humid zones is the high amount of rainfall, which automatically leads to rapid growth of the forage. This is accompanied by lignification and consequent decrease in nutritional quality, which accentuates as the dry non-growing season progresses [22]. The reduction in nutritional value is due to the fact that mature plants have lower palatability and digestibility.

Also, the poor climatic factors in arid and semi-arid zones make these natural pastures and forbs nutritionally inadequate over a prolonged period [23]. To counter such and other situations like drought, soil and water salinity and water scarcity, the best activity has been promotion of cultivation of nutrient-rich leguminous and non-leguminous pastures/forages and fodder crops has been promoted.

On the other hand, due to global warming, the characteristics of various pastures have begun to change, these are being replaced by plants with shrubby characteristics such as cactus species, which have a great chance of surviving in such environments and have been used as fodder [24].

3.3 Crop residues and agro-industrial by-products

Growing population and urbanization automatically led to the need for food production to meet the needs of this population. During this process, new sources of feed have emerged, sometimes referred to as wastes or by-products. These by-products, such as: Soybean hulls, wheat middlings, corn gluten feed or dried distillers grains, corn cobs, potato peels, cassava peels, vegetables, fruit by-products, grape seed pulp, starch industry by-products, dairy industry by-products, olive by-products and many others have been incorporated into the diets of livestock in reasonable amounts and have been reported to have beneficial effects on health, performance and control of feed costs. Therefore, currently more and more by-products and residues are being investigated and evaluated as novel feeds in ruminant diets.

Studies by Teklebrhan et al., [25], reported an increase in dietary protein, fiber and sulfur content when corn was replaced by corn gluten in goat feeding. Reduction in methane emissions was also evidenced. Replacement of 61% of maize in the diet with dry citrus pulp and soybean hulls had no negative effect on milk yield in Murciano-Granadina goats during mid-lactation [26]. Cassava by-products [27, 28] are successfully utilized by goats with no effect on performance. In a recent study [29], silages of tomato and olive oil by-products replaced oat hay at a supplementation rate of 20% and there was no effect on goat performance. Tzamaloukas et al., [30], gave a comprehensive review on the use of olive oil by-products in the feeding of goats.

There is also an increasing use of biofuel or alcohol by-products in animal feed, mainly due to their high nutritional value. The corn-dried distillers grains with solubles (DDGS) is an example of alcohol by-products. A study in which DDGS (180 g) was mixed with dried citrus pulp (180 g) and exhausted olive cake (80 g) showed that this mixture can replace up to 44% of the cereal grains and protein feeds in the concentrate for lactating goats. No adverse effects on nutrient utilization and rumen fermentation characteristics were observed, as well as an increase in milk yield and unsaturated FA profile of milk [31].

Crude glycerin is another by-product of the biodiesel industry that is recently gaining more research coverage, especially in Asia. Crude glycerol is associated with high energy content ranging from 1.98 to 2.27 Mcal NEL/kg, which is close to that of maize (2.0 Mcal NEL/kg) as studied by Chanjula [32]. In a study

Item	Dietary crude glycerin, %			
	0	5	10	20	SEM
Initial BW, kg	17.08	17.52	16.76	16.76	0.42
Final BW, kg	25.20	27.40	27.44	26.96	1.17
Weight gain (kg)	8.20	10.08	10.88	10.16	1.16
DMI kg/day	0.653	0.674	0.738	0.654	0.02
OM, kg/day	0.611	0.632	0.691	0.611	0.03
CP, kg/day	0.101	0.103	0.113	0.101	0.01
NDF, kg/day	0.288	0.285	0.282	0.255	0.01
ADG, kg/day	0.090	0.112	0.120	0.112	0.01

Table 2.
Effects of different dietary crude glycerin percentage on performance and dry matter intake in goats (adapted from Chanjula, et al., [33]).

(Thai Native × Anglo Nubian) weaned goats were fed on diets containing 0, 5, 10, and 20% of Crude glycerin (87.61% pure), and it was concluded that Crude glycerin can be substituted with corn grain up to 20% of dry matter without any effect on performance **Table 2** [33].

4. Feed additives

Feed additives are one of the most topical and discussed issues in animal nutrition. Feed additives can be defined as animal feed supplements consisting of non-nutritive substances or microorganisms added to feed to improve growth, DM intake and feed conversion efficiency. This improves animal welfare and health, profitability and production performance [34]. Essential oils, organic acids, probiotics, prebiotics, coccidiostats, mycotoxin binders, methane inhibitors, etc. are some of the feed additives currently used.

In the past, antibiotic additives were widely used to modify the microbiota in the digestive tract and improve animal productivity and health. However, the long-term use of these agents has led to the development of drug-resistant microorganisms that pose a threat to consumer health and the environment [35]. Since the ban of antibiotic feed additives in Europe on January 1, 2006 [36], new research areas emerged in the search for better additives. In this current study, recent developments in feed additives used in goat nutrition, including their utilization, are discussed.

4.1 Probiotics and prebiotics

Probiotics are live microbial feed additives, which confer a health benefit when administered to the host animal. The most commonly used microorganisms are bacteria of the genera Bifidobacterium, Lactobacillus and Streptococcus, but yeasts (*Saccharomyces cerevisiae*), bacilli and fungi such as *Aspergillus niger* and *Aspergillus oryzae* are also commonly used in commercial probiotic production [37].

In particular, feeding probiotic bacteria has a lot of positive effects on goat health, such as reducing susceptibility to pathogen infections and their abundance [38], increasing average daily gain [39], improving nutrient digestibility coefficients [40], and increasing feed intake [38]. Supplementation of probiotics in the ration of lactating goats has also shown an increase in milk yield and positive effects on milk composition such as protein content, fat yield and lactose yield [41, 42].

The supplementation of probiotics in the dietary ration is of importance in the mitigation of methane reduction in goats [43]. A study in which common rice was replaced with red yeast rice resulted in a reduction of enteric CH_4 emissions in castrated Boer goats [44]. Chaucheyras-Durand et al., [45], in their review paper explained the mechanism of the ability of yeast cells to reduce enteric CH_4 by diverting hydrogen atoms from methanogens to acetogenic strains of rumen bacteria to increase the production of acetate.

Prebiotic can be defined as non-digestible feed ingredients which act by inducing the growth of one or a limited number of bacteria in the gut flora. Mannan-oligosaccharides, fructooligosaccharides, lactulose, lactitol, malto-oligosaccharides, xylo-oligosaccharides, stachyose, and raffinose are some of the commonly used prebiotics [35].

Despite their well-known significance in non-ruminants, the application of prebiotics in ruminant diets is limited because of the possibility that they are degraded by rumen microorganisms [46]. This could be the reason for the minimal modifying effect observed on rumen fermentation variables when the potential effects of inulin (0, 2, and 4%) with different ratios of forage to concentrate (i.e., 20:80, 40:60, and 60:40) were examined in an in vitro experiment that lasted 48 hours [47]. However, it is hoped that enhancement in rumen-protective technologies may provide an opportunity for further use of prebiotics in ruminant diets [48, 49]. Therefore, this is another area that requires further research.

The effect of synbiotics in creep feed has a positive effect on the hematological characteristics of kid goats, resulting in improved production performance and fecal value. When synbiotics are added at 0.03% and 0.04% of DM, it has shown a positive influence on FCR, in addition to average daily gains and final body weight. They are also associated with a greater impact on microbial populations and nutrient digestibility, as well as volatile fatty acid content [50]. Mycotoxins and Shiga toxin-producing *Escherichia coli* infections are part of the disease complex for Haemorrhagic Enteritis during the winter months when animals consume moldy feed, and studies have shown that they can be controlled by the use of prebiotics and probiotics [51].

There is currently a growing study of biochar, a charred biomass that resembles charcoal. When added to feed, it is said to improve animal health, increase efficiency of nutrient uptake, and control methane emission [52], and it is said to act like a prebiotic [53]. Biochar has the ability to improve microbial growth in the rumen and is also associated with increasing amino acid absorption [53]. DM intake was increased by 5% and daily weight gain was improved by 27% as a result of biochar supplementation in the diet of goats **Table 3** [54].

Based on this study, there is limited research on feeding different probiotics and prebiotics in goat diets, especially there is a need for more research on prebiotics regarding their application and utilization in different goat breeds and growth stages.

4.2 Plant extracts and essential oils

Essential oils from plants are saturated hydrophobic liquids containing volatile aroma compounds of the plants from which they are extracted. They are a mixture of different compounds and differ from the so-called fixed oils in both their chemical and physical properties [55]. Currently, synthetic feed additives are increasingly used in feeding, and the study of phytogenic feed additives, which like essential oils are of plant origin, has shown the same efficacy [56]. However, it should be mentioned that the use of phytogenic feed additives and supplements is still surrounded by conflicting and contradictory research reports.

As discussed in Section 3.1, plants or plant extracts containing secondary metabolic compounds (i.e., condensed tannins and saponins) and plant oils have

Parameters	Diet type	
	Biochar	No Biochar
DMI, g/d	472	451
Initial BW, kg	12.6	12.3
Final BW, kg	17.1	15.8
Daily gain, (g)	49.4	39.0
FCR	11.0	12.8

Table 3.
Effects of biochar supplementation in the diets on the performance of goats (adapted from Silivong and Preston, [54]).

been studied for their significant effects in ruminant feeding. Some of their values include: Increase in feed intake, digestibility, feed efficiency, reduction in methane emissions [21], and antihelminthic ability [57].

In ruminants, essential oils are said to have inconsistent and dose-dependent effects on rumen microbial fermentation. They are said to inhibit methane production in the rumen, although this effect is associated with a reduction in diet digestibility [55]. However, most experiments related to essential oil studies such as their effect on rumen fermentation are mainly in vitro experiments and few in vivo experiments have been conducted. Therefore, there is a need for the assessment of in-vivo experiments.

In lactating goats, the addition of 17.6 g/kg sunflower oil, flavonoids and essential oils of *Piper betle* in the diet increased milk production and its composition [58]. Plant oils in the ration of lactating goats improved milk fat synthesis and altered the fatty acid composition of milk without negative effects on animal performance [59]. In another study, the supplementation of garlic oil (*Alilum sativum*), Cinnamon oil (*Cinnamomum cassia*), or Ginger oil (*Zingiber officinale*) to the diet of dairy goats had advantageous effects on the milk yield and milk protein. It was also associated with the enhancement of healthy fatty acids i.e. Omega 3 and CLA in the goats' milk [60].

Feeding goats with diets containing essential oils also improves meat quality. *Syzygium aromaticum* buds oil extracts addition to the goats' diet resulted in improved concentrations of beneficial FA in meat, without effects on digestibility and growth performance in Black Bengal goats [61]. Feeding soybean and sunflower oil to Black Bengal goats at a concentration of 45 g/kg of the total diet had no adverse effects on nutrient digestibility and performance. However, an increase in the content of polyunsaturated FA and conjugated linoleic acids was observed in the muscle and adipose tissue of goats [62].

Since the development of anthelmintic resistant populations [63], the use of new drugs such as essential oils has proved so important in maintaining the production of small ruminants. For example, *Eucalyptus staigeriana*, an essential oil from the *Eucalyptus plant*, showed anthelmintic activity against goat gastrointestinal nematodes in vitro and in vivo [64]. Furthermore, extracts of Garlic (*Allium sativum L.*) were found to reduce coccidial load and enhance goat performance [65]. Similar studies that have shown the anthelmintic effect of plant extracts and essential oils are [66, 67].

The studies on essential oils and plant extracts containing secondary metabolite compounds are likely to increase, but there is a need to provide detailed information on their mode of action and their use in goat production.

4.3 Exogenous enzymes

The idea of exogenous enzyme supplementation is not new, intensive research interests on this topic started in the 1990s. Basing on the particular substrate on which the exogenous enzyme activity can perform, leads to their three main groupings i.e. fibrolytic, amylolytic and proteolytic. Bacterial and fungal species plus some yeasts are the main sources of these enzymes. Solid-state and submerged fermentation are the main techniques for enzyme extraction, which have been combined with several other biotechnological aspects [68].

The considerable number of endogenous proteolytic enzymes produced by rumen microbes limit the supplementation of exogenous proteolytic enzymes in ruminants [69]. However, there are currently some major efforts to improve the application and efficacy of proteolytic enzyme supplements in ruminant diets. For example, some studies have shown that there are possibilities of forming a synergistic link between endogenous and exogenous enzymes [69, 70].

The addition of cellulolytic enzyme an exogenous fibrolytic enzyme to the diet of lactating goats improved nutrient digestibility in the diets and thus increased

	Diet type	
Parameters	**Control**	**Cellulase enzyme**
DMI, g/d	3.10	3.50
Digestibility (g digested/g ingested)		
Organic matter	0.76	0.80
Dry matter	0.74	0.77
Neutral detergent fiber	0·62	0·68
Ruminal fermentation		
CH4 (g/day)	20·10	19.90
pH	6.44	6.62
Acetate (A; mmol/l)	45	47
Propionate (P; mmol/l)	14·20	15·80
Milk yield (kg/day)	3.10	3.40
Milk composition (g/kg)		
Total solids	104	114
Fat	34	40
Protein	29	31
Lactose	41	44

Table 4.
Effect of cellulase enzyme supplementation to the basal diets of goats on feed intake, nutrient digestibility, rumen parameters, milk yield and composition (adapted from Rojo et al., [71]).

milk yield, although no effect on milk constituents was observed [70]. Rojo et al., [71], showed improved milk production and composition in French Alpine goats supplemented with exogenous fibrolytic cellulase at 2 ml/kg DM in the diet. In another study [72], an increased average daily live weight gain of 83.49 g was recorded in Beetal-Dwarf Crossbred Goat fed fibrolytic enzymes supplemented diet compared to the control group with 68.33 g. Song et al., [73], recorded an increase in average daily gains which can be explained by the enhanced Feed Conversion Ratio and nutrient utilization in black Lezhi goats after supplementation of exogenous fibrolytic enzymes in the diet (**Table 4**).

Feeding wheat straw with a concentrate containing exogenous fibrolytic and proteolytic enzymes improved nutrient digestibility in Baladi goats [74]. Yeast and exogenous enzymes improved intake, nutrient digestibility, rumen fermentation, milk yield and milk fat concentration in Nubian goats [75].

Although several researchers have studied supplementation with exogenous enzymes with positive results on growth performance, feed intake, nutrient efficiency, digestibility and other production parameters. There has also been some inconsistency and variability in the various results, so more research is needed on this topic in ruminant nutrition in areas such as mode of action and inclusion rates.

4.4 Organic acids

In recent years, the use of organic acids as substitutes for antibiotic feed additives has steadily increased due to the risks of antibiotic resistance in animals and the effects on human health [76].

Organic acids are known as weak acids used as drinking water additives or feed additives (acidifiers). Potassium, sodium or calcium salts are other forms in which organic acids also exist. The acids have the advantage over the salts that they are usually odorless, less corrosive, more soluble in water and are easier to handle in feed manufacturing because of their solid and less volatile form [76].

The addition of organic acids to animal feeds can increase feed flavor, body weight, FCR, and reduce colonization of pathogens in the gut, while beneficial bacteria such as lactic acid bacteria that support and resist the organism can dominate the gut environment. In silage production, organic acids are used to lower pH to produce high quality silage [77].

Citric acid (CA), which is an organic acid, when added to the ration of dairy goats, increased the rumen pH and thus reduced the possibility of rumen acidosis. It also improved milk yield and milk fat test as shown in **Table 5** [78].

4.5 Antioxidants

Antioxidants are natural or synthetic compounds added to commercial feeds to inhibit lipid peroxidation (polyunsaturated fatty acids) and oxidative rancidity

	Diet	
Item	**Ground corn steeped in water**	**Ground corn steeped in 0.5% citric acid (CA) for 48 h**
Intake		
DM (kg/day)	1.04	1.02
Organic matter (kg/day)	0.98	1.00
NDF (kg/day)	0.22	0.22
Starch (kg/day)	0.46	0.47
Metabolizable energy(MJ/da)	11.70	11.80
Milk yield (kg/day)		
Actual	0.48	0.52
4% FCM[2]	0.52	0.67
Milk fat		
%	4.54	5.15
g/day	20.6	26.8
Milk protein		
%	4.45	4.37
g/day	20.5	22.1
Milk lactose		
%	4.25	4.24
g/day	20.30	22.1
Milk efficiency	0.46	0.49
Milk efficiency = kg actual/kg DM intake		
2FCM = 4% fat-corrected milk		

Table 5.
Effects of citric acid (CA) treatment of corn grain on feed intake, BW, milk yield and milk composition of dairy goats (adapted from Shen et al., [78]).

during manufacture, processing and transportation, and storage of the feed [79]. Antioxidants are important for maintaining sensory properties and prevent the degradation of critical nutrients such as pigments (oxy- and keto-carotenoids) and vitamins (A, D, E and B group vitamins) in commercial feeds. They also prevent the decrease of energy and protein in the feed [79].

There are natural and synthetic antioxidants. Vitamin E, C are the most abundant and common natural antioxidants. Vitamin A (retinol) and carotenoids are the other examples. Synthetic antioxidants are phenolic and nitrogen compounds. The major synthetic phenolic antioxidant compounds are; tert-butylhydroquinone, propyl gallate, butylated hydroxyanisole and butylated hydroxytoluene. Details of the different types and their structures and sources are discussed in detail in this study [80].

Selenium as an antioxidant has become increasingly important in animal nutrition in the context of increasing production, fertility and disease prevention in animals. Although it is a more potent antioxidant compared to vitamins E, C, A and beta-carotene, it is said to be more toxic [81].

Antioxidants are important in animals specifically for the prevention of oxidative stress. Heat stress could be a consequence of the current climate change, which is characterized by a lot of sunshine, which may affect the performance and health of livestock. Vitamin E and selenium supplementation can improve the antioxidant status of sheep, therefore this could reduce some of the negative consequences as a result of heat stress [82].

In goats, supplementation of antioxidants (vitamin C and vitamin E with selenium) was studied on Acid–Base Balance during Heat Stress and had ameliorative effects on physiological parameters, endocrine responses and acid–base status during heat stress [83]. Reduction of endogenous heat by decreasing respiratory thermolysis in dairy goats was also reported with supplementation of organic selenium, in addition to increasing sensible and latent heat release and maintaining rectal temperature within normal limits [84].

Vit E and Se are shown to have improved the quality of milk, making it nutritionally safe for human consumption and increased milk production [85]. Dietary herbs and synthetic antioxidants are also seen in improving feed efficiency and increasing the quality of meat (by increasing lean meat and reduction of body internal fat in the carcass of goats [86]. Antioxidants supplementation improved the meat oxidative stability in Kacang goats [87].

Vit E and Se have been shown to improve the quality of milk, make it nutritionally safe for human consumption, and increase milk production [85]. Dietary herbs and synthetic antioxidants are also seen in improving feed efficiency and increasing meat quality (by increasing lean meat content and reducing internal body fat in goat carcasses) [86]. Supplementation of antioxidants improved oxidative stability of meat in Kacang goats [87].

Ingale et al., [88], in their study explained the role of inclusion of organic acids such as malate and fumarate in the ration in reducing methane emissions from ruminants. The addition of fumaric acid in goat diets decreased methane emissions and resulted in an increase in propionate [89]. Methane mitigation through the use of organic acids is further discussed by Hook et al., [90].

5. Goat dietary composition and feeding aspects

5.1 Practical aspects of feeding protein to goats

The main aim of feeding protein feeds to ruminants is to ensure that they are supplied with a minimum level of dietary crude protein. On the other hand, the goal is to provide sufficient amounts of rumen degradable protein (RDP) for ideal rumen efficiency and microbial crude protein production by the rumen microorganisms [91].

The major sources of protein for ruminants are natural (or true) protein (consisting of amino acids), and Non-protein Nitrogen (NPN) (consisting of nucleic acids and ammonia). The commonly used sources of natural protein for ruminants worldwide include soybean meal and alfalfa hay, and other leguminous fodders [92]. NPN sources (including: urea and other ammonia compounds) are cheaper compared to true protein sources. A review by Tadele & Amha, [93], reports more on their use and their various sources.

Other, forms of protein utilization in ruminants are: (i) Ruminally Degraded Protein (RDP), which are broken down into different molecules in the rumen. Examples of these molecules are the amino acids, peptides, and ammonia that are utilized by rumen microbes for the production of microbial protein (MP). These MPs provide the bulk of amino acids in the small intestine, which is considered the main source of protein for ruminants. (ii) The other is the Ruminally Undegraded Protein (RUP), which is not broken down by the rumen and passes directly into the intestine [94].

There is a continuous supplementation of goats with proteins especially in goats consuming low-quality forages to maximize their intake and digestion. In most cases, increased intake and digestion leads to improved production such as increased milk, meat, and hair production. In most tropical countries CP can reach up to 12–15% for most grasses during the rainy season, but may drop below 5% during the dry season, necessitating protein supplementation [95]. On the other hand, nutrient requirements are always high during lactation so supplementation with feeds rich in nutrients such as proteins is necessary.

West African Dwarf goats fed *Panicum maximum* basal diet were supplemented with different protein sources: palm kernel cake (18.23% CP), soybean meal (41.46% CP), cottonseed cake (25.05% CP), and brewer's grain. The author found increased dry matter intake, digestibility, weight gain and feed conversation ratio [95]. Arigbede, [95] concluded that the higher CP content of the supplement may have led to the enhanced weight gain and feed utilization. Male Saanen kids fed wheat straw-based diets supplemented with concentrates containing 8.7, 11.7, 14.4 and 17.6% crude protein (CP) based on DM responded positively with increased feed intake and body weight gain [96].

Interestingly, a recent study found that supplementation of RUP in goats reduced the proliferation of parasite *Haemonchus contortus* [97] and positively affected periovulatory ovarian activity in goats [98]. These detailed reviews [99, 100] have already discussed that supplementation with protein-rich foods is essential for increasing host resistance to gastrointestinal nematodes, especially in small ruminants. Feeding rumen-protected tryptophan potentially improved growth performance, N utilization, and fiber growth in Liaoning Cashmere goats [101].

In another study, goats and sheep were fed isoenergetic diets (1.6% BW) with either addition of a high rumen degradable (RDP, 12.5% CP) or non-degradable (RUP, 12.5% CP) protein source or no added protein (control, 5% CP) to a seed juniper. Diets containing RDP and RUP showed an increased voluntary intake [102].

There is still a continuous supplementation of forages with NPN sources especially urea. However, when urea is supplemented in the feed, there is a need to supplement it with an energy source for utilization by rumen microbes as nitrogen is not efficiently utilized by rumen microbes [103]. This can be evidenced in a study where the addition of high N supplements to high energy diets (3.0 McalME/kg DM) enhanced the N balance and microbial protein synthesis in young dairy goats [104].

In a recent study by Lopes et al., [105], goats were fed diets containing buffelgrass hay and different levels of ruminal ammonia nitrogen ($N\text{-}NH_3$) (3.43, 9.95, 17.2, 23.0, and 33.7 mg/dl). Their results, showed that an increase in $N\text{-}NH_3$ concentrations had no effect on PH (6.43), and rumen Volatile fatty acids. Moreover, an increase in $N\text{-}NH_3$ resulted in a higher abundance of the rumen bacteria (Ruminococcaceae). They also recorded a positive linear effect ($P < 0.050$) on nutrient intake, nitrogen excretion and balance. Since excess inclusion of such NPN may cause toxicity, they concluded by recommending 3.43 mg/dl $N\text{-}NH_3$ as the lowest level for maintaining the activity of goat rumen microorganism and 14.5 mg/dl of $N\text{-}NH_3$ for optimization of the rumen microbial community.

A study, which involved the use of slow-release urea (SRU) as a supplement to groundnut straw (*Arachis hypogaea*), improved digestibility and weight gain of male goats and male sheep [106]. There was an increase in milk yield and milk fat and a reduction in blood urea nitrogen content when lactating goats were supplemented with slow-release non-protein nitrogen [107]. Other studies addressing to supplementation of NPN in goat diets include: [108, 109].

Therefore, this study it's shows us the increasing importance, use and need for research on NPN in ruminant nutrition. This can solve the current problems of scarcity of protein-rich legumes or the protein of plant origin and the high costs associated with other alternative protein sources.

Recently, single-cell proteins have been increasingly used in human and animal nutrition. Examples of these used in animal nutrition are: Blue-green algae, bacteria, yeast, fungi, etc. Even though the use of single-cells dates back to ancient times. Their commercial production and application in animal diets are new [110]. Microalgae are said to be rich in nutrients such as proteins, amino acids, pigments, vitamins/minerals, and polyunsaturated fatty acids [111]. There are promising novel feed additives, mainly because of their high protein content [112] and there are some studies that have shown that they are added to livestock feeds. In goat nutrition, the addition of dried algae resulted in an increase in the nutritional quality of goat milk due to changes in the fatty acid profile, as the content of oleic acid, linoleic acid, and linolenic acid increased [113].

However, it is important to note that excessive protein addition to the diet is lost through urine, which is not financially conducive to an efficient livestock production system.

5.2 Practical aspects of concentrate and forage feeding to goats

Diets for ruminants consist mainly of roughage, energy feeds, high-protein feeds, and additives such as vitamin-mineral salt. Among the feeds in the first three groups, roughages are the cheapest. The use of roughages, in ruminant rations at the highest possible level is the rule of thumb for a cheap ration. Therefore, in goat nutrition, correct estimation of the concentrate – roughage ratio is necessary to use for proper utilization of the feed and to minimize the costs [114]. One of the main consequences that can result from feeding high concentrate is subacute ruminal acidosis (SARA) [115]. SARA occurs when the rumen pH level becomes lower than 5.6 for a period greater than three hours per day [116].

Supplementation of forage with concentrates has been done mainly in dairy goats due to the high nutrient requirement during this stage. It has been observed that the nature of the diet does not only affects the amount of milk produced, but also its composition and the quality of the products made from it [9]. In this context, a study [117], was conducted on the effects of different levels of concentrate and supplementary hay feeding on the occurrence of rancid and tart flavors in Norwegian goat milk. It was concluded that increasing concentrate and hay feeding, had the potential to reduce these off-flavors. In another similar study feeding concentrate resulted in the production of milk with less off-flavors and high in unsaturated fatty acids [118]. This supports the factor mentioned above that the type of the feed influences the composition of milk.

In most studies where concentrates were supplemented with roughage, an increase in production was reported. For example, one study [114] showed that an optimal ratio of 40% roughage to 60% concentrate resulted in increased milk secretion in goats. Feeding adlibitum green forage with a concentrate admixture of 300 gm had a positive effect on protein conversion rate (PCR), FCR and live weight gain of dairy goats. Increased milk yield, positive effect on birth weight and growth of kids were observed [119]. There was also increased milk yield when dairy goats were fed 50 g of concentrate daily in addition to ad libitum roughage [120]. In addition to the live weight gain of the kids in the first month, which could be due to the fact that they get enough nutrient-rich milk from the dams.

It was also found that feeding green grass (roughage) alone did not meet the appetite and nutritional requirements of Black Bengal goats [121]. Gradual increase in concentrate content in goat diet also resulted in gradual increase in live weight, nitrogen balance, carcass yield and net gain [121]. This undoubtedly explains the benefit of concentrate addition in meeting nutritional requirements.

Nevertheless, a study by Saijpaul & Saini, [122], justifies the statement that roughage feeding can only meet the maintenance and part of the growth requirements of ruminants. In this study, [122] concentrate supplementation showed increased digestibilities of OM, CP, NDF, and total carbohydrates, and this explains the higher body weight gain in the Beetal kids. Tadesse et al., [123], in their study showed an increase in goat body weight gain upon concentrate supplementation.

Creep feeding is the supplementing of kids with a special feed designed to meet their nutritional needs. In most cases, this is either creep grazing or grazing with high quality, nutritious forage or concentrate supplements. A study where lactating kid goats were supplemented with creep feed showed improved rumen morphology where muscle layer thickness and rumen wall thickness were greater in the creep feed supplemented treatment group [124].

Increasing environmental concerns have led to the need to investigate the effects of concentrate supplementation on methane emissions. Although feeding grass and legumes showed lower performance in goats, there was a reduction in methane emissions [125]. In this context, the addition of concentrates may lead to higher emission of another environmentally unfriendly gas, namely ammonia. This is the case because most concentrates have a high protein content and they are rapidly degraded in the rumen of goats, releasing ammonia [126]. To solve such cases, more research is currently being done to find methods that can reduce ammonia and methane production in the rumen. The application of bioactive phytofactors found in many different plant varieties is one of the identified potential mitigation methods.

Based on this study, the differences between feed ingredients in different continents, the wide variability in properties and their interaction with each other, and the effects on different animal groups automatically indicate that research on this topic will continue.

5.3 Practical aspects of feeding fats and oils to goats

The addition of fats in the feed is reported to increase the energy density of the feed [15] and the feed utilization [127] in goats. It improves palatability and reduces dustiness of the feed [116]. However, the addition of high levels of fat in the feed, especially at concentrations above 6–7% of the dietary DM, can reduce digestion DM especially of fiber, as described in [128].

Feeding soybean or flaxseed oils 20 mL/day to lactating Anglo-Nubian goats increased total VFA, propionate and blood glucose. There was also significant feed utilization, which may have resulted in increased milk production [127]. Oil supplementation has been reported to affect milk composition, especially increasing the concentration of fatty acids [129]. The study by Kholif et al., [127]] showed an increase in unsaturated fatty acids (FA) and conjugated linoleic acid (CLA) in milk, but a decrease in saturated fatty acids. An increase in CLA in goat milk was also previously found by Mir et al., [130], when goats were supplemented with canola oil. There are also many recent studies showing similar results on the effect of FA, such as [131] and [132]. The alteration of the milk fatty acid content is because when ruminants are fed with lipid sources, they alter the fatty acid profile of the lipid which enters the intestine of the rumen [133].

However, enrichment of essential fatty acids is also seen in other goat products such as meat. One study showed that the addition of linseed oil to goat feed enriched goat meat with essential fatty acids (i.e. n-3 FA) [134]. Other studies such as [135, 136] showed improvement in meat characteristics of goats by adding oil in the feed.

Another important factor related to fats is their ability to reduce methane emissions depending on the amount, a form of fat and fat source for supplementation [137]. The effects of fat supplementation on methane production may be due to its ability to inhibit the growth of methanogens and the number of protozoa. In addition to reducing rumen internal fermentation of organic matter and hydrogenation of unsaturated fatty acids (which act as an alternative H2 sink) in the rumen [128].

Dietary supplementation with a mixture of 80% rapeseed oil and 20% palm oil altered VFAs in the rumen and reduced the acetate: propionate ratio and methane [138]. Methane reduction after oil supplementation was also observed in studies by (Martin et al., [139] and Puchala et al., [140]. It seems that proper supplementation of fats and oils is a promising technology to consistently mitigate CH4 without affecting production as seen with our discussions. However, fat supplementation is associated with high costs which could not be economical for livestock producers.

6. Conclusion

Within our scope of the study, goat feed resources, feed additives, and the different dietary aspects are examined. Summarizing information on the effect of feeding on the intake, digestibility, utilization, health and performance. This updates our knowledge of these developments in the field of animal nutrition. This study has shown us the advances in animal nutrition that are being made in terms of financial criteria, sustainability and product quality. We have seen the importance of these advances in goat nutrition in terms of environmental protection, such as the reduction of methane emissions. The importance of some dietary ingredients (such as essential oils and plant extracts, probiotics, prebiotics and other additives) was highlighted and their use is likely to increase, but there is a need for more research on their mode of action and standard inclusion rates.

Abbreviations

DM	Dry Matter
Mcal	Megacalorie
NEL	Net Energy for lactation
CH4	Methane

N	Nitrogen
FA	Fatty acid
CLA	Conjugated Linoleic Acid
OM	Organic Matter
CP	Crude Protein
NDF	Neutral Detergent fiber
FCR	Feed Conversation Ratio
VFA	Volatile Fatty Acid

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Chapter 6

Strategies for Goat Feeding and Management during Drought

Mulisa Faji Dida

Abstract

Nowadays, climate change is becoming a serious problem threatening livestock production by affecting their environment, health, and feed sources. Many parts of the tropical countries, particularly the pastoralist area, experience extended periods of drought, leading to shortages of feed and water. During these periods, goats are incapable of meeting their nutrient requirement for maintenance and will begin to lose weight as body reserves are depleted, causing economic loss to the goats. In the extremely long dry season, animals die, with the youngest, weakest, and oldest dying first. As a result, drought management entails balancing pasture and water supply against forage and water demand. In most cases, no single strategy will suffice to address this issue. Each situation would need a different set of strategies Therefore, this chapter will come with some common options/strategies that can be avail feed shortage during drought. Those strategies are purchase of feed from surplus location, adjustment of animal management, policy intervention, destocking, adjusting grazing strategies during drought, supplementation, maintenance feeding, reallocation of a given amount of feed in the herd, early weaning and creep feeding, lowering stocking rate, water sources and supplies, development and effective utilization of feed resources, and creation of feed banks.

Keywords: goat, drought, feed, humane destruction, strategies

1. Introduction

Drought is affecting livestock production across the globe, especially in tropical countries, resulting in a lack of fodder and water [1]. Droughts happen when there is not any rain or other precipitation for a longer period of time. During a drought, there is a lack of water and decreased soil moisture, which prevents forage growth and quality. Small ruminants can graze on available pasture for a shorter period of time if there is prolonged dry weather or drought. Drought is most commonly associated with hot summer weather, although it can occur at any time of year and have a significant influence on sheep and goat output [2, 3].

Droughts often raise special and daunting management challenges. Drought often becomes an economic question of supply and demand during which the demand for forage and/or water exceeds the availability. Underfeeding during the dry season can have an impact on livestock's immediate production as well as their long-term results. Goats are unable to fulfill their food requirements during these times and will begin to lose weight as their body reserves are exhausted [4, 5].

Drought is often transformed into an economic issue of supply and demand, in which the demand for forage and/or water exceeds the supply [5]. The difficult decision becomes whether to increase the supply of forage by purchasing hay or other feedstuffs or to reduce the demand for forages and/or water by reducing the number of livestock reliant on those commodities. Granted, it would be a lot easier to address the question if we knew how long the drought would last, but we will not know until it's over [6, 7]. Make choices based on logic rather than feelings when dealing with a drought. That is always easier said than done, but it is the rational decisions, not the emotional ones, that will ensure the operation's long-term viability [8, 9].

In most cases, no single strategy will sufficient to address the problem of drought. Every circumstance would necessitate a different set of tactics. In this book chapter, some popular options are discussed. It is up to the extension worker and farmer to determine which options are best for a given set of circumstances. The availability and costs of off-farm inputs, as well as the perceived value [sales and outputs used within the household], will be deciding factors. The choices to make and the extent to which they are implemented are determined by the situation. A combination of the tools listed here would likely be the most powerful [5, 10, 11].

2. Research methods and analysis

To prepare this chapter, technical reports from various journals and research from scientific articles and books were reviewed. The thorough insight into literature discussed put some highlight on the common strategies that can tackle feed shortage during drought.

3. Alternative strategies for goat feeding and management during drought

3.1 Purchase of feed from surplus location

The major option for saving animals is to buy feed from surplus areas. High transportation costs are involved, where extreme droughts and rains can occur at the same time. Even though the calculation shows that at greater distances, i.e., beyond 200 km, the cheaper transport of concentrates favors the cost of nutrients from grains over dry grass. However, the option of grain feeding has limited value because grain is already scarce under normal conditions and is unlikely to be diverted from human consumption in a disaster that also affects human nutrition. As a result, agro-industrial by-products such as bagasse, grain milling by-products, and molasses, as well as field grasses and straws, are available for purchase as feeds. The availability of transportation is determined by the nature of the disaster. Feed transportation is only an option if the drought is local. It has little or no value if the infrastructure is severely damaged (flooding) or the disaster is on a much larger scale [5, 11–13].

3.2 Adjustment of animal management

The following changes in animal management can help improve feed resource utilization during a drought.

- Parasite control: Animals that are under nutritional and heat stress are less resistant to parasites than animals that are not. During a drought, strategic deworming will alleviate some of the nutritional stress on the animal and "clean up" the herd in preparation for the next favorable season [14, 15].

- Herd segregation: Young animals cannot compete with mature animals for basal or supplemental feed. Drought feed is expensive, and it is critical to feed only those animals that truly require it. Vulnerable groups can be separated and given special treatment. The older, dry animals can be relocated to less desirable pasture or range areas [5, 16].

3.3 Policy intervention

3.3.1 Legislation

There is an important need for a feed and fodder development policy. The establishment of the Feed and Fodder Development Board can effectively serve as a key instrument in achieving the sector's policy objectives. Policies for the use of permanent pastures, as well as a policy for animal migration, are required to develop a grazing policy for the region. Strict enforcement of the policy decisions through communication and attractive schemes could help ease the pressure on degraded grazing lands [11, 17].

3.3.2 Education

Forage production research should be considered as a national agenda. Chairs should be created in universities for teaching graduate and postgraduate students. A sound syllabus is prepared, covering all major aspects of forage production and enforced at the university level [18, 19].

3.4 Destocking [limit numbers of animals]

Destocking is the process of removing drought-affected animals from the herd by accelerating off-take to terminal markets or slaughtering them immediately for wet and/or dry meat delivery. During droughts, livestock may support their owners by providing food and/or cash by being destocked [5].

3.4.1 Selling stock

This is dependent on a strong social framework in the community for communal grazing areas. Government-imposed restrictions are rarely successful. Drought-related issues may be compounded by widespread veterinary care, but better marketing opportunities to improve off-take should be encouraged. In severe drought situations, this entails livestock traders/exporters accelerating livestock off-take in emergency operations. If the requisite linkages between livestock traders and pastoralists are established promptly, such an intervention could significantly increase the volume of off-take. Even if the perceived drought does not occur, early de-stocking of mature male animals provides a significant financial benefit to pastoralists [5, 11].

In the early stages of a drought, the option of selling stock should almost always be the first step. The goal should be to keep the breeding flock as intact as possible so that farmers/pastoralists can recover their stock numbers as soon as the drought ends. To accomplish this, the stock should be sold by class as the drought progresses, beginning with finished young stock and progressing through the aged stock and older breeders until a nucleus of healthy, young, sound, breeding females that is most precious for restocking when the drought ends remains. Important factors to consider when selling stock include the timing of the sale and the condition of the stock at the time of sale. Prices will most likely be higher if stock is sold early in the drought before the market becomes overcrowded with a large supply of animals. The stock should be in good condition to command higher prices. For prolonged droughts, this strategy is more effective. During short droughts, only a small percentage of stock may need to be sold. This is usually offset by higher performance per animal of the remaining stock as a result of the lower stocking rate [11, 20, 21].

3.4.2 Move animals to other areas

Traditional animal movements out of feed-scarce areas during the dry season, which are routinely practiced in pastoral and agro-pastoral areas, will help reduce pressure on grazing resources and animal conditions. Traditional practices can be supplemented with assistance in the form of information that guides movements to locations of available resources [11, 22].

3.4.3 Emergency slaughter [humane destruction]

Humane stock destruction is another strategy that may be used when livestock prices are extremely low or when animals are unable to be transported. When animals are nearing the point of no return, they should be destroyed humanely. Reduced competition for feed will help the remaining animals stay in better condition and be more productive after the drought. During a drought, the emergency slaughter of livestock for fresh or dried meat production for distribution as food aid or sale may be considered. Construction of specific slaughter/processing infrastructure and the employment of local labor for meat processing, as well as the use of existing facilities and contracted processors who sell the finished product plus offal and skin, can be alternative options [5, 15].

A simple slaughterhouse is likely to be required; however, meat drying can be done in the open with little risk of infestation if the meat is first soaked in a brine solution. Fresh carcasses should be inspected for health risks regardless of the processing system. Compensation for slaughtered stock can be in the form of grain or cash, with the latter being preferable in areas where grain markets are active. This is the type of intervention that requires Non- governmental organization or government agencies to organize and coordinate at a higher level than the Peasant associations Development agent. The first management practice to think about is whether or not to reduce the herd size. Supplemental food, grazing strain on stressed grasslands, and demand for limited water supplies are all reduced when herd size is reduced. Older females and those with a poor reproductive or health history should be sold, but the best breeding stock should be kept. Dams with persistent lameness and mastitis, as well as those with mastitis, should be sold (**Table 1**) [23, 24].

3.5 Maintenance feeding

Drought feeding is often done with the aim of survival or maintenance [13]. Goats are typically fed just enough feed to keep their weight stable at a body condition score of at least 2 until the drought ends. Because of their feeding habits, goats have better body conditions. Maintenance feeding is analogous to watering during a short drought. Maintenance feeding, on the other hand, maybe costly if the drought lasts for a long time. This technique works best if it's paired with a decrease in the number of animals before beginning to feed them. If there is still some low-quality vegetation available, protein-rich concentrates, enough to meet about half of the animals' maintenance needs, should be provided. If the drought worsens, the supplementary feed will be

Flock group	Action	Typical animal	Reason for action
A	Cull	Late born twin or orphaned kid.	Unlikely to respond to feeding. Problem kids.
B	Sell immediately or grow out for market	Twins and late born single kids.	Will not breed this year. Can sell easily for kid meat if in good condition. Can handle short-term feedloting but must be economic.
C	Evaluate	Well grown twins or singles born to maiden does.	Put best does in Group D and remainder in Group B.
D	Keep	Best grown potential breeding kids.	Likely to mate and rear a kid.

Source: Ferguson and McGregor [13].

Table 1.
An example of how a flock of maiden does could be assessed at the onset of a drought.

required to meet the entire maintenance requirement. If the protein content of the available concentrate is low, a protein supplement such as urea at a rate of a few grams per day may be required. Oilseed cake can be demonstrated to be especially effective at increasing roughage consumption during a drought [24, 25].

When a limited amount of supplement is available, it should be a supplement to the flock members who are most in need [pregnant and lactating animals]. Feeding should begin before the goats become weak. It may take some time for them to get used to a new feed supplement. If animals have lost too much condition before feeding, it may be difficult to restore their live weight to desirable levels. This is especially true for kids or weaners who were not fed supplements while grazing with their mothers. One general rule of thumb is to feed a supplement when half of the flock has a body condition score of 2 or lower. If the condition still worsens after this level of supplementation, increase the feeding rate. When only a quarter of the stock has a body condition score of 2 or less after the drought has ended, stop feeding [20, 25].

3.6 Adjusting grazing strategies during drought

A list of drought-resistance strategies is provided below to assist producers in avoiding a crisis. It is best to evaluate options as soon as there is a sign of drought.

- Adjust the stocking rate according to the carrying capacity of dry years.

- Reduce the stocking rate as soon as possible. After the drought, gradually increase stocking rate over a period of 1–3 years,

- Grazing areas with limited water reserves should be prioritized.

- Rest pastures or postpone grazing in all pastures regularly. Increase pasture rest periods during slow or no growth periods. Plants can withstand heavy grazing if it is followed by adequate rest periods. These periods of rest allow plants to replenish tissues both above and below ground.

- Maintain emergency pastures that are only used in emergencies,

- Transport animals.

3.7 Reallocation of a given amount of feed in the herd

The first major option for dealing with a feed shortage is to adjust animal production to the availability of feed. Some hypothetical and simplified calculations on the economics for various feeding strategies are reported by [26]. Because no pasture was available and no feed was available to dying animals, the mortality in the herd was assumed to be entirely caused by starvation from animals other than productive stock in the absence of a strategy intervention. Three strategies for adjusting feeding patterns and lowering mortality rates were considered:

A. Nutrient redistribution from milk-producing animals to all other animals in the herd. This would reduce total milk production from 290 to 60 l, reducing farmer income significantly while ensuring the survival of more animals.

B. To save other livestock, nutrients are taken from growing animals including bullocks. If growing animals were fed enough nutrients to gain 400 g/day, and bullocks and old cows were fed 80% of their requirements, 10 of the 29 animals at risk could be saved. Milk production is not reduced under this strategy. In addition, the livestock mortality can be reduced.

C. Nutrient redistribution from milk-producing and growing animals to starving animals: In this case, the farmer does not want to lose so many animals, and if he or she cannot afford to drastically reduce milk production as in option A, the strategies can be combined. Some nutrients would be diverted from milking as well as growing animals, saving nearly all animals at 120 kg milk per day. A decrease in milk yield in strategy A lower daily income is the result, which may be difficult to accept for farmers who do not have enough other sources of income or cash reserves. Feeding animals less than their requirements [strategy B] is risky because more animals may die if the disaster lasts longer. The nature of the feed shortage, whether regular and predictable or irregular and unpredictable, obviously influences the strategy choice. Strategy B also produces underfed cattle, which are less valuable after the disaster. The extra value or costs of these animals, however, are difficult to assess, due in part to compensatory gain or lower fertility rates, particularly in younger animals. Furthermore, the value of animal survival is much higher in India's predominantly Hindu society than in many other countries around the world. The relative necessity of owning an animal capable of pulling the plow during the next rainy season complicates the valuation of mere survival as a form of animal production [11, 25].

3.8 Early weaning and creep feeding

Creep feeding: Creep feeding is the practice of feeding supplemental feed to young animals while they are still sucking. Creep rations should contain 12–13 MJ/kg of metabolizable energy and a protein content ranging from 13 to 16%, depending on forage protein levels. Early weaning: The nursing doe's energy and protein requirements are 200–300% of those of a dry doe. Weaning reduces the doe's nutritional demands, and she is more likely to maintain body condition, which is important for re-breeding and critical for improving conception rates. During a drought, the quality and quantity of pasture and rangeland forage rapidly decline. During a drought, early weaning and placing weaned kids on feed-in dry lots reduce grazing pressure on pastures and allow

	Months											
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Collected tree fruits								$\underline{*}$	$\underline{*}$	*		
Collected crop residues								$\underline{*}$	$\underline{*}$	$\underline{*}$		
Fallen leaves and fruits					$\underline{*}$	$\underline{*}$	$\underline{*}$	*				
Crop residues in fields				*	$\underline{*}$	*						
Dry leaves and dry grass				$\underline{*}$	$\underline{*}$	*						
New shoots										*	$\underline{*}$	
Green leaves and grass	$\underline{*}$	$\underline{*}$	$\underline{*}$	$\underline{*}$	$\underline{*}$						$\underline{*}$	$\underline{*}$
Feed shortage						*	*	*	*	*	$\underline{*}$	

Source: from [12].
Underlining of symbols indicates greatest reliance on a particular feed resource.

Table 2.
An example of a feeding calendar for goats in a dry area of Zimbabwe.

existing forages to be used to maintain the body condition of the doe flock. For growing/finishing children, several protein supplements are designed to be mixed with whole-shelled corn [5, 11].

3.9 Development and effective utilization of feed resources

Supplying an adequate amount of roughage during drought season can be accomplished by using the following strategies (**Table 2**).

3.9.1 Grazing management during drought

Good grazing management produces a lot of leaf material, which is necessary for the plant to take advantage of any moisture that does fall and produces energy for its roots and basal buds. The less energy a plant can provide to its roots, the more vulnerable it is to drought and grazing. A drought may necessitate a reduction in livestock numbers based on forage availability. In a drought, a rotational grazing system is preferable to continuous grazing because periodic rest helps plants maintain vigor. Concentrating more animals in a single herd is preferable to having several smaller herds because having more animals in a pasture allows the entire pasture to be grazed more uniformly and allows for more use of less preferred plants (**Figure 1**) [11, 19].

3.9.2 Densification of feeds

Compressing or densifying bulky feeds is one way to reduce transportation costs. According to [27] report, the bulk density of straw-based complete feed increased by 2.25–2.70 times. Densities can be increased by baling from 65–75 kg/m^3 to 100–110 kg/m^3 or even 300–500 kg/m^3 by briquetting [28], which appears to be very high. Considering the costs of baling grass by hand and bullock-driven presses, the amount of feed that can be transported in each truck more than doubles after baling. The calculations show that when the transport distance exceeds 50 and 150 km, the costs of baling with pada and hand press are recovered by lower transport costs. Extra benefits such as lower storage costs, less spoilage, and thus higher feed quality are possible, but it is dependent on the type of straw and the method of densification [29].

Figure 1.
Goats grazing on natural pasture.

3.9.3 Forage production from sandy wastelands

There is enormous potential for increasing fodder production from 6.36 million ha of wasteland, particularly sandy wastes and land with and without shrubs, which accounts for approximately 1I3td of wastelands. Silvopastoral systems with multipurpose tree species such as *Prosopis cineraria* and *Ziziphus nummularia*, as well as grasses, should be strongly recommended for increasing forage production from degraded and wastelands. If properly stabilized and managed, these lands have the potential to be a hugely productive site for afforestation and grassland development. Dune rehabilitation entails protection against biotic influences, treatment of shifting dunes by erecting barriers [mulching-micro windbreaks] from the crests down to the heel of the dune. Grazing should be prohibited in such areas until the dunes are stabilized, and grasses should be harvested manually to ensure the longevity of grass species [30, 31].

3.9.4 Forage production from irrigated areas

Many problems in drought-affected areas can be solved by staggering planting of cropping sequences rotationally by subdividing forage fields into 2–3 plots and conserving excess fodder as silage or hay during the lush green period.

3.9.5 Use of unconventional feed resources

Nonconventional feeds can help to reduce animal feed deficits while also making livestock production more economical and profitable [32].

3.9.6 Use of crop and industrial by-products

Sugar factory by-products such as cane tops and bagasse [for those living near a sugar factory] provide a significant quantity and quality of feed resources for use during drought. Some residues are well utilized, while others are just getting started, and much is wasted. The feeding value of these residues must be recognized, and practical issues such as transportation and feeding method must be addressed. The nutritive value of residues can be increased through proper harvesting and storage, protein supplementation, and physical/chemical treatment.

Figure 2.
Goats fed crop residue.

Local protein sources, such as tree pods [e.g., Acacia pods], should be fully utilized (**Figure 2**) [33, 34].

3.9.7 Planting of additional feed resources

Growing higher-nutritive-value grass species, legumes, fodder crops, controlled grazing, fertilizer use, and the integration of small ruminants with plantations, such as sugar cane plantations, can all help to improve feed supply throughout the year. Improved forage production should prioritize species with high biomass yield potential. Growing grasses and legumes that retain their nutritive value into the dry season is possible under rain-fed conditions. In this case, *Stylosanthes* spp. can be used successfully. Many palatable trees retain their leaves throughout the dry season and can thus be lopped for fodder. Growing drought-resistant plants, such as spineless cactus, can be used as fodder during drought [9, 30, 33].

3.9.8 Conservation of forage

In drought-prone areas, pastoralists, agro-pastoralists, and farmers should devise a forage conservation strategy, and raising awareness is critical in this regard [35]. Hay production is an option in areas with adequate grass growth during the normal pasture growing season. Hay can be used as a supplement during both the dry and wet seasons. Making hay requires labor, and the other option for the pastoral setting is "standing hay," which preserves some of the rangeland. However, when used in the form of standing hay, the quality of this feed resource is significantly reduced [6, 12].

Standing hay is forage that is left in situ for grazing. The downsides of this strategy include a lack of control over the amount of forage grazed by domestic and wild animals, increasing the chance of running out of fodder before the next crop arrives, as well as fire and termite damage. Protein content of the crop declines significantly as the dry season develops, whereas fiber content increases, owing to senescence and the loss of leaf material [4, 17, 19].

Silage is the storage of green forage, as cut or after wilting, in anaerobic conditions established by compression of the material and the absence of air, to allow the conversion of plant sugars to lactic acid, which is especially important for succulent crops [36]. Crops that are poor in fermentable carbohydrates may require an addition, such as molasses, maize meal, or a purchased product. The stage at which the crop is cut will depend on whether it is required as a high-energy/high-protein feed, in which case it will be cut early, or as a bulk feed, in which case the nutritional value will be lower but the quantity gathered will be higher [35].

3.9.9 Use of drought-tolerant plants

Cactus is a drought-tolerant plant that thrives in arid and semiarid environments [32]. It can be grown on roadsides and in degraded soils that are unsuitable for other crops. Young cactus leaves [cladodes] are high in water [about 90%], ash [20%], and calcium [1.4%] and can be used as a source of soluble carbohydrate and water during a drought. Protein, fiber, and phosphorus levels, on the other hand, are low. As a result, when cactus is used as drought feed, it should be supplemented with low-cost protein and essential minerals such as phosphorus and sulfur. It is best to feed fibrous feeds such as hay and straw before or alongside the cactus. Spines in spiny varieties can be removed by either burning individual pads or chopping. Because of its large size, the cactus must be chopped for goats to consume it [9, 17].

3.9.10 Reduction of wastage by chaffing

If there is not enough straw to feed all of the animals, chaffing is a choice that saves 15–20% of the straw offered [12]. Chaffing is popular on farms in Haryana and Punjab states, but not so much in other regions, owing to nutritional reasons [37].

3.9.11 Urea treatment of straw

The transportation and treatment of urea or ammonia could be less expensive than the purchasing and transportation of additional concentrate or roughage [38]. Urea-treated straw reduces the need for concentrate feeding, increases milk yield by 1–2 l/animal per day, improves farmers' economic returns, and can help reduce the amount of land needed for green fodder production. The procedure is straightforward and involves evenly spraying urea solution over the straw and storing it for a specific period of time. The following is the procedure for urea ammoniation of straw. In that case, increased consumption of treated straw also tends to boost the health and efficiency of livestock. Straw—100 kg, urea—40 kg, and space requirement is 180 × 150 × 150 cm.

3.9.12 Complete feeds

Complete feeds refer to a feeding method that includes all ingredients, including roughages that are processed and blended uniformly and made available to the animals at will [39]. When this feed is fed as a selling source of nutrients, it can be in mash or pelleted form. Pelletizing feeds increases dietary intake by 3–30% but increases processing costs by 57–130% depending on the form, percentage, and original cost of roughages in the ration. If fibrous feeds are baled, it is possible to make full feeds for use during droughts by adding some concentrate ingredients. Biologically, using full feeds with an adequate mix of roughage and concentrates can help animal's better use locally available crop residues, agricultural by-products, and waste. If feed and transportation costs can be kept low, complete diets for livestock may support rural farmers during times of feed scarcity. Many full feeds have been developed using locally available by-products such as bagasse mixed with tree leaves and other unusual by-products. The composition of the complete feed, on the other hand, must be tailored to the output level of die animals [11, 40].

3.10 Supplementation

Supplementary feed can only be provided in drought-stricken areas if it is available. This usually means that the government or an aid program must organize the transport of feed into these areas. Because of their higher nutrient density and ease of transport, concentrates are preferred over roughages for drought feeding. Supplemental feeding should normally begin before animals have lost more than 15% of their body weight. Assess animals of various categories at intervals before the drought begins and at various stages throughout the drought period. Simple hanging balances with slings can be used to weigh samples of animals from each category. If animals are allowed to lose weight gradually and systematically, they will be able to survive on survival diets during droughts at 66% of their normal mature body weight. Pregnant animals are exempt from this rule because significant weight loss can result in abortion [5, 11, 25].

When one nutrient is deficient, a supplement can have a significant impact on productivity. Urea, minerals, and molasses, for example, provide nonprotein nitrogen, specific minerals, and energy, respectively. Although supplements are frequently given on a daily basis, they can also be given as infrequently as once a week. However, urea-containing compounds must be handled with caution when using this strategy, especially with group-fed animals. Depending on availability and access, the following supplements can be used during a drought [29].

3.10.1 Use of urea molasses mineral blocks

Molasses contains a high concentration of sugars that are easily digested in the rumen. It is also high in minerals such as calcium, potassium, sulfur, and trace minerals, but low in nitrogen and phosphorus. It can make up a significant or minor portion of drought feed. It is a concentrated energy source that can be stored for an extended period of time. Because it is palatable and contains a variety of minerals, molasses is frequently used as a carrier for urea. During a drought, urea molasses blocks as lick, in addition to straw feeding, are recommended. The block contains urea, molasses, minerals, grain/cakes, and a binder. Animals get their energy, protein, and minerals from licking these blocks. Molasses/urea supplements in liquid or block form: Depending on the proximity and availability of molasses, these are good methods of supplement feeding. Molasses-urea mixtures can be used in the form of liquid lick in areas close to sugar factories, while the block is the preferred mode of use in areas further away [29].

Transportation of molasses and the availability of storage tanks are the main limiting factors in the use of liquid molasses as emergency feed in areas far from sugar factories. This necessitates long-term planning for molasses transportation and storage in drought-prone areas. Molasses/urea blocks are consumed slowly, and intake is limited by the hardness of the blocks, which is important in conserving the primary feed resource where intake is difficult to control. The blocks on the market are compact, typically weighing around 3 kg, occupying less space, and are easy to transport [29].

3.10.2 Providing vitamin "A" doses

Green fodder contains carotene, which is converted into vitamin "A" in the animal body. However, during drought, green fodder is not available to livestock, and thus animal shows symptoms of vitamin "A" deficiency, which are predominantly as: lachrymal discharge, loss of resistance power to diseases, and frequent diarrhea. Treatment is vitamin A injection at bimonthly interval and/or in ration adds vitamin A containing mineral mixture [14].

3.10.3 Cheaper and balanced concentrate for lactating animals

Supplementation of seed cake of arid zone that has been evaluated as feed to provide protein and some minerals is crucial. This seed cake can be incorporated in concentrate at appropriate level, reducing cost of concentration [29].

3.10.4 Feeding of mineral mixtures and common salt

Animal feeding managers should have mineral bricks and common salt on hand so that mineral and common salt deficiencies do not occur [29].

3.10.5 By-products

Based on their availability and ease of use, a variety of agricultural and agro-industrial by-products can be used as supplements. Agro-industrial by-products are by-products of crop primary processing and include the following: milling by-products, oilseed cakes, molasses, and the occasional surplus or damaged grain [30].

3.10.6 Herbaceous or tree legumes

Herbaceous or tree legumes can also be used as supplements during drought, but their widespread use is limited due to limited availability. Tree foliage and/or pods, such as various Acacia species, can be used as a substitute for concentrate supplements. In general, the supplements are expected to catalyze feed utilization and are required in small amounts relative to the basal roughage. As a result, they may be more expensive and must be transported over longer distances (**Figure 3**) [19].

3.10.7 Mixed ration supplements

For maintenance or survival feeding, animals of reproductive age [25–30 kg live weight] should have access to an adequate supply [400–600 g] of native grass hay or cereal straw and can be fed a concentrate supplement of 150–200 g DM per day [29].

3.11 Creation of feed banks

Dry and green fodder, straws, and stovers are fed to animals without chaffing in some parts of the world, resulting in the waste of a large portion of these resources. Chaffing fodder, straws, and stovers should be encouraged in order to maximize the amount of energy available for animal production. Technologies such as urea treatment and complete feed, which incorporate nonconventional feed resources,

Figure 3.
Goats browse on tree.

minerals, and complete feed blocks, will also help in the availability of more nutrients from existing feed resources [11, 38].

In the arid region, storing fodder from good to bad years was a traditional drought coping mechanism. One of the major issues that require more attention is the establishment of fodder banks in arid regions. The establishment of fodder banks may be mandated for fodder security during famine years. The fodder bank could be the ultimate solution and backup plan to meet the demand for lean period shortages, particularly during droughts and floods. Following feeds and fodder could be stored in these banks. Feed bank for unfit-for-human-consumption ingredients, such as grasses from the outskirts of forest areas, wastelands, and farm lands stored as briquettes and high-density piles, crop residues in densified form, coarse cereals, legumes, and haulms left over after grain removal [30].

4. Conclusion

Goats are essential for the development of environmentally friendly and sustainable production systems. Efforts should be intensified to improve this animal's productive and reproductive capabilities using simple and cost-effective methods. Desertification, drought, and global warming all point to the need for a serious rethinking and/or implementation of new feeding strategies aimed at increasing animal production while minimizing environmental impact. As a result, various researchers have identified a variety of alternative strategies to balancing pasture and water supply with forage and water demand during drought. Purchase of feed from surplus locations, animal management adjustments, policy intervention, destocking, adjusting grazing strategies, supplementation, maintenance feeding, reallocation of a given amount of feed in the herd, early weaning and creep feeding, lowering stocking rate, development and effective utilization of feed resources, and creation of feed banks are some of these strategies.

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Section 5

Production Systems

Chapter 7

Smallholder Goat Production in Southern Africa: A Review

Gracinda Andre Mataveia, Carina Visser and Alcides Sitoe

Abstract

Goats play a crucial role in improved livelihoods and food security in Africa. Indigenous and locally developed types exhibit a wide range of phenotypic diversity, but are commonly well adapted to the harsh environment in which they need to survive and produce. They have various functions in communities in developing countries, from providing food security to being a liquid form of cash and playing a role in ceremonial occasions. The Southern African goat population exceeds 35 million animals, most of which are kept in small-scale traditional production systems in communal areas. These traditional production systems are characterised by informal, lowly-skilled labour, small numbers of animals and limited resources. Most goats are part of mixed crop-livestock systems, where different livestock species and crop farming compliment one another. The productivity and offtake from these animals are relatively low. Some goats form part of agropastoral production systems, with marginally higher management and resource inputs. Both of these systems are dependent on a high degree of variability where the keepers/farmers can exploit various resources as and when necessary. Goats possess a range of adaptive mechanisms that enable them to deal with harsh and challenging environments, making them the ideal species for use in these production systems. This chapter aims to provide background information on the current smallholder management practices of goat keepers in Southern Africa.

Keywords: Communal, smallholder, Extensive, Indigenous Goats, Reproduction

1. Introduction

In Africa, goats are deeply entrenched in almost every African culture [1], particularly within communities that are not able to keep large livestock. Goats offer advantages in animal production as they have a relatively high productivity in harsh environments, use inexpensive feed resources, have a short reproductive cycle and have higher prolificacy when compared to cows [1, 2].

The global goat population has seen a sharp increase over the past decade, and the worlwide population is currently estimated at more than 1 billion animals [3]. Approximately 96% of these animals are meat goats and are found in developing countries in Asia and Africa [4]. Following the global trend, the African goat population has also increased over the last five years to represent 41% of the world's population, and currently approaches 423 million goats. Approximately 35 million of these goats are part of the Southern African population.

Goats have been an important part of humanity since their domestication 10 000 years ago and they have since spread across the globe [5, 6]. Their roles and relative importance are not static but vary according to the agro-ecological zone, production system and socio-cultural context in which they are found [7]. Goats are one of the most important livestock species in developing countries [8, 9]. Their importance hinges on the fact that they provide meat, hides, fibre, and can be milked for home consumption [1, 10, 11]. Goats are also used for socio-economic purposes, such as festive, religious and ceremonial occasions [7, 12, 13]. They play an important economic role, providing cash-flow and being an accessible source of credit in order to meet immediate social and financial obligations [9]. Goats are therefore often described as the "village bank" [9, 14].

Goats and sheep are the preferred livestock species in dry areas due to their ability to convert poor quality pasture into good quality protein for human consumption [15]. Additionally, because of their small size, goats allow the slaughter and consumption of the entire carcass by a family in few days, without the risk of deterioration due to the absence of conserving/cooling facilities in villages of developing countries [1, 16, 17].

Goats have the potential to decrease poverty in Africa due to the role they play in food security. Through the exchange of goats for agricultural labor, they could potentially increase food security for many people in rural areas where crop production is their main activity and source of food [18]. Goat meat can significantly contribute to food security in terms of preserved (dried) protein, as their meat is of high nutritional value, with superior lean characteristics [19]. Furthermore, food security can be increased through exploiting synergies between crops and livestock, using manure and conversion of crop by-products by livestock [20–22]. Livestock plays an important role in the production of staple foods, such as cereals. They provide fertiliser (via manure) and contribute to land preparation by means of draught power. Additionally, they can be sold to generate cash necessary to buy resources for farming practices [20]. Therefore, livestock can contribute to an increase in both the area of land cultivated, as well as the productivity and efficiency with which crops are produced, resulting in the sustainability of farming systems [20]. It is estimated that worldwide livestock manure supplies up to 23% of gross nitrogen input in mixed crop–livestock systems and approximately 12% for cropping in developing countries [23]. Despite these well-known arguments, the real contribution of goats at household level has not been quantified, as most valuation systems depend on monetary standards which only take the financial contribution into account, and frequently neglect the non-monetary contribution of goats. Thus the real contribution of goats to improved livelihoods due to increased food security, especially for poor-resource communities, is unknown [13].

This chapter aims to review smallholder goat production in Southern Africa. A literature review was performed to discuss the importance of the main indigenous goat breeds and the production systems in which they are kept, as well as the constraints faced by goat farmers.

2. Methodology

This review aims to provide background information on the current smallholder management practices of goat keepers in Southern Africa. For this, relevant information from scientific works (literature reviews, original articles, scientific reports, proceedings, and systematic reviews) related to the topic of interest and related keywords (e.g., "smallholder", "communal", "goats", "reproduction", and "extensive") were searched. The review provides a systematic and comprehensive analysis of the findings, strengths, and limitations of the compiled studies.

3. The role of goats in southern Africa

3.1 Importance of indigenous goats

Goats play a vital role in the cultural, social and economic life of rural communities. Indigenous goat breeds contribute significantly to both food security and to improved livelihoods for various resource-poor communities, especially those in rural and hard-to-reach areas [11, 24, 25]. Althought the information on the real contribution of goats to human food security and livelihoods is scarce [26], their role and relative importance varies noticeably across regions and cultural groups. The role of goats is socioeconomic well-being of people in terms of nutrition, income, savings, insurance against emergencies, cultural and ceremonial purposes [7]. Goats are used to help family members, conduct ceremonies and rituals, make linkages with ancestors, pay bride wealth (*lobolo*), and gain social status. Furthermore, goats play a complementary role to other livestock in the utilisation of available feed resources and provide one of the practical means of using vast areas of natural grassland in regions where crop production is impractical [7, 18]. Goats are multipurpose animals which have been bred for milk, skin, hair, and meat. They can provide meat and milk for human consumption and are one of the easiest and most readily accessible sources of income available to meet immediate social and financial needs of village farmers [5, 9, 18, 27]. Goats are also valued for their productivity, adaptation capacity and disease resistance [28].

A survey by Mataveia *et al.* [29] in Mozambique revealed that goats and cattle are used as investments and status symbols. Additionally, they play a pivotal role in traditional ceremonies [8] and generate income among communal households through sales of goats and their products. Improvement in goat production and commercialization have a positive impact on the whole value chain, including processors and marketers [28, 30–33].

3.2 Southern African goat populations and their distribution

According to FAOSTAT [34], during the last decade there was an increase in goat production globally and currently there are more than 1 billion goats, with Africa contributing 36.2%, Asia 58.2%, Americas 3.5%, Europe 1.7% and Oceania 0.4%. In Southern Africa, goats are the second most important livestock species after cattle [13]. Approximately 96% of the world's goat population is kept in developing countries, of which 64% are found in rural arid (38%) and semi-arid (26%) agro-ecological zones [13]. The top-ten countries producing goat meat are all from Asia and Africa; indicating the importance of goat meat to people in resource-poor areas [5]. In Africa, goat meat production has increased from 1.1 million tons in 2008 to 1.3 million tons in 2017 [4]; of which the majority is produced and consumed locally (within households) [5, 35].

The Southern African goat population currently consists of approximately 38 million goats [36]. There are various goat breeds in Southern Africa, of which the Mashona, Matabele, Tswana, Nguni, Landim [13] and Pafuri [29] are the dominant ones. The goat populations in Southern Africa vary between countries: these variations in goats population are summarised in **Table 1**. Tanzania has the highest number with 18.9 million goats while Botswana has the smallest goat population (1.4 m) in Southern Africa [34].

FAO [37] reported that there is approximately 576 goat breeds currently distributed across the world, with 17% of these in Africa. Although goats are found in all types of ecological zones, they are mainly concentrated in tropical, dry zones. As a result of natural selection, goats exhibit a wide range of physiological diversity which results in an ability to adapt to different environments [35]. The main breeds of indigenous goats breed in Southern Africa are shown in **Table 2** (**Figure 1**).

Country	Population (in millions)
Angola	4.7
Botswana	1.4
Malawi	8.9
Mozambique	3.7
Namibia	1.9
South Africa	5.2
Eswatini	2.4
Tanzania	18.9
Zambia	2.9
Zimbabwe	4.7

Table 1.
Number of goats in southern African countries from [34].

Country	Breed	Sources
Angola	Angola dwarf	[38]
Botswana	Tswana	[38–41]
Malawi	Malawi goats	[38, 42, 43]
Mozambique	Pafuri, Tete, Cabo Delgado and Landim	[12, 38, 41, 42]
Namibia	Capriviti, Ovambo	[44]
South Africa	Boer*, Kalahari Red*, Savanna*, Nguni, Tswana, Venda, xhosa, Swazi Zulu and Tankwa	[32, 38, 45–47]
Eswatini	Nguni and Swazi	[13, 38, 45]
Tanzania	Maasai, Gogo, Small East African, Sukuma, Sonjo, Pare, Kunene and Kavango	[48, 49]
Zambia	Tswanaand Matabele	[38]
Zimbabwe	Matabele, Binga, Chipinge, Matopo, Tswane, Shurugwi and Tsholotsho	[13, 38, 41, 50]

**The Boer, Kalahari Red and Savanna are commercial meat-type goat breeds that were locally developed.*

Table 2.
Main indigenous goat breeds found in southern Africa.

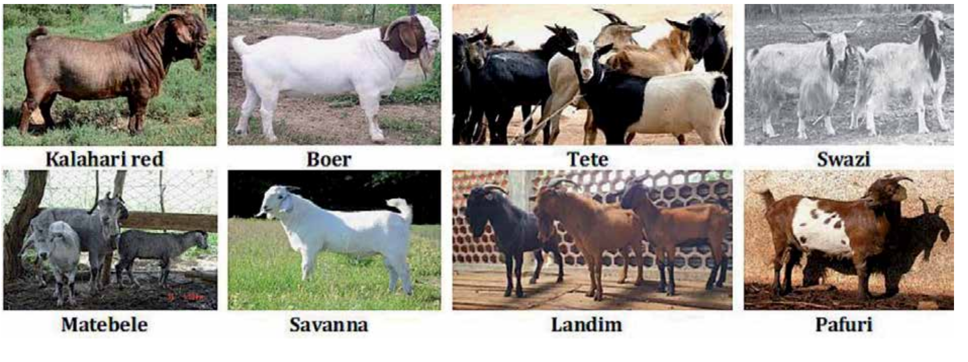

Figure 1.
Some of the indigenous goat breeds found in southern Africa region [51–56].

Breed	Birth		Kid mortality (%)	Body Weight (Kg)							
				Months							
				3		5–6		12		Mature	
	Male	Female		Male	Female	Male	Female	Male	Female	Male	Female
Boer [10, 57, 58]	4.0	3.5	40.6	30–33	22.3	40–50	No	92.0	No	120–140	70–90
Landim [10, 58–60]	2.5	2.3	37.0	9.6	8.2	14.3	12.3	22.0	21.6	50.0	35.40
Swazi [61]	2.0	1.8	30.0	No	No	8.0	No	14.5	No	35.2	30.0
Matabele [8, 13, 62]	2.5	2.5	30.0	No	No	11.3	10.2	18.4	17.5	50–55	39.0
Malawi [13, 43]	2.0	1.8	16.7	9.0	8.9	25.0	No	No	No	29.0	21.0
Pafuri [13, 56]	3.0	2.4	No	8,0	No	10.1	No	16.7	No	60.0	43.0
Tswana [13, 63–65]	4.3	3.6	33.3	13.4	11.4	17.8	16.2	25.39	24.14	44.0	40.0
Kalahari red [66, 67]	2.7	2.0	19.7	9.8	8.3	15.6	12.8	No	No	115	75.0
Savanna [66, 68]	No	No	17.5	30	25	No	No	No	No	No	60.0

Table 3.
Main production parameters of some indigenous goats in southern Africa under communal conditions.

Breed	Age at first kidding (months)	Kidding interval (d)
Boer [57, 71, 72]	15–18.0	234–238
Landim [13, 73, 74]	15–20.0	243–394
Pafuri [73]	15.6	—
Matabele [13, 75, 76]	14–23.0	240
Malawi [13, 77]	15.6–16	330–365
Swazi [61]	11.5	248
Tswana [63]	10.0	365

Table 4.
Doe fertility of indigenous goats in southern Africa under communal conditions.

Table 3 shows the production parameters of some indigenous goats in Southern Africa under communal conditions. Because of their small physical size and superior adaptation traits, indigenous breeds are still preferred in the harsh environments of Southern Africa [10]. According to Sebei et al. [69], the major constraints to goat production are the high mortality rates among kids and slow growth among those that survive. The high disease and parasite challenge and low levels of nutrition contribute to the commonly observed poor growth performance resulting in lower production and reproduction performance [70].

The reproductive performance (age at first kidding and kidding interval) of some indigenous goats in Southern Africa are shown in **Table 4**. Gracinda et al. [60] suggested that supplementing goats with highly nutritive alternative feed sources has a positive effect on physiological functions. Supplementation with lupin grain [78] and soybean meal or corn grain [79], can improve reproduction efficiency by reducing the age at puberty and increasing ovulation rates. Energy deficiency decreases kid growth, and has an adverse effect on reproduction [80, 81]. There is a need to supplement the goats utilising the selected species with energy, protein, and phosphorus to meet the nutrient requirement for maintenance and reproduction [82].

4. Goat production systems

In Southern Africa, small ruminant production systems are classified as traditional (communal) or commercial (intensive) production systems. Most local and indigenous goats are kept in small-scale production systems in communal and resource-poor areas [82]. These systems depend on the exploitation of resources in dry-land areas, and a balance between the livestock's requirements and the environment'al resources [83]. Kaufmann et al. [83], also classifies this system as a "social-ecologogical system".

The traditional production system is characterised by informal labour (mostly from a family member), commonly with low livestock numbers per unit area and minimal use of technology and other inputs [84, 85]. The system is often hindered by land and water shortages, infections and predators [29]. The smallholders generally do not have the skills or resources available for animal recording and there is uncontrolled breeding, often resulting in inbreeding. The traditional production system is further divided into two main production systems, namely the mixed crop-livestock system and the pastoral production system [1, 86, 87].

4.1 Mixed crop-livestock system

The mixed crop-livestock system is used in most member states of the Southern African Development Communities Countries (SADC), including Mozambique [13]. This system is characterised by raising a small number of goats together with other livestock, such as cattle, pigs and poultry. Livestock and crop cultivation are maintained as complementary ventures; e.g. animals provide manure that will be available for fertilising the soil for crop production while livestock in return benefit by feeding on crop residues during the time of feed shortages [87, 88]. This system is characterised by low managerial and financial inputs [89]. It is an extensive farming system, with free-ranging, herding and tethering as the main management systems. This system is used by almost all pastoralists in Africa, where goats are frequently kept in mixed flocks with sheep. Children commonly herd goats, while the day-to-day management and care of young stock usually fall to women [1]. Under this system, animals graze communal land and animal herds owned by different families or individuals move from one area to another for grazing and water [87, 90, 91]. The goats graze over large areas of unwanted or marginal lands which are usually ill-suited for agricultural use [87, 92, 93].

In this system, low-skilled labour (often family members and children) are used as the primary goat handlers. They usually herd goats, sheep and cattle (as well as camels) together to graze wayside or waste vegetation. Management is limited to letting the goats out to graze during the day and confining them at night in enclosures, which are constructed using thorn bushes or wooden poles to protect them from theft and predation [92, 93]. There is no controlled breeding and no supplementary feeding or veterinary care for the animals, except for the extension services provided through government institutions [13]. Due to a shortage of water and forage, malnutrition is the primary limiting factor for profitable production of small ruminants, particularly during the dry season [13]. Goat productivity and offtake rates from these systems are typically low. Shortages in nutrients and exposure to diseases, parasites, as well as challenging climatic conditions with frequent and prolonged droughts are responsible for slow growth, which leads to low productivity [94, 95].

4.2 Semi-intensive or agropastoral production system

The semi-intensive or agropastoral production system is typically encountered in urban and peri-urban areas [88]. In this system, the goats usually graze two to four hours daily and then return to their paddocks. Usually, the farmers returning with the flock at night supply tree leaves and/or grass to feed them until the following morning, when they can graze again [93].

Tethering is a widespread practice of small ruminant management by smallholders in Southern African countries such as Mozambique [29], Zambia [13] and South Africa [57]. This system is used to protect animals from theft and to prevent them from destroying crops and also allows farmers to conduct other activities [13]. Goats are often tethered in the morning and herded in the afternoon when children have returned from school. In this management system, water is provided when the goats are moved to shelter at night and supplementation is limited (i.e. salt or mineral bricks), or absent. The only supplements, (which are provided infrequently) are household scraps, small quantities of grains or their by-products [60].

Both these traditional systems make use of a high degree of variability – in terms of composition and nutritional value of forage, quantity and quality of the water supply, accessibility of supplements, veterinary care and any other resources. The variability is almost seen as an advantage and is used to keep production costs low by strategically selecting available resources at specific time points.

5. Adaptive mechanisms of goats

Approximately 70% of Southern African goats are kept under traditional management systems where the farm structure comprises of about twenty goats [33]. The resultant goat productivity is relatively low due to minimal inputs, poor infrastructure, undefined marketing channels and multiple breeding objectives [29, 96]. Goats are popular and most preferred by smallholder due to their ability to deal with a range of climatic condition including disease challenges, inadequate feed resources and low management [3, 97]. Devendra [98], pointed out the important criteria in Southern African region for the selection of the suitable type of animal to be grown. In the criteria were included the environments (semi-arid and tropical), limited feed resources, differences in energy requirement and digestive efficiency among ruminants.

5.1 The physiological adaptation of goats to harsh environments

Goats are resistant to heat stress, droughts, food and water scarcity as well as diseases; they can maintain production and reproduction performance under harsh environmental conditions. This is in part due to their smaller body size which enables efficient utilisation of low-quality forage and their tolerance to water scarcity and ability to retain superior thermoregulation [38, 99, 100]. Climate change is expected to increase the frequency, intensity and length of droughts with a negative impact on rural areas, especially in sub-Saharan Africa where the human population is mostly dependent on rain for crop and livestock production [101]. However, indigenous goats have developed mechanisms, which allow them to adapt to high environmental temperatures and to achieve thermo-tolerance in extremely challenging environments [38, 102]. These mechanisms include physical, physiological and biochemical changes, such as a reduced feed intake and metabolic heat production [99, 103].

There is ample evidence that livestock and indigenous breeds that evolved in stressful tropical environments have a range of unique adaptive traits that enable them to survive and be productive and reproductive [102, 104, 105]. These goats feed primarily from browsing fodder, as potential sources of affordable feed for ruminants in developing countries. This is especially true during dry seasons, due to the ability of the available foliage to remain green and maintain its protein content, making these fodder potential sources of energy and protein to the goats [39].

5.2 Adaptation to heat stress and drought conditions

Heat stress is an element that negatively affects livestock production and reproduction performance [99]. However, goats are considered less susceptible to heat stress than cattle because of their small metabolic size and their capacity to conserve water [106, 107]. Indigenous breeds of small ruminants in arid zones, such as the black Bedouin goats and Barmer goats herded in the deserts of Sinai (Middle East) and Rajasthan (India), can survive without drinking water for several days, often only drinking water once every four days [107, 108]. Desert goats have been reported to have a superior ability to withstand dehydration, and are considered among the most efficient ruminants in this regard [109]. The biological mechanisms that enables desert goats to cope with droughts depend on their ability to withstand dehydration and to minimise water losses via urine and faeces [99, 108].

Most indigenous goat breeds are physically small which help them to regulate water loss and heat gain in scorching environments [103, 110]. Their colour adaptation of the integumentary system also helps them to reflect heat [103]. Various morphological traits, such as body size and shape [108], coat and skin colour, hair type, and fat storage aid goats in their superior adaptation to harsh environments [103, 106, 111]. Typically, dark-coated animals have higher heat loads than light-coloured ones [112] and the light-coloured coat is deemed superior in tropical regions [113]. Additionally, skin pigmentation provides protection for deep tissues against solar short-wave radiation in tropical regions [114].

Reducing feed intake is another way to decrease heat stress in warm environments as the heat increment due to feeding, especially in ruminants, is a significant source of heat production [115, 116]. Goats are one of the ruminant browsers that suffer least during droughts [117]. This is due to their ability to survive on a diet constituted normally of browsing, which is least affected by the drought [102]. If the drought persists, the carrying capacity of the veld will inevitably fall but it will still be able to support goats longer than other herbivores, such as sheep and cattle, due to the goats' capacity to reduce their metabolism and to maintain this low metabolic requirement [38, 102]. The ability of goats to survive prolonged periods of water deprivation also allows them to graze far from watering sites and to exploit available pastures optimally.

5.3 Adaptation to feed scarcity

The adaptation of goats during periods of feed shortage can be via the following processes: low metabolic requirements, their capability to decrease their metabolism, increased digestive efficiency, an ability to utilise high-fibre feed and the deposition of nutrients in the form of fat as feed reserve [102].

Goats have low metabolic requirements during a period of shortage of natural pasture [38]. They can adjust to a low energy intake by reducing their energy metabolism [108, 118] and are thus able to maintain their body weight in times when food is scarce. A low metabolic requirement is an advantage if the quantity and quality of vegetation are inadequate. The improved temperate breeds are more productive than indigenous tropical breeds if ample high-quality feed is available; however, they lose weight and have increased mortalities when the environment becomes challenging and they must graze on poor quality veld. Under the same circumstances, adapted indigenous animals still grow and other physiological processes continue, such as reproduction and milk yield [102]. The adapted tropical animals recycle nutrients more efficiently than improved temperate breeds and their metabolism is reduced when the animal is losing weight [107].

The ability to reduce their metabolism permits goats to survive even after prolonged periods of severely restricted food availability [38, 102]. Their selective browsing behaviour [108] and an efficient digestive system allow the goats to maximise food intake and scarce nutrients [118]. Adejoro and Hassen [119] showed that the intake and digestibility of low quality foods could be increased by adding urea to that diet. Therefore, there is a favourable association between the improved reutilising rate of urea and better digestion of such food in desert goats.

Silanikove [108] reported the digestive efficiency of indigenous goats and their ability to utilise high-fibre feed. Goats have superior digestive efficiency compared to sheep and cattle when using high-fibre low-quality forages because of the longer mean retention time in the rumen [98, 120]. They can also eat more tannin-rich material and can thus utilise plant species that cannot be consumed by sheep [100, 108]. Goat breeds that are indigenous to semi-arid and arid areas can utilise low-quality high-fibre feed more efficiently than their exotic equivalents and also outperform indigenous sheep and cattle breeds [121]. For instance, indigenous desert black Bedouin goats outperformed Swiss Saanen goats in terms of digestive efficiency when fed on roughage diets in both controlled environments [121] and under natural conditions in a harsh environment [122].

Ruminants accumulate energy in adipose tissues when the quality and quantity of feed is sufficient, and mobilise it to meet energy requirements during periods of shortage [123, 124]. In a tropical environment, the rainy seasons alternate with dry seasons. The capacity to accumulate fat during the rainy seasons for its subsequent use for maintenance and biological functions (like pregnancy and lactation) in the dry season is an essential strategy for survival [124]. The typical vegetation of grass and shrub during the dry and rainy in Southern Africa are shown in **Figures 2** and **3**, respectively.

Figure 2.
A typical vegetation of grass and shrub during the dry season. Source: the figure developed by the authors.

Figure 3.
A typical vegetation of grass and shrub during the rainy season. Source: the figure developed by the authors.

Figure 4.
A herd of veld goats during dry season. Source: the figure developed by the authors.

In Southern Africa, the veld quantity and quality are highly variable and represent the main limitation of livestock production [125]. In addition, the grassland is affected by seasonality, where the dry seasons are generally long and characterised with low quantity and quality veld [81]. A herd of veld goats are shown in **Figure 4**.

6. Conclusion

Most indigenous and locally developed goats in Southern Africa are kept in small-scale production system in communal areas. The goat keepers exploit the severe variability of these systems (in terms of nutrition, water availability, environmental factors and livestock resources) to make strategic choices to keep production costs as low as possible.

Due to their ability to adapt to harsh environmental conditions and different foods, goats can maintain sufficient levels of production and reproduction performance in adverse climates. Goat keepers need to strike a careful balance between human-animal-environment interactions to ensure that goats maintain their essential contribution to the livelihoods of limited-resource populations in developing countries.

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Conflict of interest

The authors declare no conflict of interest.

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Chapter 8

Assessment of Management and Breeding Practices among Indigenous Goat Farmers in a Tropical Humid Forest Zone

Oluwatosin M.A. Jesuyon, Oluwapelumi Boluwaji, Modupe Orunmuyi, Adeolu A. Aganga and Sunday I. Ogunjimi

Abstract

The study was undertaken to assess indigenous breeding practices and structure of back-yard goat farming in humid tropical forest zone. Pretested questionnaires and interview schedules were used to collect information from farmers in Ekiti, South-west Nigeria. Profile assessed were purpose, management, breeding and reproductive performances, disease prevalence, healthcare and challenges. Data were analyzed by descriptive statistics of SPSS, Version 20.0. Bucks run with does on free-scavenging system, mature sexually at 6–10 months, while mature does settle for bucks from about 7 months (52, 44, %). Main goals of farmers were flock multiplication, meatiness and coat color (24, 11, 6, %). Breeding was by natural random mating. Prolificacy was 1–4 kids but resistance to diseases was low. Selection practices were lowly engaged (7.5%), although based on health status and fecundity (19 and 13, %) for bucks and does respectively. Vaccination knowledge was high (77%), but mortality was also high. Drenching, castration and dehorning were performed (47, 24 and 5, %). Official intervention on breeding and improvement was nil. Challenges of farmers were stealing and accidents (46%), diseases and poisons (14%), lack of organized backyard sector, and the poor management system. Intensification of ethnoveterinary practices could promote improved healthcare in backyard goat farming.

Keywords: backyard farmers, breeding targets, selection criteria, management, reproductive capacity, West African dwarf goats

1. Introduction

The livestock sector is highly dynamic globally. In developing countries, it is evolving in response to rapidly increasing demand for livestock products. Historical changes in the demand for livestock products have been largely driven by human population growth, income level, urbanization and the production response in different livestock systems has been associated with science, technology and increases in animal population. In the future, production will increasingly be affected by competition for natural resources, particularly land, water, competition between food and feed; and by the need to operate in a carbon-constrained economy [1]. Developments in breeding, nutrition and animal health will continue to contribute to increasing potential production, higher efficiency and genetic gains. Livestock production is likely to be increasingly affected by carbon constraints, environmental and animal welfare legislation. Demand for livestock products in the future could be heavily moderated by socio-economic factors such as human health concerns and changing socio-cultural values. There is considerable uncertainty as to how these factors will play out in different regions of the world in the coming decades [1]. Small ruminants such as goats and sheep are important sources of meat and cash bank for farmers. Although goats are traditionally raised as back-yard livestock for subsistence among Sub-Saharan African farmers, it is increasingly being marketed. Many rural small ruminant farmers own small ruminants, which are kept for home consumption, sale, and source of manure. Small ruminants are increasingly becoming a major source of animal protein in Nigeria, contributing over 30 percent to total meat consumption. The West African Dwarf goats are commonly kept by farmers in the Rain forest zone. Backyard goat breeding is popular among small-scale farmers for several reasons. It plays significant socio-economic roles in the life of the people: meets the immediate needs of households for meat and milk, useful for ceremonies and festivals, serve as banks of ready cash. Goats survive well in marginal lands and are efficient in converting high quality forage into milk [2] and flesh. The generally accepted problem is said to be lack of feed; either farmers lack an alternative source that provides sufficient feed (by-products, scrubland, etc.), or they are unable to satisfy the nutritional requirements for meat and milk production. An additional problem is selecting goat breed or individuals for each management system, although when farmers have alternative sources of food, they can select local genotypes or high-yielding goat breeds [3]. The humid zone has varying levels of tsetse fly challenge, therefore small ruminant production is limited to breeds that tolerate tsetse fly-transmitted trypanosomiasis. The zone therefore supports trypano-tolerant West African dwarf breeds of goats [4]. Reproductive potential of female animals is measured by the number of young ones produced per year, which depends on age of the animal at first kidding, litter size, kidding interval and kidding rate [5]. Reproductive performance of 2.2 kids/doe/year has been reported among village West African dwarf goats in Southwest Nigeria, while survival index of kids to 90-days was reported as 0.75. Overall mortality of 23.7% has been reported for goats [6]. This survey sought to characterize goat breeding in Ekiti humid forest zone to provide base-line information to proffer adaptable policy recommendations to relevant agencies for goat breeding. The objectives of the study were to:

i. examine flock breeding practices

ii. assess healthcare practices

iii. elucidate problems facing backyard goat breeding in the area

2. Materials and method

2.1 Study area

Ekiti State is in South-west Nigeria. The state was carved out from old Ondo State in 1996 which consists of the former 12 local government areas. It is located between longitude 405.10 and 50 4.51 East of the Greenwich meridian and latitudes 701.51 and 805.10 North of the equator. It covers an area of 6,353 km^2. Vegetation pattern varies with climate and rainfall. There are two ecological zones namely tropical rainforest in the southern, and derived savannah in the northern periphery.

2.2 Data collection

Multi-stage sampling procedures were used to collect the data. First stage involved selection of six communities noted for high concentration of WAD farmers namely; Omuo (7.7573 N and 5.7228E), Isan (7.917 N and 5.317E), Emure (7.4317 N and 5.4621E), Oke-Imesi (7.8167 N and 4.9167E), Ikole (7.7897 N and 5.5106E) and Ayedun (7.6656 N and 5.3103E); all in Ekiti state. Second stage involved selection of 20 goat farmers from each community making total of 120 respondents. Structured questionnaires and interview schedules were adopted. Eighty-Eight (88) questionnaires were returned, with return rate of 73.33%. Data collected included breeding practices, reproductive performance, healthcare and challenging problems.

2.3 Data analysis

Data obtained were analyzed with SPSS v20.0 [7], using simple descriptive statistics of means, percentages, and charts.

3. Results and discussion

3.1 Purpose of farming and breeding objectives of farmers

Table 1 shows the reasons of farmers for engaging in goat farming. These included income generation, hobby, household protein supply, sacrifices and ceremonies (46, 23, 18, 2 and 2%) respectively. Economic reasons predominate the minds of farmers engaged in WAD goat farming. Next was hobby, revealing that many farmers also started out in order to engage their spare time for backyard goat production. About 18% raised goats to supply household animal protein. Thus, the need to nourish the family with adequate animal protein seemed to be gaining ground among Ekiti Farmers. Use of goats for sacrifices and ceremonies were not strong reasons for engaging in goat production among Ekiti farmers. Results shows that the principal reasons for raising WAD goats in Ekiti were to generate profit, get busy and supply household protein need.

Purpose of farming	Farmers' Response	%
Income generation	49	45.8
Hobby	25	23.4
Household protein	19	17.8
Sacrifice	2	1.9
Ceremonies	2	1.9
Others	10	9.3
Total	107	100.0

Note: Total responses exceeded 88 due to multiple responses. Source: Field survey, Own results.

Table 1.
Purpose for engaging in goat farming in Ekiti state.

Table 2 reveals different breeding objectives or goals among Ekiti goat farmers. About 24% breed for flock multiplication to ensure regular income through sales for family needs and welfare. Eleven percent breed for meatiness, while 6% breed for color. Thus, the main targets of backyard goat farmers in Ekiti were to breed for income and profit maximization through flock multiplication, high meatiness and coat color. The common coat colors observed were black, brown, white and mixtures of these colors with white.

3.2 Breeding flock management

About 69% of farmers (**Table 3**) allowed their bucks (males) to run with the does (females) throughout the year on free-range scavenging system, while 9% of farmers allowed their bucks to run with does at specific periods or during the two known seasons of the year. These few farmers thus engaged in controlled breeding.

3.3 Time of breeding

The few Ekiti farmers who practiced controlled breeding (**Table 4**) vary widely in period of practice. About 2% allowed their bucks to breed with Does during the rainy season between April to June, while 5% practiced controlled breeding

Goal	Observed no. of farmers	Percent frequency
Multiplication	21	23.8
Coat color	5	5.7
Meatiness	10	11.4
Body weight	3	3.4
None response	49	55.7
Total	88	100.0

Source: Field survey, Own results.

Table 2.
Breeding goals among WAD goat farmers in Ekiti state.

Method of Running Males with females	Yes	No	None-Response	Total
Buck run with Does all-year round	61 (69.3)	3 (3.4)	0 (0.0)	64 (72.7)
Buck run with Does at periods of the year	8 (9.1)	12 (13.6)	4 (4.5)	24 (27.3)
Total	69 (78.4)	15 (17.0)	4 (4.5)	88 (100.0)

NOTES: Value outside bracket is observed frequency while value in bracket is percentage. Source: Field survey, Own results.

Table 3.
Number of farmers and breeding method in practice in Ekiti state.

Seasonal Period	Rainy Season (April–June)	Rainy Season (May–Oct)	Dry Season (Nov–April)	Total
No of Farmers	2 (2.3)	4 (4.5)	2 (2.3)	8 (9.1)

NOTES: Value outside bracket is observed frequency while value in bracket is percentage. Source: Field survey, Own results.

Table 4.
Percentage of farmers, and seasons in which they practiced controlled breeding of WAD goat in Ekiti state.

between May and October. The third category of farmers (2%) allowed animals to breed during the dry season between November and April. Thus, farmers' breeding season in Ekiti span mainly from April to October.

Farmers claimed that April to June has abundant grass that support natural breeding of goats. Edible crop residues and peels were also available during the harvesting and dry period from November to April, ensuring abundant feed resources for goat production. Since majority of backyard goat farmers were engaged in free-range goat production which promoted extensive uncontrolled free – range breeding. The practice of record keeping and pedigree tracking of kids born was unknown. Inadequacy or absence of housing, and use of informal housing types such as backyard, shed and open spaces, all promote the random mating system.

3.4 Sexual maturity and reproductive capacity of breeding flocks

Sexual maturity stage is also referred to as puberty in the matured doe. From our findings, early maturing males (bucks) begin mounting attempts at 6–7 months (52.3%), while late maturing males begin to mount females at 8–10 months of age (12.5%). Thus at 6–10 months, male goats could be observed fighting and mounting receptive does. Early maturing does begin to settle for mating with bucks from 7 months (44.3%). Thus, average sexual maturity of WAD goats in Ekiti ranged from 7 to 12 months (210–365 days) in both sexes. Late maturity in goats could have been caused by multiple factors such as low level or absence of supplementary feeding, and nutrition by farmers, low healthcare and low level general management. The average onset of puberty in WAD goat was reported as 141 days in Cameroonian dwarf goats of Croatia but varied with season [8]. It was recommended that does should be mated at 12 months and 20 kg body weight at first breeding [9], while sexual maturity age of 15–18 weeks [10] and 6–7 months [11] had been reported for male and female WAD goats. Our findings support the early sexual maturity age of 6–7 months reported in literature.

Kidding Interval is the interval between successive births in reproductive does. Kidding interval of 4–7 months (64%) was reported by farmers, although majority tilted towards 6–7 months. This was lower than the kidding interval of 7.3 to 9.4 months [12]. WAD goats in humid areas also exhibit shorter kidding intervals compared to other areas of the tropics probably because of the relative abundance of feed resources all year round. Mean kidding interval of 247 days (8.2 months) for WAD goats under formal breeding station management has been reported [13].

Parity is the number of times a Doe gives birth to kids in a year. Claims varied among farmers interviewed. 62.5% of farmers reported 1–2 kidings per year, while 12.5% reported 3 parities in 2 years. We noted that very prolific does could kid up to 3 times in 2 years. Since farmers did not keep formal record system, a doe that kidded in January and latter in October were easily taken as having kidded twice a year.

Prolificacy is the average number of young ones in each litter after birth, and also known as kidding rate. Nine percent (9.1%) of does gave birth to 1 kid at first kidding (parity). 48% of goats gave birth to 2 kids at second parity, while occurrence of 3 and 4 kids per litter at kidding were 13.6% and 15.9% respectively. The multiple births occurred as does progressed in their reproductive life-span, especially if doe flushing was done. Does become more prolific as they progressed to peak of their reproductive life, while bucks become more sexually active and experienced in mounting reluctant does. In humid environments, does are exposed to abundant feed resources during the harvesting period, and usually produced multiple births than those bred during other periods. Average litter size range of 1.42–1.79 kids had been reported [14, 15] at weaning. But the mean litter size was

2.07 for Sidama goats in Ethiopia [16], while [17] reported 1.86 weaned kids per litter but [18] reported average prolificacy of 4.64% for WAD goats.

Fecundity is the potential or the natural ability to reproduce, or the number of kids that a female goat gives birth to. It is also referred to as Kidding percentage. It is the average number of kids born by each doe in a year. Fecundity could best be estimated for indigenous free-ranging goats by summing up all surviving kids born by a doe in two years and dividing by 2 to obtain a mean, or it could be expressed as total number of kids born in two years. Mean fecundity of 91–130% had been reported for WAD goats under savannah conditions [19]. Both Prolificacy and Fecundity could be classified into low, medium and high categories for WAD does in humid tropics.

3.5 Kid nursing and management

Young goat kids were nursed and suckled by their nursing does for variable number of weeks. Experienced farmers (31%) allowed does to nurse kids for 4 to 6 weeks, while majority (60%) of farmers allowed kids to be suckled for 7–12 weeks before withdrawing the kids and re-breeding the does. Observations revealed that nursing does weaned kids naturally. This was accomplished by delivering frequent kicks to kids attempting to suckle. Thus, a pregnant doe back-kicks when nutritional demand of kid nursing, growing foetus, and own physiological maintenance are becoming too high to support. Few owners provided supplementary concentrate feeds to pregnant does at this period to support body and foetal development, and prevent abortion.

3.6 Selection practices and criteria

Knowledge on selection was known to about half (47%) of goat farmers but was only practiced by 7% for male breeders (bucks). Selection entailed making deliberate choice among males in the backyard flock, purchase of desired males (2%), or borrowing males from other farmers. This third option was not widespread among farmers because of the system of management which permits random mating of bucks with does (**Table 5**).

The use of purposeful selection criteria was low due to inadequate education and knowledge. Only 38% of farmers employed meaningful selection criteria on males and females in flock.

Table 6 lists the main selection criteria used for breeding in Ekiti. Selection in bucks was mainly based on health status and coat color (13 and 10, %); but on fecundity and coat color (19 and 9, %) in does respectively. These traits were easy

Male Selection	Yes	No	None Response	Total
Knowledge of Selection for goats	41 (46.6)	41 (46.6)	6 (6.8)	88 (100)
Selection of male within flock for mating	6 (6.8)	37 (42.00	47 (51.2)	88 (100)
Purchase of new males for mating	2 (2.3)	41 (46.6)	45 (51.1)	88 (100)
Borrow males for mating	0 (0.0)	43 (48.9)	45 (51.1)	88 (100)

NOTES: Value outside bracket is observed frequency while value in bracket is percentage. Source: Field survey, Own results.

Table 5.
Male selection for breeding among WAD goat farmers in Ekiti state.

Selection criteria/Sex	Male	Female	Total
Maturity Status	5 (5.0)	2 (2.3)	7 (3.9)
Flock record	4 (4.5)	3 (3.4)	7 (3.9)
Coat color	9 (10.2)	8 (9.1)	17 (9.7)
Health status	11 (12.5)	4 (4.5)	15 (8.5)
Fecundity	3 (3.4)	17 (19.3)	20 (11.4)
None response	55 (62.5)	54 (61.4)	109 (61.9)
Total	88 (100.0)	88 (100.0)	176 (100.0)
Average involvement in selection	6.4 (7.3)	6.8 (7.7)	13.2 (7.5)

NOTES: Value outside bracket is observed frequency while value in bracket is percentage. Source: Field survey, Own results.

Table 6.
Selection criteria used for breeding WAD goat by farmers in Ekiti state.

to observe without having to keep performance records. About 63.3% of farmers did not engage in purposive or organized selection, since flocks were permanently scavenging on the free-range. However, farmers readily cull sick bucks (12.5%) for sale or consumption, while retaining does for breeding. Average practice of selection for WAD management and breeding was 7.5%, while the none-response of 62% revealed the population of farmers un-involved in formal goat selection. The none-use of flock records for management, selection and improvement are main reasons for the slow pace of WAD goat development in Ekiti.

3.7 Breeding practices

Sires (**Table 7**) were used for breeding for variable number of years before disposal. 26% of farmers used them for 1–2 years, while 11% used desired and highly reproductive bucks for 3–8 years before disposal. Does were used till old-age. More than 63% of farmers gave no response on the number of years they kept breeding bucks, partly because they did not keep male goats but depend on random field mating. Sixty-nine percent (69%) of farmers (**Table 8**) engaged in pure breeding by mating of pure WAD male to pure WAD females within breed in the environment, through random mating. Sixty-one percent (61%) of farmers allowed their bucks and does to run together on free-range, while about 15% bred does in enclosed-yards.

	Years	Observed	% Farmers
Number of years for using Sires for breeding before sales	1 yr	14	15.9
	2 yrs	9	10.2
	3–4 yrs	4	4.5
	8 yrs	5	5.7
	None-response	56	63.5
	Total	88	100.0

Source: Field survey, Own results.

Table 7.
Number of years for using male WAD goats for breeding females before disposal.

Breeding Practice	% Yes	% No	% None Response	Total
Kept Females in an Enclosure or yard	13 (14.8)	34 (36.6)	41 (48.6)	88 (100)
Allowed Males to run with Females freely (Random mating)	54 (61.4)	3 (3.4)	31 (35.2)	88 (100)
Pure breeding	10 (11.4)	17 (19.3)	61 (69.3)	88 (100)
Line Breeding	4 (4.5)	18 (20.5)	66 (75.0)	88 (100)
Crossing within breed	2 (2.3)	58 (65.9)	28 (31.8)	88 (100)
Use of Artificial Insemination	2 (2.3)	79 (89.8)	7 (8.0)	88 (100)

NOTES: Value outside bracket is observed frequency while value in bracket is percentage. Source: Field survey, Own results.

Table 8.
Indigenous breeding practices among backyard WAD goat farmers in Ekiti state.

3.8 Linebreeding and crossbreeding

Line breeding involves breeding to a desired individual in a herd. This was only practiced by 5% of farmers, about 21% gave negative response probably due to lack of knowledge, and neither practiced controlled breeding nor confined housing; while 69% farmers remaining did not respond. Observation showed that most farmers attempted line breeding to a desired male, which runs with does in flock but most times on the free-range. Therefore, the paternity of subsequent progeny was doubtful. Crossbreeding was known and practiced by 2% of farmers. Methods employed included male exchange (10%), purchase of new male (4%) or borrowing of new male from distant farmers for mating own flock (1%). Mating was usually random within herd and neighborhood (>25%) and not organized, while only 3% of farmers employed mating ratio of 8–10 does per male in the survey area. This implied that breeding practice was highly unorganized and random, with high level of in-breeding.

3.9 Artificial insemination

Two percent of the goat farmers practiced artificial insemination (AI) either by themselves, by veterinary technician or extension officer. Majority (90%) of farmers did not engage in AI because 50% of them were unskilled and lack knowledge of AI. Moreover, it was expensive for about 3% of farmers, 2% had no facility to perform it on-farm, while 1% lack interest. The regular AI practitioners were extension workers and veterinary technicians who had skilled training and had practiced for several years, and performed the operation for other farmers who requested it (**Table 9**).

Culling was practiced by 46% of farmers as a WAD management practice (**Figure 1**). Criteria employed were old-age, economic (profit), infertility and natural destructive tendency (37, 5, 3 and 1%) respectively. Field observation showed that culling was popularly practiced by farmers who would rather remove 'unproductive' and troublesome animals. Culling helps to maintain genetic purity of backyard stock but the gains were usually canceled out by random mating with out-of-flock males during scavenging on free-range.

Figure 2 reveal the methods of management of unselected individual does and bucks. Culled does were managed by selling, consuming at home, given out as gift and lease out for contract rearing (33, 9, 5, 1%); while bucks were disposed mainly by sales and consumption (36 and 15%). Market observation revealed that majority

Disease	Observed	% Prevalence
Skin mange	50	56.8
Diarrhea	8	9.1
Ectoparasites	6	6.8
Intestinal parasites	10	11.4
Cold	2	2.3
Goat Flu	1	1.1
PPR	1	1.1
None response	10	11.4
Total	88	100

Source: Field survey, Own results.

Table 9.
Prevalent diseases of WAD goats in Ekiti state.

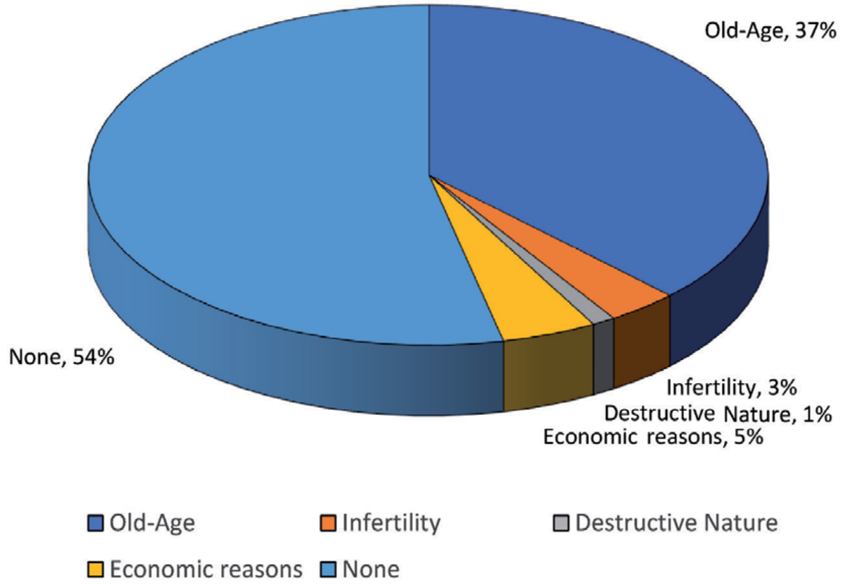

Figure 1.
Percentage of farmers and culling criteria practiced on WAD goats in Ekiti state. Source: Field survey, Jesuyon et al. 2021.

of goats offered for sales were primarily due to illness; and although treated for a period but failed to respond to treatment. These were presented in local markets for sale when considered safe for consumption.

3.10 Drenching and dipping

Drenching is the act of giving a broad-spectrum endo and ecto-parasitic drugs and intradermal injections to ruminants to deworm and delouse them. Drenching was practiced by 47% of farmers although the frequency of operation was not determined by survey instrument. About 14% of farmers interviewed used broad-spectrum ecto and endo-parasitic injections such as ivermectin, DDT powder for oral skin dusting, pour-on liquid chemical applied to the spine-line, and formal engagement of veterinarians where available and affordable. Dipping in acaricides' chemical-solution pool was rarely used for goats.

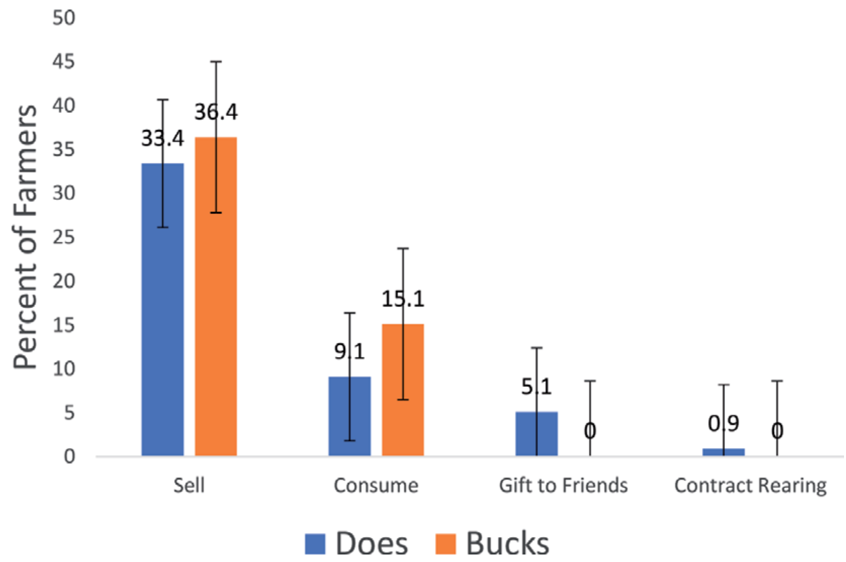

Figure 2.
Management of unselected goats for breeding in Ekiti state (with standard error bars). Source: Field survey, own results.

3.11 Castration

Twenty-four percent (24%) of farmers carried out castration for surplus males while 65% did not engage in castration due to health, religious (Islam, 1%) or customary reasons. Castration was conducted by some technically oriented farmers (2%), technical animal health assistants (TAHA, 2%), and veterinary workers (23%). Fourteen percent (14%) of farmers did castration at 2 months of age. Ten percent (10%) conducted castration of male at 2 weeks of age, while 2% of farmers did castration at 4–6 weeks of age. The late castration exercises were more painful for grown-up kid bucks. Investigations also revealed that 45% of farmers claimed ignorance of the benefit of castration, while 2% indicated lack of interest in castration probably due to religious or customary reasons.

3.12 Dehorning

Interviewed WAD goat farmers did not engaged in dehorning. Some 47% of farmers did not believe in the benefits of dehorning. About 6% believed that goats need the horns for protection from predators, for defense and offensive purposes. 1% of farmers would not consider dehorning for religious reasons. Muslims require perfectly intact animals without physical defects such as crooked legs, defective eyes, injuries, defective scrotum, broken horns etc. for religious celebrations, although would prefer sheep for religious celebration. Observations on the field revealed that most horns on goats got damaged due to frequent fighting among mature bucks and fragility of the horns.

3.13 Disease prevalence and treatment

Mortality occurred most during the rainy season (10%), and was lower in the dry season (3%) but generally at any time of the year (7%). Diseases that ranked highest were skin manges, intestinal worms, goat diarrhea and ecto-parasitic infestations (57, 11, 9 and 7, %). WAD goats were usually treated either by owner farmers using local knowledge of ethnoveterinary medicine (18%) by a veterinary/extension/technical staff (69.3%) or by farmers' friends (1.1%). Samples of dead animals were rarely sent for post-mortem examination at veterinary clinic or laboratory for investigations/post-mortem examinations because veterinary clinics were non-existent in most farm communities. Only 9% of farmers investigated causes of mortality and invited technical staff or veterinarian to the backyard to investigate causes of death; but only 2% of farmers sought feedbacks from the laboratory or veterinary officer. About 75% of goat farmers did not consult veterinarian for examination, for lack of appreciation of the need (23%), lack of money for such elaborate investigations (2%), or considered it as waste of scarce resources (1%). As a result, endemic and zoonotic diseases festered in backyard flocks due to neglect, lack of proper disposal and handling of dead animal, and inability to recognize the signs of such diseases.

3.14 Disease prevention and healthcare provision

Seventy-seven percent of farmers had some knowledge of veterinary treatment and vaccination (**Table 7**). About 55% accessed veterinary services for treatment of their animals, while 21.6% of them could not probably due to distance to veterinarian, non-availability and high cost. Seventeen percent (17%) never engaged in regular prevention and healthcare provision. This group of farmers were reluctant to vaccinate due to high cost of veterinary services per head of goat. Even after reported vaccinations, 16% of farmers still incurred deaths from diseases claimed to have been vaccinated against in the wet season; while 45% did not record such death among treated animals. These deaths might be due to improper vaccination techniques, wrong diagnosis or late application. Farmers did not have formal health and vaccination records or programme in place for their flocks, because of the small number kept (8–12 goats per household), the highly dynamic and continuously changing structure of flocks due to natural and human decimating factors. Findings showed that employment of high level hygiene, dry atmospheric conditions, timely and proper vaccination, and good nutrition could reduce death of kids among flocks. Despite the perception of high resistance of WAD goat to diseases, this was rated by farmers as low (9–14%), but as inverse of disease occurrence, resistance to disease was deduced at 30% among less-closely interacting flocks under freely-scavenging management system in backyard farms (**Table 10**).

Health and management Practice	Yes	No	None-response	Total
Awareness and knowledge of veterinary treatment and vaccination	68 (77.3)	15 (17.0)	5 (5.7)	88 (100)
Access to veterinary services	48 (54.5)	19 (21.6)	21 (23.9)	88 (100)
Use of veterinary and advisory services	40 (45.5)	19 (21.6)	29 (33.0)	88 (100)
Drenching (deworming) of animals	41 (46.6)	31 (35.2)	16 (18.2)	88 (100)
Dipping of animals	12 (13.6)	49 (55.7)	27 (30.7)	88 (100)
Castration of males	21 (23.9)	57 (64.8)	10 (11.4)	88 (100)
Dehorning of males	5 (5.7)	76 (86.4)	7 (8.0)	88 (100)
Average use of management practices	34 (43.6)	38 (36.0)	16 (20.4)	88 (100)

NOTES: Value outside bracket is observed frequency while value in bracket is percentage. Source: Field survey, Own results.

Table 10.
Health care and management practices among goat farmers in Ekiti state.

3.15 Use of veterinary advisory services

About forty-six percent (46%) of farmers adhered to veterinary or extension workers' advice, 22% did not keep to such advice, while 32% were unconcerned about veterinary advice. There was a high level of farmer disregard for professional advice, but depend on age-long traditional methods of treatment. This scenario could be improved, by official encouragement and teaching of ethnoveterinary practices which are easily understood, cheap and embraced by farmers. Farmers' healthcare delivery to backyard goats was thus considered low compared to the required standard for high productivity.

3.16 External intervention on management, breeding and improvement

No formal institution was reported to be engaging farmers on goat production, improvement and conservation. Thus, deliberate and visible external intervention on indigenous goat farming was lacking. There was no reported case of governmental or non-governmental organization (NGO) aiding or supporting goat farming, or showing concerns on conservation and utilization of West African Dwarf goats. Findings revealed an age-long traditional attachment of the people to the breed. The customary and traditional values placed on WAD goats by the people ensured continued production, utilization, preservation and conservation of the breed. These factors combined to ensure the breed's continued production, existence and prevented its extinction.

3.17 Problems facing backyard goat breeding

Study revealed that goat production and breeding was conducted on free-range scavenging system. Farmers were inadequately skilled and equipped to carry out most technical breeding and management techniques to achieve high productivity and improvement. The most striking challenge before farmers was stealing and accidents (46%) leading high losses of goats and diseases (14%). Lack of adequate housing and range facility was also observed (6%). The scavenging system must be replaced with better systems such as backyard-confinement goat production system, mixed-farming with animal paddocks that focus on enterprise integration, resource recycling and efficient utilization, adoption of adaptable technology and sustainable goat-farming practices. The use of these approaches to solving these three major problems of farmers would boost productivity and improvement of WAD goat in Ekiti (**Table 11**).

Challenges	Response
Stealing and Accidents	40 (45.5)
Diseases and Poisons	12 (13.5)
Lack of confinement	5 (5.7)
Lack of feed and inadequate care	2 (2.3)
Inadequate cash for management	2 (2.3)
Lack of official and external assistance	1 (1.1)
None-response	26 (29.5)
Total	88 (100.0)

Source: Field survey, Own results.

Table 11.
Problems and challenges facing backyard goat farmers in Ekiti state.

4. Conclusion

High reproductive performance among indigenous WAD goats could be achieved through improved feeding, good housing system, paddocking of animals and adequate ethno- and or veterinary care to reduce mortality, losses, and thus improve prolificacy. Optimum management of the backyard goat would require adaptable technical innovations, training of farmers and extension service. The high percentage of farmers who did not answer some of the questions posed in survey instrument also provides important information for both researchers and Ekiti state authorities that could benefit from these findings. These results also call on the state authorities to put in place policies that may enhance significant goat farming productivity, continuous training and information for goat keepers and other livestock farmers.

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Conflict of interest

The authors declare no conflict of interest.

Notes/thanks/other declarations

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Chapter 9

Characterization of Native Goat's Production Systems in Eastern of the Democratic Republic of Congo

Bwihangane Birindwa Ahadi

Abstract

Phenotypic characterization of goats is an important step in the breeding sector, recognition and selection of breeds. This study assessed the various biometric morphological characteristics of goats in different farming systems in Eastern of Democratic Republic of Congo. A total of 90.6% of farmers practice goat's free range. *Imperata cylindrica*, banana leaves and avocado nuts with the respective percentages of 100; 70.4 and 64.5 are the most common feeds for goats. Goats reared in sheds have an average body size at the withers (55,5 cm), a large weight (24 kg) and a large body length (80.1 cm) and livestock systems significantly influenced the total goats body length (p-value 0.03404 at 5%). The weight of adult goats is increasing in proportion to the length of the head (0.38), ears (0.01), tail (0.19), body (0.22), and chest circumference (0.66). Adult male animals have a bright higher average body size (26 kg) than females (21,8Kg). Almost 97% of investigated goats had tails and horns.

Keywords: Diversity, goat productivity, phenotype, DRCongo

1. Introduction

Goats are among the most common farm animals on the Earth and their genetic evolution since domestication is the basis of their broad distribution and adaptation [1]. The potential to survive under environments with high natural constraints or the rugged topography make the goat an appreciated and favored breed for livestock [2]. Goat also plays an important role in food production systems in developing countries. Goat rearing is an integral part of the lives of many people [3].

Socio-economically, goat rearing requires modest start-up capital for investment and savings are easily mobilized. Also, it is better suited to the economic regime of the local population and facilitates market access [4]. Taking into account the morphology of characters in a selection scheme requires the consideration of multiple interests. On one hand the aim is to act on the functional longevity of animals, reducing the frequency of preterm-related reforms morphological original default, to limit production costs that result. Furthermore, it facilitates the work of the farmer by reducing the time spent in the milking parlor and can act on udder health, particularly breast morphology [5]. The selection of goat rearing for specific purposes such as the production of milk or meat involves taking into account the morpho performance metrics of the animal [3]. Despite the importance of the goat to the peasant economy, data on the performance of low altitude goats bred in South Kivu are unknown and nonexistent. This study aims to evaluate the different morphological characteristics (measurable or not) of goats reared in different farming systems at low altitude in the province of South Kivu in order to enhance knowledge of local strains for performance and facilitate the work of higher breeding.

This study which was conducted in South Kivu province for a fourteen-month period has a double interest. From the point of view of socio-economic knowledge of morpho-metric characteristics of local native goats (*Capra hircus*), it gives a general idea of the performance for slaughter, productivity and subsequent selection plane breeds in accordance with the expected goals. Scientifically, it gives an understanding of the performance of the local breed and serves as a database for subsequent improvements of goats rearing in South Kivu.

2. Materials and methods

2.1 Geo- climatic characteristics of the study environment

This study was conducted at the eastern part of the Democratic Republic of Congo, specifically in South Kivu province, one of the provinces deemed agro pastoral areas of the country. South Kivu is imitated in the north by the province of North Kivu, Katanga to the south and west by the Maniema, South Kivu shares borders with eastern Rwanda, Burundi and Tanzania. It has a vast landmass of 66,814 km^2. South Kivu is located at 00′ 58′′ North latitude, 4° 51′ 21′′ South latitude and 26° 10′ 30′′ - 29° 58′ East longitude. The relief prevailing in South Kivu is characterized by mountains that reach up to 3,000 meters above sea level and decrease progressively westward. The hydrographic system of the province of South Kivu consists mainly of Lake Kivu, the Ruzizi River and Lake Tanganyika in the east as well as numerous rivers and streams, most of which are drained from east to west [6].

Most of the animals found in the province are chickens, rabbits and guinea pigs (often held by young people). Ovine, stoning, swine and cattle are sold especially by farmers in times of great necessity and during important festivities. The animals are acquired largely from nearby markets. The number of bred or kept animals per household is very low (on average 3 goats with large disparities). Also, much of the people raise goats for family subsistence etc.

Following the long civil war which resulted in the looting and killing of many cattle in this part of the country, goats have remained today a source of revenue for most of the people. It is called a "cow of the poor" [7].

2.2 Materials

The living material used in the study was local native goat animals on which was done all the barometric analyses to assess performance metrics and phenotypic. The tape was used for the measurements of chest circumference, length of the animal, etc. The scale was used for direct measurement of body weight of the animal; calipers were used to measure the length of the ears, horns and tail, while GPS (Geographic Position System) was deployed for collecting geographic coordinates. The survey questionnaire was used to collect data on the systems of rearing and feeding.

In a total of 341 native goat's sampled, 30% were males and 70% where females. In overall 10% of all sampled animals were unweaned kids (out of which 50% of males and 50% females), 20% pregnant females aged from above 12 months, 30% were none pregnant female aged from above 12 months and rest 40% were animals aged with less than 12 months.

2.3 Methodology

A combination of the descriptive and historical methods was used to describe the study medium and the goat farming structure in this region. Documentary and interview modalities were also used to collect data on the different goat farming methods in the study area. The body measurements such as height, girth or chest circumference, the lateral length of the body of an animal, length of the head, horns, ears, etc. were taken after holding the animal by hand. To evaluate the live weight of the animal using a scale, the goats were carried in the arms of someone who climbed on the scales. The difference between the initial weight (PI) and the final peas (PF) gave the body weight (BW) of the animal. The following formula was applied:

$$\mathrm{PV}(\mathrm{Kg}) = \mathrm{PF}(\mathrm{Kg}) - \mathrm{PI}(\mathrm{Kg}).$$

With: PI: Initial weight of the animal without someone caring the animal of hands.

PF: Initial weight of man with animal mobilized in his arms.

PV (Kg): Live weight of animal.

Statistical analysis was done using Statistix, R and SPSS software after data encoding in Microsoft Excel 2010.

3. Results and discussion

3.1 Livestock systems

Table 1 below shows the various systems of rearing goats in South Kivu. From **Table 1**, we find that among the goats rearing systems practiced in South Kivu, almost 90.6% of farmers practice straying, while 7.9% are attached Stake. A small number of 1.4% or less recourse to the house with zero grazing goats is observed. This would lead to the risk of uncontrolled coupling which in turn can generate cases consanguinities leading to high mortality rates. The calculated p-value (0.068) is greater than the significance level (alpha: 0.05), we conclude, therefore, that the production site does not influence the choice of breeding system adopted by farmers.

Territories	Attached on stick	Free grazing	Zero grazing	Khi^2	P-value	Total
Mwenga	15	114	1	3,97	0,068	130
Fizi	7	102	3	—	—	112
Kabare	5	93	1	—	—	99
Grand total	**27**	**309**	**5**	**3,97**	**0,068**	**341**

Table 1.
The goats of livestock systems in the three territories of South Kivu.

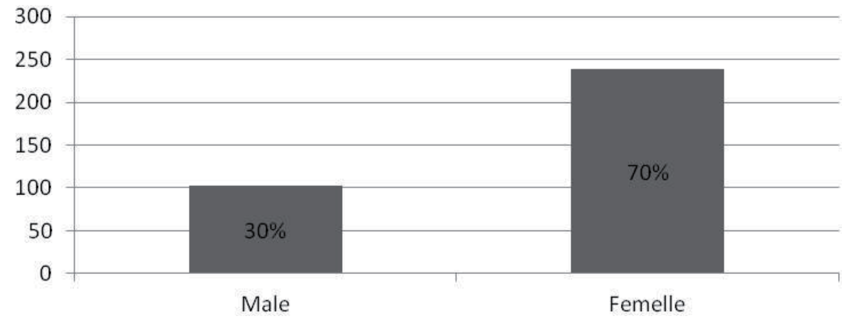

Figure 1.
Distribution by sex of the animals in the study area.

3.2 Goats sex ratio in the study area

Figure 1 above illustrates the relationship between the male and the female in the kennel capricole in South Kivu. Based on **Figure 1**, we see that at all surveyed 341 goats, females constitute a large percentage 239, representing 70%, of the population, while males constitute 108 or 30%). This gives us a gender composition and a sex ratio of about 1/3.

3.3 Goats food

The kinds of food served daily to goats bred in South Kivu are shown in **Table 2** above.

Data in **Table 2**, indicates that all 341 breeders representing 100% of the population feed their goats with Imperata cylindrical; 240 of the breeders (70.4%) use banana leaves; 220 use avocado nuts (64.5%); another 101(29.6%) use Titonia diversifolia; 92 others (27%) use *Tripsacnm million*; 22 farmers (6.5%) use *Foxtail sphacelata*; while 24 others (7%) use *Hairy Bidens*. Only 12 of the breeders (3.5%) use salt lick.

3.4 Characteristics of livestock

Table 3 above presents the different characteristics of the surveyed livestock goats in the different production systems in South Kivu.

No.	Daily Food	Daily (n = 341)	Percentage (%)
1	*Imperata cylindrica*	341	100
2	Banana leaves	240	70,4
3	Avocado Nuts	220	64,5
4	Titonia diversifolia	101	29,6
5	Tripsacnm million	92	27
6	Foxtail sphacelata	22	6,5
9	Hairy Bidens	24	7
10	Salt (lick)	12	3,5

Table 2.
The most rationing administered to the goats in the South Kivu.

Training System	Size Withers (cm)	PV (Kg)	Length body (cm)
Zero grazing	55.5	24.0	80.1
Attached on stick	53.2	23.6	74.2
Free Grazing	48.3	22.1	72.0

Table 3.
Average values of the height at the withers of goats bred in South Kivu by farming system.

Table 3 indicates that goats that are raised in stalls have great height at the withers (55,5 cm), a large weight (24 kg) and a long body length (80.1 cm). However those attached to the stake have an average wither height of 53.2 cm, a live weight of 23.6 kg and a total body length of an average of 72,2 cm. Finally, those that are of high scavenging barometric had lower performance compared to the first two above described livestock systems with a size at withers average of 48.3 cm, adult live weight of 22,1Kg with a total length of 72 cm.

The results of the statistical analysis showed that livestock training systems do not significantly influence statistically on height at the withers. (p-value 0.059) is greater than the significance level 0.05. By contrast, livestock training systems significantly influenced the total length of goats body (p-value with Khi2 0.03404 and p-value 0.04265 with Kruskal-Wallis) to the same level of significance of 5%. Whatever be the found statistical values biological differences that need homes for senior statistical parameters measured it.

3.5 Sexual dimorphism

The live weight of male goats compared to females in adulthood are shown in **Figure 2**.

It shows from this **Figure 2** above that male adult animals have a higher live weight surrounding medium (26 kg) than female animals (21,8Kg). It can therefore be said that gender influences the live weight of the animals. This observation is made for the value of the p-value 0.0032 which is below the 5% significance level.

The data of **Table 4** shows that some parameters studied are positively correlated with the length of the head. Among these parameters are: wither height

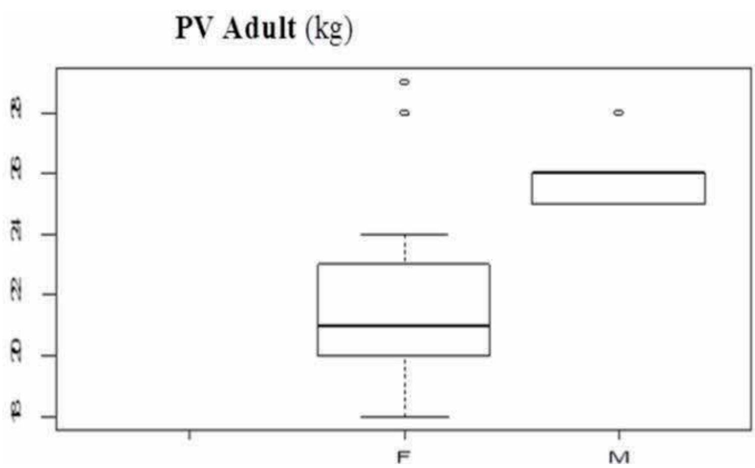

Figure 2.
Box-plot of the variation of body weight of goats classified by sex in South Kivu.

Length of Head/Correlations	
Size of withers	1.00
Length of ears	0.23
Length of thorax	0.38
Length of Tail	−0.07
Length of body	0.03
Length of horn	0.03
PV or Body weight of adult	−0.02
PV withdrawal	0.21

Table 4.
Correlation between measured parameters and the length of the head in goats in South Kivu.

(0.11), the length of the ears (0.23), the chest circumference (0.38), body length (0.03), the length of the horns (0.03) and live weight of weaned animals (0.21).

The measurement of these statistics by some parameters has shown there is a negative influence; that is, when they increase, the length of the head decreases and they decrease when the length of the head augments. These are: chest circumference (−0.07) and live weight of adult animals (−0.02). This data makes no biological sense but are rather statistical.

The data in **Table 5** signifies that when the chest circumference increases there is increase in wither height (cor 0.38), the length of the head (cor 0,43), length of ears (cor 0.09), the length of the body (cor 0,49), the live weight of adult animals (cor 0.66) and live weight at weaning (cor 0.33). In short, the correlation between the thoracic circumferences and these other parameters mentioned is positive.

By contrast, when the chest circumference increases, the length of the tail and the horns do not increase. This indicates a negative correlation of these with the chest circumference. In addition, the correlation between the length of the tail and the size at the withers (−0.07), the length of the head (−0.04), the thoracic circumference (−0.03), the length of the body (−0.09), the length of the horns (−0.26) and live weight at weaning (−0.31) is negative, while the length of the ears (0.06) and live weight of adult animals (0.19) is positive.

	Thorax length (Cm)	Length of Tail (Cm)	Body length (Cm)
Size of withers	0.38	−0.07	0.03
Length of head	0.43	−0.04	0.55
Length of ears	0.09	0.06	−0.21
Length of thorax.	1.00	−0.03	0.49
Length of Tail	−0.03	1.00	−0.09
Length of body	0.49	−0.09	1.00
Length of Horns	−0.23	−0.26	−0.16
PV adult	0.66	0.19	0.22
PV withdrawal	0.03	−0.31	−0.08

Table 5.
Correlation between the length of the body of the tail, body and other parameters measured in goats in South Kivu province in the DRC.

	PV adult	PV withdrawal
Size withers	−0.02	0.21
Length of Head	0.38	0.24
Length of Ears	0.01	−0.21
Length of thorax	0.66	0.03
Length of Tail	0.19	−0.31
Length of body	0.22	−0.08
Length of Horns	−0.56	0.02
PV adult	1.00	0.14
PV withdrawal	0.14	1.00

Table 6.
Correlation between body weight of adults, the live weight at weaning and other parameters measured in South Kivu goats.

Finally, the length of the body is positively correlated with the size of the withers (0.03), the length of the head (0.55), the thoracic circumference (0.49) and live weight of adult animals (0,22), while the negativity occurs when the body has a length correlated to that of the lugs (−0.21, the tail (−0.09), the horns (−0.16) and live weight of weaned animals (−0.08).

It is seen from **Table 6** that the live weight of mature animals is increasing in proportion to the length of the head (0.38), ears (0.01), tail (0.19) the body (0.22), the thoracic circumference (0.66) and live weight of weaned animals (0.14), the correlation is positive. Measured against the one with the size of the withers (−0.02) and the length of the horns (−0.56), this is negative, which means that its growth is disproportionate with respect to these two parameters.

Similarly, a positive correlation was observed between live weight at weaning with wither height (0.21), the length of the head (0.24), the chest circumference (0.03) and the length of the horns (0.02), while with the length of the ears (−0.21), the tail length (−0.031) and the body length (−0.08), it is negative.

3.6 Phenotypic characterization

From **Table 7** below, we find that over 97% of respondents had goats with tails; 87.39% owned goats with horn as against a small percentage of animals investigated

Parameters observed	Male		Female		Total	
	Freq.	%	Freq.	%	Freq.	%
Tail	99	97	233	97, 48	332	97,36
Horn	80	78,4	218	91,2	298	87,39
Pendants	5	4,9	6	2,5	11	3,23
Tassels	6	5,88	4	1,67	10	2,93
Empty sub-sternal	10	9,8	20	8,37	30	8,8

Table 7.
Frequency of some parameters observed for both sexes among the goats bred in South Kivu.

that had pendants (3.23%), and Pimples (2.93%). In contrast, the sub-sternal vacuum goats are estimated at 8.8% of respondents.

4. Discussion of results

The knowledge of farming is one of the parameters that often dictate the success of livestock because each area has specific requirements regarding livestock [3]. The predominance of the husbandry system of goats scavenging and without control in the South Kivu region can lead to a high rate of mortality at farrowing and inbreeding due to uncontrolled couplings and low performance metrics as indicated in **Table 3**. These results are similar to those found by Alexander et al. [8] and Akréo [9] showing that the method of producing capricole straying increases the percentage of inbreeding in the herd and reduces reproductive performance of animals.

Although the sex ratio depends on several factors such as, live weight, physiological state of animals, nutritional status, breeding system, etc. In South Kivu, there is a note on using the female, the ratio between male and female being 1male/3 females. The technical reference of ANOC [10] again shows that the sex ratio recommended in adult females goats 25–30 should be a free up or projections of 5–6 per day on hand rises.

The mode of straying remains the most common system in South Kivu. This less controlled system significantly affects the performance metric morpho in goats. In contrast, Didier de Failly [11] and Théwis et al. [6], show that the barn is a farming system that facilitates the control of reproduction, feeding and hygiene of the animal and the stable, etc. The same situation was also observed by Faugère et al. [12] in Dakar, Senegal. Boujenane et al. [13] support the hypothesis that high stray animals are weak morphological performance and reduced reproductive ability in Morocco.

As has been observed at South Kivu, the live weight of adult goats is increasing in proportion to the length of the head, ears, tail, body, thoracic circumference and live weight of weaned animals. These results are almost similar to those found by Faye [14].

5. Conclusion

The coproculture plays an important socio-economic role in South Kivu. Despite its low productivity, it was observed in the east of the DRC that the goat is considered a poor cow that does not require very large financial investments. The sex ratio is on average 1/5 or a goat for five goats. Often, the males from the same keep operate with the risk of inbreeding. Females almost always give a little by farrowing.

The most common livestock system is the straying of animals leading to uncontrolled couplings and low morphological and reproductive performance metric. In this type of capricole production system, the feed is poorly controlled whereas it needs to be adequately nutritional for goats to produce milk, meat and skin, and overcome food insecurity in order to meet the self-subsistence needs of the farmers. The goats are fed with nutrient-poor leaves often at home or on unimproved poor community pastures.

The females are used for breeding, often too early due to lack of breeding selection program. Live weight of adult goats is increasing in proportion to the length of the head, ears, tails, bodies, thoracic circumference and live weight of weaned animals and males are heavier than females. Most of the goats bred have tails and horns.

Appendix: some photographs of studied native goats of drcongo

Figure A1.
Local goat's from Uvira district in DRCongo raised in free grazing system.

Figure A2.
Goat from Kabare district of DRCongo rose in a banana plantation and attache on a banana plant.

Figure A3.
Native goat from Kalehe region in DRCongo raised in zero grazing and attached on stick.

Figure A4.
Indigenous goat from Mwenga district in DRCongo attached on a stick.

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Section 6

Heat Stress

Chapter 10

Adaptive Mechanisms of Goat to Heat Stress

Bhabesh Mili and Tukheswar Chutia

Abstract

Goat is popularly known as 'poor man's cow', rears mostly by the rural people due to better adaptive capability to harsh environment. Heat stress either hot or cold; negatively influence the goat productive and reproductive performance. Both survivability and reproductive performance of goat most often depend on its ability to cope with heat stressor. Goats can rears in a wide range of environment and geography may it be hilly terrain or undulating topography due to cope with the heat stress via combination of behavioral, morphological, physiological, biochemical, metabolic, hormonal and molecular changes at the gene level. All these adaptive mechanisms and genes are important for the assessment of heat stress, adaptability and strategies for management, production of heat-tolerant transgenic goat using advance biotechnological tools for sustainable goat production in challenged environment due to climate change.

Keywords: adaptation, climate, environment, goat, heat stress

1. Introduction

Heat stress is one of the challenging stress factors for goat farming under changing climatic scenario across the world due to global warming [1]. It is well established that environment stressor either hot or cold negatively affect the productive and reproductive performance of goat via reducing growth [2], milk yield [3], reproductive performance [4] and meat production [5], as well as immunity, making the goats more susceptible to various diseases and extreme cases even death [6, 7]. Therefore, the focus should be on adaptive capacity of goats for selection of breed which are best suited and reproduce, perform better under extreme environment [8, 9]. Hence, there is a growing demand for selection of goats that are best suited to a wide range of geographical and harsh environment. Like every animal, goats possess several unique morphological and physiological adaptive mechanisms [6]. It is important to understand the adaptive mechanisms of goat to heat stressor, to evolve fast-growing new breed of goat, identification of bio-markers at the gene level to produce heat-tolerant transgenic goat having high growth rate and adaptability. This chapter is therefore, an attempt to provide the underlying various adaptive mechanisms of goat to heat stressor.

2. Adaptation

Adaptation is the capacity and the process of adjustment of an animal to itself, to other living material and to external physical environment. In term of biology, adaptation (biology) is defined as the morphological, anatomical, physiological, biochemical and behavioural characteristics of the animals, which promotes welfare and favour the survival in a specific environment. According to genetic, adaptation (genetic) is defined as the heritable animal characteristics which favour survival of a population in a particular environment. Further, in term of physiology, adaptation (Physiology) is defined the capacity and process of adjustment of the animals to itself to other living materials and its external physical environment. These adaptive changes either genetic or phenotypic (physiological) occur in animals in response to internal and external stimuli [10], which allows normal activity of the animals in an altered but tolerable climatologically range. There are series of behavioral, physiological, biochemical, hormonal, and molecular changes at the gene level to cope with heat stressor which may or may not lead to permanent genetic changes. Therefore, the adoptive capacity of animals to a stressful condition is a function of both its genetic and the intensity & duration of the stressor.

3. Materials and methods

Adaptive mechanisms of goat to heat stress either hot or cold were evaluated on the basis of behavioral, morphological, physiological, biochemical, hormonal and molecular changes at the gene level. This adaptive response to heat stress experiments were conducted either in climatic chamber under control climatic conditions or under natural environmental conditions especially seasonal variations such as extreme hot (summer) and cold season (winter). Many experiments were conducted in terms of comparative assessment between indigenous native goat breeds in their own home tract with that of exotic, crossbred as well as goat breed originated in different environmental condition under similar managemental condition, sufficient feed and clean adlibitum water.

A temperature humidity index (THI) was the most preferred method to detect goat under heat stress and co-relation to access adaptive capacity of goats to different environments/heat stressor. It was calculated from dry and wet bulb temperature using following formula.

$$\mathrm{THI} = 0.72\left(\mathrm{Dbt} + \mathrm{Wbt}\right) + 40.6,$$

where Dbt = dry bulb temperature in °C and Wbt = wet bulb temperature in °C.

3.1 Measurement of different morphological variables

Body length, body height, body heart girth, horn length, ear length, tail length, coat colour, pigmentation and body weight are the mostly studied morphological variables to determine the adaptive capacity of goat to heat stressor. Body weight of the goats were weighed in fasting condition at early morning on settled platform after the setting of weighing balance at zero [9].

3.2 Measurement of behavioral variables

Behavioral responses like standing time, lying time, drinking frequency, defecation frequency, and urination frequency were recorded during the study period [11].

3.3 Measurement of physiological variables

Physiological variable such as respiration rate (RR) was recorded by counting flank movements per minute, from adistance of 4–5 meters without disturbing the experimental goats. The unit of measurement of RR was in breaths per minute. Rectaltemperature (RT) was recorded using a clinical thermometer by gently restraining the goats. The unit of measurement of RTwas in degrees centigrade. Skin temperature ST) o f goats varies based on the quantum of sun rays to which the different body parts were exposed. Generally, in male goats, the skin temperature was recorded on the head, scrotum, and flank region. Skin temperatures were recorded using a infrared thermometer (B.S.K. Technologies, Hyderabad, India) by maintaining a distance of 5 to 15 cm [11].

Heart rate (HR) was measured by auscultation method with the aid of a flexible stethoscope by counting the number of heart sounds and beats for 20 s; the results were multiplied by 3 to express the values on a minute-time scale.

Sweat glands number was analyzed by the histological method [12]. Approximately 1–2 cm of skin sampled from the neck, flank and hindquarters were collected. These samples were processed by paraffin embedding and prepared skin smear and stained with hematoxylin and eosin. The stained skin smear was conducted on a photomicroscope under 20 × magnifications. A total of 20 fields were examined for each skin smear and images were captured to count the number of sweat gland appeared by the ImageJ® software program. The numbers of sweat glands in these images were counted on the basis of the number of hair follicles that were observed.

3.4 Blood sampling and measurement of hematological, biochemical and hormonal variables

Blood samples were collected from experimental goats from jugular vein in vacutainer tubes with anticoagulant under aseptic conditions at fortnightly intervals for estimation of hematological, biochemical and hormonal variables. Plasma was immediately separated aftercentrifugation at 3500 g for 8 min and aliquated the plasma samples were stored at−80 °C until analysis.

Haematological variables were measured in fresh blood samples. These variables were measured using an automated blood analyzer. It was also measured as per conventional methods. Total erythrocyte and total leucocytes was measured by haemocytometer method. Packed cell volume was determined using capillary tubes inmicrohaematocrit centrifuge based on the technique described by Wintrobe method. Haemoglobin concentration was estimated by cyanmethemoglobin method. Fresh blood was used for preparing smears for differential leukocytes count (DLC). The bloodfilm was dried by waving the slide in the air and stained with field stain, and counting was done under microscope. The biochemical variables such as AST, ALT, glucose, total protein, albumin, globulin, total cholesterol, triglycerides, and blood urea nitrogen (BUN) were analysed using a biochemical analysis apparatus (Thermo Scientific Genesys 10S Vis, Centreville, VA, USA) as well as few experiments quantified by using commercial diagnostic kits as per manufactures protocols. Non-Ester fatty acids (NEFA), betahydroxybutyrate (β-HBA), cortisol, aldosterone, triiodothyronine (T3) and thyroxine (T4) were quantified by using commercial diagnostic kits as per manufactures protocols.

3.5 Measurement of molecular markers

Blood samples were collected from experimental goats from the jugular vein in a heparinized vials and centrifugation was done at 3500 rpm for 25 min at 4 °C for collection of peripheral blood mononuclear cells (PBMC) pellet. Total RNA was extracted from the PMBC pellet using RNA extraction kit as per manufacturer's protocol. The total RNA was reverse transcribed into complementary DNA (c-DNA) using cDNA synthesis kit for real-time quantitative polymerase chain reaction as per manufacturer's protocol. Relative expression of mRNA transcripts of Heat Shock Protein (HSP) and other stress associated genes by quantitativereal-time PCR using SYBR Greenas per manufacturer's protocol. Each sample was run in triplicate and in all cases, samples of total RNA were used as negative control.

3.6 Statistical analysis

The data were analyzed by two way ANOVA using SPSS 16.0 statistical software. Results were expressed as the mean ± SEM. A difference with value $p < 0.05$ was considered statistically significant.

4. Behavioral adaptive response

Behaviour is the first and foremost one of the most effective adaptive mechanism, at least for the short term period. This mechanism allows goat to reduce the heat load by avoiding/reducing direct exposure to solar radiation. Behavioral changes include seeking shelter [11], changing posture (eg: standing or altering orientation to the shade or wind breaks [13, 14], reducing feed intake (When exposed to hot) or increasing feed intake (When exposed to cold) [15], standing time, lying time, drinking frequency, defecation frequency, urination frequency [11] etc. Goat tends to spend more time on standing in hot humid environment to avoid direct solar radiation as well as radiation heat from the ground. For example; Fawn goats have different eating behaviors in comparison with Saanen x hair goats, when they were exposed to heat stress and poor nutritional condition [16]. These behavioral responses are to prevent additional heat load from the ground as well as to facilitate effective heat dissemination from the body of the animals to the surrounding environment [17]. Hence, the understandings of normal behaviors goats are paramount for assessing the impact of heat stress and adaptive capabilities.

5. Morphological adaptive response

Goats can cope with a variety of geography that include deserts, alpine regions, high altitude mountain hilly area, wet and dry tropics, arctic and temperate zone. Morphological or phenotypic variations are part of adaptive changes to a wide range of geography and environment. These variations are depending upon their ecological niche where they are originated. The most common morphological changes are

a. Size and shape.

b. Coat colors and pigmentation.

5.1 Size and shape

Morphological adaptive changes due to heat stressor in animals are the most pronounced and efficient response to cope with the heat stressor. Bergmann [18] stated that the smaller sized breed of a given species are found in the warmer regions of ecological range and the larger sized breeds in the cooler localities. Further, the extremities (eg. ear, tail, bills) are smaller in the species inhabiting the cooler part of ecological range than those in warmer parts [19]. All these morphological characteristics are very crucial from the adaption point of view as it directly influence the heat exchange mechanisms via convection, radiation and evaporation between goats and surrounding environment [13]. For example Sudanese and Egyptian desert goats have relatively medium to large body size, which help in evaporative heat loss and it is a part of morphological adaptive response [20]. Similarly, non-dwarfed breeds of goats in the desert and savannah areas of Africa are much smaller than typical European breed of goats [21].

5.2 Coat colors and pigmentation

Coat colors and skin pigmentation are directly attributed towards heat loss from the body via conduction and convection in goats. The sensible heat loss via conduction and convection from the body of the animal are affected by the surface area per unit body weight, coat color, the magnitude of the temperature gradient between the goats the skin to the surrounding air [22]. Light coats colour and sleek and shiny hair coats are reflected a greater proportion of incident solar radiation than hair coats that are dark in colour or more dense and woolly [23]. For example, West African dwarf goats have smooth, short, and straight hair, which helps them to adapt in hot and humid environment [22]. Similarly, Black coat colour goats are dominant in hot deserts area and they have advantages to cope with direct exposure of solar radiation over white goats. Although, the black coat absorbs much more incident of direct solar radiation, these goats can drink an amount of water that equal to about 35% of their body weight, thus help in efficiently adjust to hot and humid environment by evaporation mechanism [24]. In addition, pigmented skin protects the deep tissues from direct short wave UV radiation by blocking its penetration in hot tropical regions. Thus, it prevents extra heat gain by the goats through direct solar radiation.

6. Physiological adaptive response

The physiological adaptations are most often caused by acute stressors. These changes are manifested as respiration rate, sweating rate, body temperature, skin temperature, heart rate etc.

6.1 Respiratory rate

Respiratory rate is the first foremost physiological response to heat stressors in goats [8, 25]. Respiration is the process of inhalation of oxygen (O_2), followed by elimination of carbon dioxide (CO_2), produced as a result of cellular metabolisms by the cells which lead to evaporative moisture loss from the respiratory tract to maintain thermal balance of the animals. This mechanism is very crucial for preventing the hypothermia which otherwise occur under thermal/heat stress [26]. As temperature increased above the thermal comfort zone of the goats, a marked increase in the respiratory rate from the normal level indicated that the goats are trying to maintain homeostasis by dissipating heat load from the body through evaporative cooling mechanism by vaporizing more moisture to the surrounding environment [27, 28]. Normally, respiration rate increased during summer due to increase in ambient temperature and decreased during winter due to decline in ambient temperature. Respiration rate increased during summer to increase heat loss through sweating and respiration. When this physiological adaptive response is failed to alleviate the effect of heat load by evaporation cooling mechanism, the body temperature may increase to a point at which goat's well-being and productive performances are compromised mainly due to reduce feed intake and extra energy loss in the process heat loss from the body. Respiratory rate increased during the summer season which indicated that goats are under stressed [29]. So, rapid increase in the respiratory rate in response to heat stress indicates the greater susceptibility of goats to heat stress. This physiological response has been found to be different from breed to breed. This adaptive response may be attributed to breed difference and adaptation to different heat stress [1, 29, 30]. For example, a higher respiratory rate was recorded in cold-adapted goats (Gaddi and Chegu) compared to that of heat adapted goats (Sirohi and Barbari) during summer [30].

6.2 Rectal temperature

Rectal temperature represents the resultant of all heat gain (both metabolic and radiation heat) and heat loss of the body. It is used to measure the core body temperature of animals. Also, it acts as a natural passage way for dissipation of extra heat to maintain physiological homeostasis and body temperature [1]. Hence, it is an indicator of heat stress and may be used to assess the heat stress and adaptive capacity of goats. Normal rectal temperature of goats ranges between 38.3 to 40 °C. An elevation of the rectal temperature occurs only when the sweating and respiratory evaporation mechanisms failed to maintain homeothermy in goats [29–31]. This physiological response is varied from breed to breed and climatic conditions. For example, a higher rectal temperature was recorded in cold-adapted goats (Gaddi and Chegu) compared to that of heat adapted goats (Sirohi and Barbari) during summer and might be attributed to different heat stress [30].

6.3 Skin temperature

Skin is an important passageway for heat exchange between the animal's body and the surrounding environment. Skin temperature is a result of blood flow to the skin, which ends with regulation of heat exchange between body core and the skin [32]. Skin temperature increased under stressful condition for redistribution of blood flow to the skin surfaces so as to form a gradient between ambient temperature and skin surface temperature for heat dissipation from the body of the animals to the surrounding environment. So, when an ambient temperature is greater than skin temperature, the temperature gradient between the body surface and the environment decreases, impeding heat dissipation in this case by an evaporative mechanism [25]. But, it depends on heat stressor including nutritional stress. For example, highest skin temperature of the head, flank, and scrotum was recorded during the afternoon of a day in Osmanabadi goats subjected to combined (heat and nutritional) stressors [11]. This increased in skin temperature for vasodilatation of the skin capillary bed and consequently increases the blood flow to the skin surface to facilitate heat dissipation.

6.4 Heart rates

Heart rate reflects primarily the homeostasis of circulation along with the general metabolic status of animals. Heart rate of animals increased under stressful condition to increases blood flow from the core to the surface of the body to give a chance for more heat to be lost by sensible (conduction, convention and radiation) and insensible (diffusion water from the skin) means [33]. A marked acceleration of the heart rate occurs during the hottest part of the day to decrease heat production [34].

6.5 Sweating

Heat stress leads to activation sweating to maintain physiological homeostasis and body temperature. Specially, when respiratory mechanism is failed to maintain physiological homeostasis, it activate the evaporative heat loss mechanisms by involving an increase in sweating rate and respiratory minute volume about 70–85% [35]. The goats have greater sweating rate and lower body weight: surface ratio, which allows efficient way to heat dissipation from the body to the surrounding environment [36]. For example Black Bedouin goats can able to store large volumes of body water, and have considerable sweating capacity which allows them to cope in hot environment [37].

7. Hematological adaptive response

The hematology profile is an attributing adaptive response to cope with heat stress either hot or cold in animals. Heat stress effects on hematological parameters such as packed cell volume (PCV), hemoglobin (Hb), total erythrocytes count (TEC), total leukocytes count (TLC), lymphocytes, neutrophils, eosinophils, monocytes, granulocytes, and pH [38]. Hb, PCV, TEC and TLC levels increased during winter season in cold climate climatic condition whereas these variables levels decreased during summer in goats [30, 39]. Similarly, Upadhyay and Rao [40] and Abdelatif et al. [41] observed decreased levels of mean TLC, TEC, Hb and PCV during summer months and increased during winter months in goat. Increased in PCV and Hb levels could be availability of adequate nutrients for synthesis of Hb as the goat consumes more feed during winter season [42]. Further, hematological response to the heat stressor is varied from breed to breed [30]. They reported a decreased in mean Hb, PCV, TEC and TLC levels during summer in Sirohi and Barbari goats as they were well adapted to hot climate and less susceptible to heat stress. But the decline in Hb, PCV, TEC and TLC was more in Gaddi and Chegu goats as they were less adapted to hot climate more susceptible to heat stress during summer.

8. Biochemical adaptive response

Biochemical composition is directly proportional to the metabolic status of animals and can be used as an index for assessing the adaptation capacity to heat stressors. Heat stress causes alteration in blood biochemical parameters such as glucose, NEFA and β-HBA, total protein, albumin, globulin, to maintain physiological homeostasis especially energy balance through basal metabolic heat production. These responses may be due to a direct effect of high temperature on metabolic function or may be a result of heat impacting gene expression.

A decreased level of blood glucose, cholesterol and free fatty acid levels were recorded in goats in response to heat stress [38]. This low level of blood glucose level could be related to reduce feed intake due to heat stress especially during summer [30, 43]. Further, increased blood glucose level in cold-adapted goat breeds such as Gaddi and Chegu was higher during summer in compared to Sirohi and Barbari goats as they are well adapted to hot climate [29]. The high blood glucose level during summer may be due to increased glucocorticoids especially cortisol due to increase level of stress related to ambient temperature. Further, NEFA and β-HBA are used for energy status of the animals [28]. Heat-stressed goat showed a decreased level of NEFA and β-HBA [36]. This may be related to the adaptive capability of the goats to maintain constant energy requirements.

Heat stress affects the protein metabolism of goats [44]. Metabolism is a part of adaptive response to the heat stress. Helal et al., [45] reported decreased in total plasma protein, albumin and globulin levels in goats subject to heat stress [45]. This might be due to an increase in plasma volume as a result of heat stress. In contrast, heat stress increased total protein and albumin levels due to increase respiration rate in goats for enhancing evaporating cooling [46]. This variation is might be due to adaptive capacity of goods. Indigenous breeds of goats are relatively better adapted to heat stress in their own native place.

9. Neuro-endocrine adaptive response

Neuro-endocrine responses to heat stress play an integral role in the adaptive mechanisms in animals. It is a crucial stress axis to accomplish physiological homeostasis by releasing several hormones for regulation of energy mobilization, cardiovascular and respiratory functions [47]. The hypothalamus serves as the main integrative control unit for neuro-endocrine responses. It receives information from peripheral as well as central nervous system and triggers an appropriate hormonal signal to maintain the internal milieu of the animals. The activation of the hypothalamo–pituitary–adrenal axis leads to enhance synthesis and release of cortisol and aldosterone levels into circulation under stressful conditions in goats [48]. These hormones are regulated the metabolism, also behavioral response to heat stressor in goats by favoring glycogenolysis, lipolysis, and proteolysis to supply required energy to restore homeostasis. However, the cortisol level was varied considerable between heat- and cold-adapted goats. For example, the cortisol level was higher in heat-adapted goats such as Sirohi and Barbari than in the cold-adapted breeds such as Gaddi and Chegu [30]. The differences in the cortisol levels may be due to adaptation of heat- and cold-adapted goats to different environment conditions, which might helps in physiological adjustment to the environment and enables goats to tolerate stressful conditions. In case of heat-tolerant breeds such as Sirohi and Barbari goats, the cortisol level increased during winter. This increase in cortisol level during winter due to cold stress so as to increase basal metabolism to maintains of the normal body temperature. However, in case of cold-tolerant goats, the cortisol level was lower during winter, thus it is reflected as adaptive response and comfortably to cold climatic condition.

Thyroid hormones (T3 and T4) stimulate oxygen consumption and heat production by the cells [49], and regulate the basal metabolic heat production in animals. Thus, the level of thyroid hormones may reflect an adaptation response to the heat stressor in order to reduce the basal metabolic heat production. Decrease levels of T3 and T4 during heat stress is an adaptive response [50], which enables reduces the basal metabolic rate and thus metabolic heat production goats [51–53] and heat production by the cells [54]. The secretion and release of thyroid hormones are affected by environmental stressor and adaptive capacity of the goats breed. For example, a high blood thyroid hormone levels was recorded in cold-adapted breeds (Gaddi and Chegu) than for heat adapted breeds (Sirohi and Barbari) goats [30]. This may be attributed to breed differences and their adaptation to different climatic conditions, which is associated with energy metabolism. The increased level of thyroid hormones may be due to low ambient temperature during winter to increase metabolic rate and increased body heat production to maintain core body temperature.

10. Molecular adaptive response

With the advancing modern biotechnological tools, it could able to identify and characterize gene expression patterns associated with cellular adaptation mechanisms of goats at the molecular level [29, 42]. A complex network of gene associated with adaptation to heat stressor in goat [55]. Out of these, many genes determine an individual's capability to adapt to the heat stress. Heat shock proteins (HSPs) are perhaps the best-studied examples of genes whose expression are associated with adaptive capacity of to heat stress. These HSP genes such as HSP60, HSP70, and HSP90 are highly conserved proteins belong to the chaperones family proteins across evolutionary lines that are expressed under various kinds of stressor and play pivotal role in regulating the proper folding of proteins [56], intracellular transport, maintenance of proteins in an inactive form, the prevention of protein degradation [57], and to adapt progressively to the changing environment to ameliorate the deleterious effects of heat stress [58]. The genes expression profile is depended on kind of goat breeds and type of environmental stressor such as heat or cold [29, 59]. For example, the expression of HSP70 was unregulated in heat stressed goats remained elevated only for 4 hours and returned back to basal level after 8 hours of heat stress withdrawal [60, 61]. Further, it was reported that cold stress was not enough to produce an alteration in HSPs gene expression except in Jhakrana goats [29]. They reported that an increase in HSP90 expression during winter season in Jhakrana goats indicated that cold stress could induce stress in Jhakrana goats, while Barbari and Siorhi goats exhibited adaptation to the same. Madhusoodan et al. [58] reported that the native indigenous goats breed was comparatively better adopted to own ecological niche or environment. They recorded a low level of expression of all heat shock response genes such as HSP70, HSP90, super oxide dismutase (SOD), nitrous oxide synthase 1 (NOS1) in Salem Black goats. The lower level of expression may be due to a sub-threshold level of the heat stress attained in the study to induce cellular stress response in Salem Black goats.

Apart from HSP genes, several other genes such as SOD, NOS, thyroid hormone receptor (THR) and prolactin receptor (PRLR) genes are associated with heat tolerant in animals [62]. Higher expression of NOS was reported in heat stressed goats, which help in vasodilatations of the skin to favor cutaneous evaporative cooling mechanisms to dissipate excess heat from the skin surface [31, 58]. Variations in the gene expression were due to gene–environment interaction and which favor the

Breeds	Genes	Function	Reference
Mexico goat	*HSP-70*	Thermo-tolerant	[67]
Chines goat	*ASIP, KITLG, HTT, GNA11,and OSTM1*	Coloration	[68]
Chines goat	*TBX15, DGCR8, CDC25A, and RDH16*	Body size	[68]
Baraki goat	*FGF2, GNAI3, PLCB1*	Thermo-tolerance (melanogenesis)	[66]
Baraki goat	*BMP2, BMP4, GJA3, GJB2*	Body size and development	[66]
Baraki goat	*MYH, TRHDE, ALDH1A3*	Energy and digestive metabolism	[66]
Baraki goat	*GRIA1, IL2, IL7, IL21, IL1R1*	Nervous and autoimmune response	[65]
Ugandan goat	*IL10RB and IL23A*	Immune response	[69]

Table 1.
Enlisted a few genes associated with heat tolerance in goats.

survival of a population in a particular environment [63–65]. Therefore; heat-tolerant genes play a significant role for regulation of physiological homeostasis and body temperature [66], and could be useful for production of heat stress tolerant goat breed by conventional approach through artificial selection as well as advance biotechnology tools using transgenic technology. Affymetrix Gene Chip Bovine Genome designed to monitor expression of approximately 23,000 transcripts, it has identified 39 and 74 genes whose expression was up- and down-regulated, and respectively by heat stressor in the blood cells of goats [3] and the genes are as follows (**Table 1**).

11. Conclusions

Heat stress has negatively affected the productive and reproductive performances of goat. Under the changing climate scenario due to global warming, the immediate need is to understand the adaptive mechanisms and identification of heat tolerant genes. Adaptive mechanism will provide basis strategies for management and to evolve fast-growing new goat breed as well as the production of heat tolerant transgenic goat for sustainable and profitable goat farming under challenged environment.

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Section 7

Gender and Climate Change

Chapter 11

Goat - A Sustainable and Holistic Approach in Addressing Triple Challenges of Gender Inequality, Climate Change Effects, Food and Nutrition Insecurity in Rural Communities of Sub-Saharan Africa

Never Assan

Abstract

A goat-centered approach to farming can help shift rural agrarian households and communities toward gender-inclusive climate change adaptation in agriculture to enhance food security and nutrition in sub-Saharan Africa. Gender inequality, climate change, and food and nutrition insecurity are the most defining and deeply intertwined socioeconomic and environmental challenges in rural communities in this region. This chapter offers an overview of the potential of goat rearing as a sustainable and holistic approach to addressing these challenges. The failure to address gender inequality and climate change has thrown sub-Saharan Africa into a state of perpetual food scarcity due to compromised food production, consequently condemning rural communities and their people to extreme poverty and malnutrition. Because of this scenario, many internal and external development agencies have put several measures in place to alleviate the situation, which has long preyed upon the region and continues to frustrate food stability there. The total failure of the previous autonomous attempt to address the triple challenges of gender inequality climate change, and food and nutrition insecurity at the household level has led to the exploration and endorsement of more sustainable and multifaceted approaches. We propose that goat rearing is one such initiative, as it combines the empowerment of women in agriculture to ensure availability of the basic food needs of the household with sustained animal production due to goats' ability to adapt to harsh environmental conditions. The goat-centered multifactorial approach is focused on the exploitation of the interlinkages among these socioeconomic and environmental ills. The major assumption is that goat rearing in rural economies simultaneously curtails the risk of food and nutrition insecurity by acting as an entry point of gender equality while leveraging the opportunities that goat rearing will effectively offset adversities posed by climate change. In most instances, women are potentially more vulnerable than men, as they directly experience the adverse effects of climate change in agricultural production, in turn

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compromising food and nutrition security. Goat rearing is central to the removal of systemic barriers that hold women back from equal participation in agriculture by broadening their socioeconomic opportunities, hence playing a significant role in agricultural value chains. The goat-rearing sustainability concept is based on establishing and maintaining the circumstances under which people and nature can subsist in productive harmony, which allows fulfilling the social, economic, and other requirements of present and future generations. Despite the adverse effects of climate change, the goat population has continued to proliferate in the harshest agroecological regions, which demonstrates that goats have managed to adapt to the current unfriendly environmental conditions. It is assumed that promoting goat rearing will narrow the gender equality gap between men and women and enhance the participation of women in agriculture, hence improving productivity and food and nutrition security. Goats, due to their large numbers and deep embedment in rural communities, have constantly contributed to poor rural farmers' livelihoods in many ways, and their contributions tend to be significant. This chapter reviews the potential of goat rearing as a sustainable and holistic approach to addressing the triple challenges of gender inequality, climate change, and food insecurity in rural communities of sub-Saharan Africa.

Keywords: goat-centered approach, gender inequality, climate change, food and nutrition insecurity, rural, sub-Saharan Africa

1. Introduction

A goat-centered approach to farming can help shift rural agrarian households and communities toward gender-inclusive climate change adaptation in agriculture to enhance food security and nutrition in sub-Saharan Africa. Goat rearing is a potential sustainable and holistic approach to addressing the triple challenges of gender inequality, climate change, and food insecurity in rural communities of this region. These challenges are deeply intertwined and are among the most defining socioeconomic and environmental concerns in rural communities' livelihoods. Since these challenges are interdependent, it is imperative to develop a sustainable holistic approach that integrates economic, social, and environmental variables to address them.

This chapter discusses the potential of goat farming as a sustainable and holistic approach to addressing the aforementioned challenges. Agriculture (crop and livestock) is a key livelihood activity, but it is vulnerable to climate change [1]. In recent decades, global awareness of the need to adapt agricultural systems and rural resource-poor livelihoods to the stressors emanating from climate change and variability has intensified [2]. In addition, gender, as a socioeconomic–cultural factor, has been applied to assess the roles, responsibilities, constraints, opportunities, and incentives of people involved in agriculture [3, 4]. Similarly, the awareness of integrating gender aspects into climate change action in the agricultural sector to enhance food security has been recognized. The disregard of gender-specific differences in adaptive and mitigative capacity allows climate change to worsen the existing gender inequalities in agriculture and beyond [5].

The question in this context is "How do goats fit into this matrix?" The frame of reference is that goat rearing is an integral component of a climate-smart livestock production strategy, acting also an entry point for gender equality [6]. The multifactorial role of goat "power" in sub-Saharan Africa first acts as an entry point for gender equality [7] and second as an agroecological zone-specific, climate-resilient, thermotolerant animal species that can sustain productivity [8] and enhance food and nutrition security. The inherent small size of goats is beneficial for socioeconomic, managerial, biological, survival, productivity, and food security reasons [9].

Goats in rural areas have been deeply embedded in the socioeconomic and environmental fabric as a major livestock species that is rapidly increasing in number and is unlikely to change significantly in the foreseeable future [9, 10]. The unquestionable potential of smallholder livestock systems to sustain livelihood to billions of rural food producers and reduce vulnerabilities in rural resource-poor economies [11] renders goats an attractive option for pro-poor agricultural development agendas and enhancement of food and nutrition security. The diverse range of agroecological zones and management systems in sub-Saharan Africa where goats are reared despite the harsh environmental conditions is a testimony to their adaptability, and the assumption is that they will preserve their productivity and thus enhance the food and nutrition situation in rural areas. Most goats are kept in rural resource-poor agricultural systems, and their relative distribution is immense because of their comparative adaptive advantages over other animal species in most agroecological zones in sub-Saharan Africa. These systems, because of climate change, are never static but are constantly evolving with changing internal and external factors. Despite this, goats have continued to play a significant role in the food chain and overall livelihoods of rural households, which are largely the property of women and their children.

The inherent proficiency to rear, reproduce, and produce goats in adverse climate conditions is ascribable to their adaptive traits, as they proffer multiple products and services and benefit rural economies greatly [12]. This chapter presents an overview of the potential of goat rearing as a sustainable and holistic approach to addressing the triple challenges of gender inequality, climate change, and food insecurity in rural communities of Sub-Saharan Africa.

2. Material and methods

For this study, we conducted research using scientific papers, books, and statistical data from the United Nations to examine the interconnectedness of goat production, gender, climate change, and food security in rural economies in sub-Saharan Africa. The concept is based on the realization that the multifactorial role of goat "power" in this region acts as an entry point for gender equality and that goats are an agroecological zone-specific, climate-resilient, thermotolerant animal species capable of sustaining productivity and enhancing food and nutrition security in resource-poor rural areas.

3. Human and goat population trends and production and their implications for rural livelihoods in sub-Saharan Africa

In 2019, the estimated population of sub-Saharan Africa was 1.1 billion [13]. This number is expected to increase to 2–2.5 billion by 2050, which will drive the population density to 80 people per square km. It should be noted that the larger proportion of the population in the region dwells in rural areas and is mainly dependent on agriculture. Therefore, it is reasonable to assume that there will be more people to feed and thus there will be more pressure on natural resources. As such, there is a need to strategize a plan for enhancing food and nutrition security. According to [14], the projection in the Sub-Saharan African population increment is that it will double by 2050. The increase in the sub-Saharan population and the need to provide food for a growing population, compounded by novel consumption patterns, will put a burden on livestock production systems and products [15–17]. This scenario is more compelling due to the advent of climate change, which obviously reduces agricultural production in general, especially in rural areas. As shown in **Figure 1**, it has been projected that sub-Saharan Africa will outpace other regions in population growth. **Figure 2** illustrates that the doubling of the human population as projected will likely pose a greater challenge to the rural population, as it makes up the greater proportion of the population in sub-Saharan Africa [14]. Similarly, **Figure 3** shows that population growth in rural areas outpaces that of urban dwellers in developing countries because of pressure on natural resources.

Livestock systems, as agricultural subsectors, are the major users of natural resources, which has a bearing on the relationship between agricultural production and resource use efficiency. Therefore, strengthening the role of livestock in rural areas is deemed a noble cause of sustaining the sub-Saharan rural food economies.

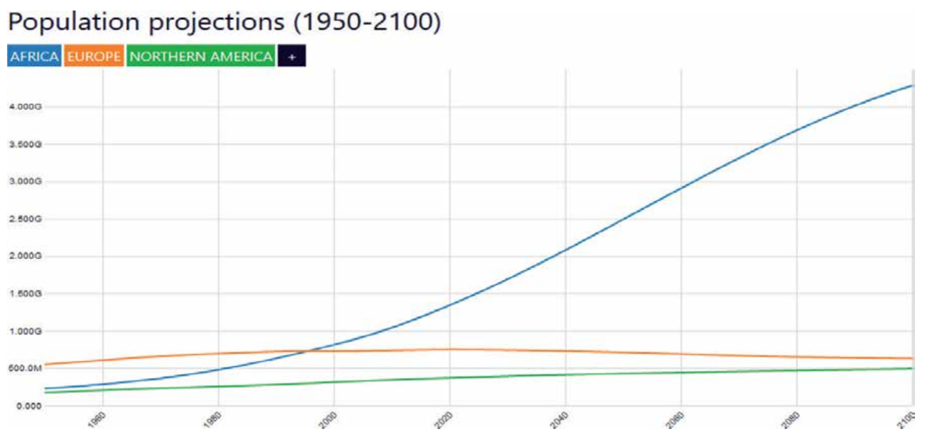

Figure 1.
Evolution of the world human population between 1950 and 2100 [18].

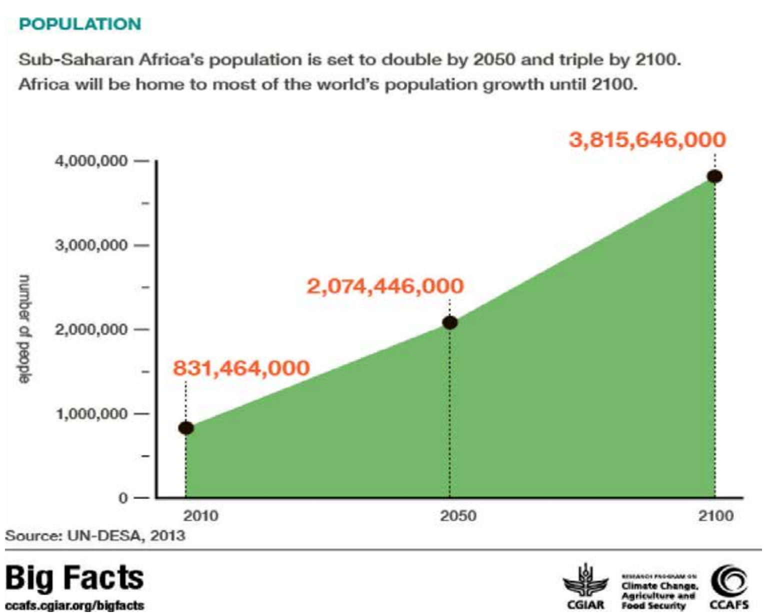

Figure 2.
Human population in sub-Saharan Africa (2000–2030) [19].

In this respect, the socioeconomic and environmental merits of livestock systems and how they contribute significantly to the livelihoods of at least 1.3 billion people in rural areas have been the focus of substantial public debate [10, 21]. **Figure 4** illustrates the increasing disparity between population growth and food production in sub-Saharan Africa.

Unless constraints on greater agricultural productivity are addressed, one-third of the population in this region will not have sufficient food by 2050. This indicates that regional poverty (**Figure 5**) and undernutrition (**Figure 6**) are rife in sub-Saharan Africa.

Figure 7 shows that the goat population worldwide increased steadily between 1994 and 2014. **Figure 8** illustrates the wider proliferation of goats in all the key agroecological zones of sub-Saharan Africa. In terms of world production, the share of goats produced by continental Africa is the second largest after Asia. This is an indication of the value of promoting goat production on the continent. Africa's goat population increased by 75% between 1980 and 2005 and constitutes 30% of the world goat population immensely contributed to the livelihoods of millions of rural economies [27]. FAO [28]

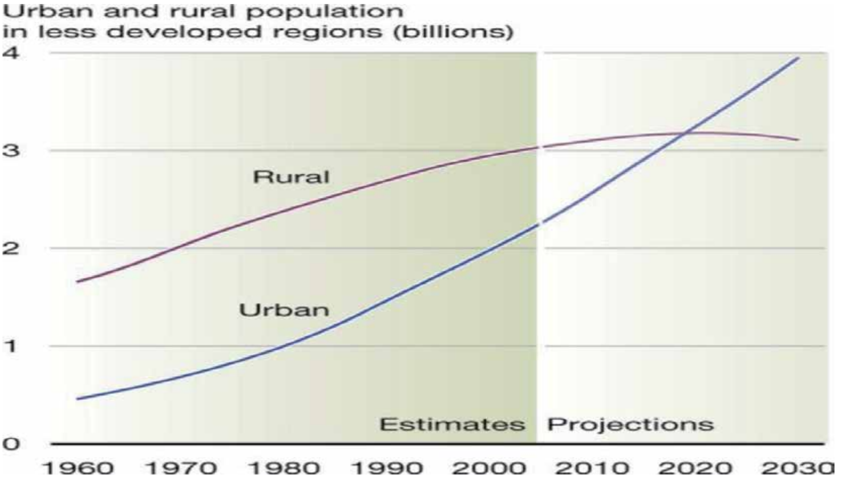

Figure 3.
Urban and rural populations in developing countries, 1960–2030 [20].

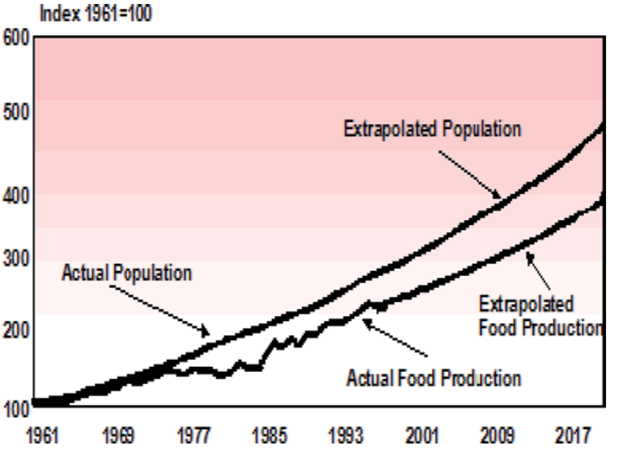

Figure 4.
Trends in human population growth and food production in sub-Saharan Africa [22].

approximated that the tropics and subtropics are home to 94% of the world's goat population. The reported livestock population of sub-Saharan Africa in 1999 comprised 182.1 million goats, [29] with approximately 64% located in rural arid (38%) and semiarid (26%) agroecological zones; more than 90% of goats in these zones are indigenous.

Despite these healthy statistics, sub-Saharan Africa has the second largest number of poor livestock farmers in the world. Poverty is rife on the continent (**Figure 5**), as are food insecurity and malnutrition (**Figure 6**). In sub-Saharan Africa, a greater proportion of the population remains undernourished, whereas Asia, the world's most populous continent, has a hunger ranking, as it is home to more than 526 million people [18]. Climate variability and extreme weather events are among the key drivers of the recent increase in global hunger and some of the leading causes of other socioeconomic and environmental challenges.

Figure 5.
Regional poverty [23].

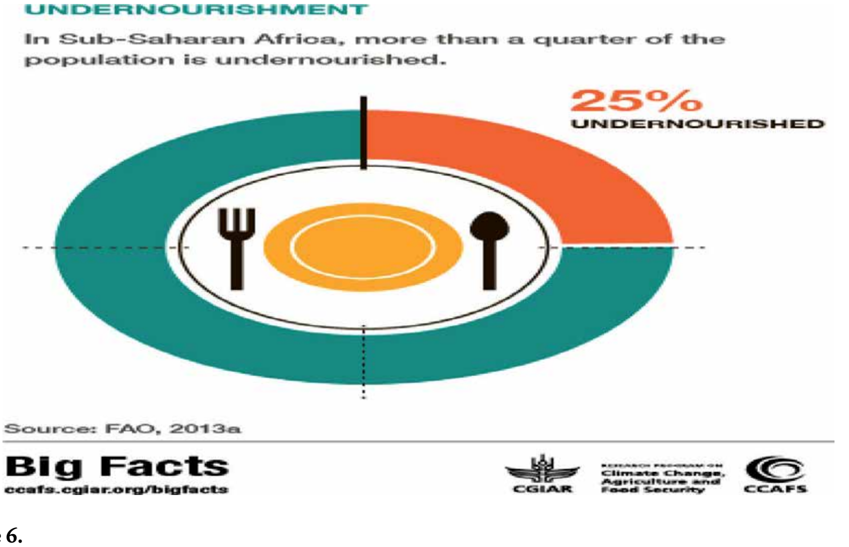

Figure 6.
Nutrition status in sub-Saharan Africa [24].

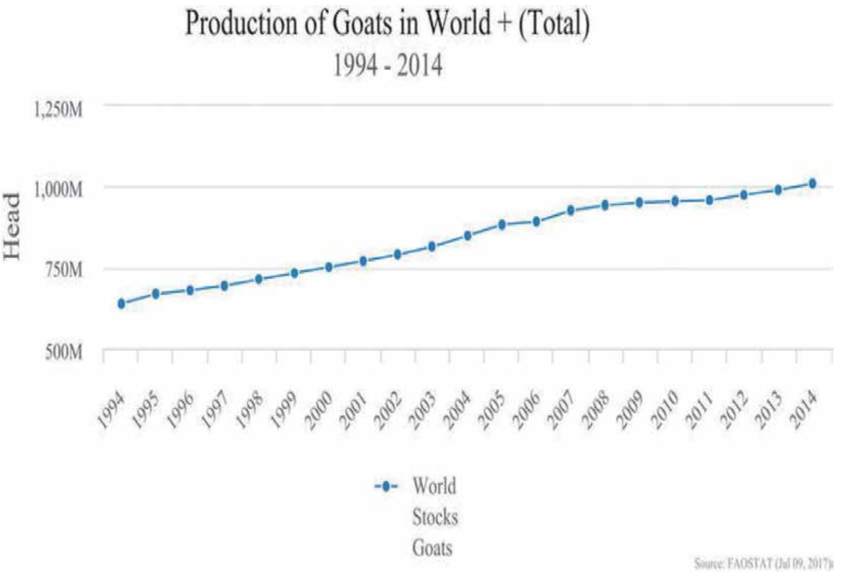

Figure 7.
Goat world population trends, 1994–2014 [25].

Figure 8 shows the adaptive potential of goats, which is clarified by the diverse. worldwide proliferation across all key agroecological zones of sub-Saharan Africa from the tropical highlands to the humid regions and environmental interface.

Figure 9 shows that Africa is home to 33.1% of the world's goat population, and a greater proportion of livestock are reared by poor farmers (**Figure 10**). Goats in Africa account for approximately 36% of the total world population of grazing animals and are vital for the development of rain-fed, less-favored areas [7]. These systems, due to the effects of climate change, are never static but are constantly evolving with changing internal and external climatic factors.

The poor resource farmers in sub-Saharan Africa are highly vulnerable to climatic and environmental hazards, as their choices for resource diversification are limited. In some cases, vulnerability due to climate change has worsened due to disparities in engendered climate change impacts and response knowledge in agriculture. This solicit for clear response strategies from the point of view of mitigation and adaptation to address the threats posed by climate change.

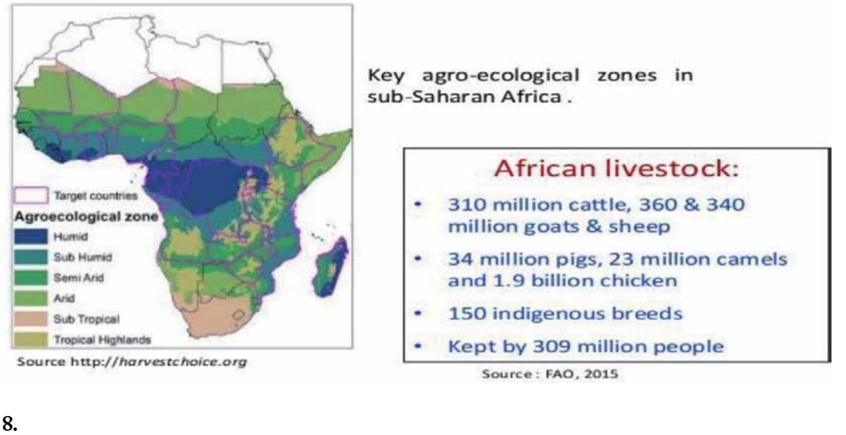

Figure 8.
African livestock and their agroecological zone in sub-Saharan Africa [26].

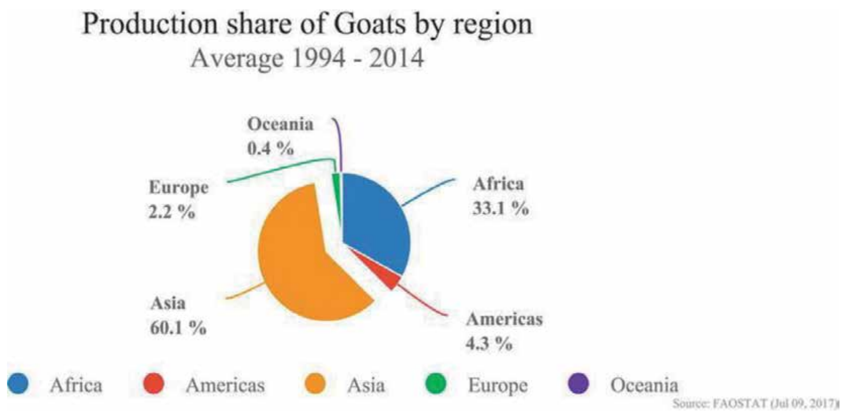

Figure 9.
Production of share of goats by continent [10].

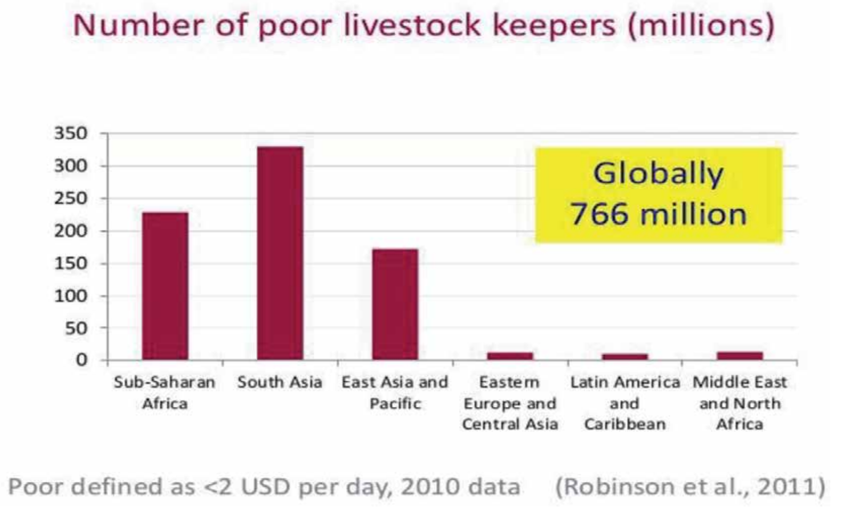

Figure 10.
Number of poor livestock farmers [30].

In this regard, the proposition of goat-centered mitigation and adaptation strategies that take into account gender relations but also curtailed the adverse effects of climate change variability and food security is called for.

4. Goat rearing: a potential strategy to mitigate climate change to cushion agricultural production and enhance food and nutrition security in rural economies in sub-Saharan Africa

Agriculture is the backbone of rural economies in sub-Saharan Africa and makes a significant contribution to households' food and nutrition security. However, despite agriculture sustaining livelihoods in rural, resource-poor farming sectors, it is one of the most climate-sensitive activities. Hence, it is imperative that mechanisms are put in place that protect the agriculture sector from the adverse impacts of climate change. At the same time, agriculture must mitigate its contributions to climate change (13.5 percent of global greenhouse gas (GHG) emissions come from agricultural activity) [31]. As a result, mitigation strategies that are not only effective but also sustainable are needed. It is clear now that climate variability and change impact both crop and livestock productivity as well as people's livelihoods [32]. The influence of adverse effects of climate variability and change on rural agrarian households are anticipated to worsen in the future. The provision of coping strategies at agrarian households in addition to formulating appropriate agricultural-related policies will minimize these adverse effects.

Climate change is debatably one of the key challenges affecting sub-Saharan African countries, primarily because of the region's greater reliance on climate-sensitive sectors such as agriculture and inability to adapt to the changing climate [33]. Thus, there is a growing interest in devising strategies to cope with climate change effects on agricultural systems to avoid compromising agricultural productivity and enhance food security. In this context, we propose that goat production is a potential strategy to mitigate climate change effects in rural economies in sub-Saharan Africa. The practicability of this undertaking is based on the fact that the socioeconomic role of goat rearing has expanded during the last decades, especially in developing countries that are routinely exposed to adverse environmental conditions [34]. In addition, goats are an integral part of resource-poor animal production systems because of their short gestation period, high prolificacy, rapid growth rate, high feed conversion efficiency, high disease resistance capacity, and easy marketability.

The impact of climate change on goat production can be assessed by considering the direct or indirect effects of climate change on agriculture and food security. The direct consequences of climate change on agricultural systems and food security incorporate goats' structural, functional, and feeding behavior and their interaction with environmental conditions, as well as issues such as the optimal use of feeding resources, which is one of the major components that has been greatly affected by climate change. The elevation in ambient temperatures across continents due to climate change increases the vulnerability of rural agrarian households and communities due to perennial drought and food and nutrition insecurity. **Figure 11** shows the world average temperature variation from 1850 to 1900, and **Figure 12** illustrates the mean temperature increment for the past 100 years in Africa. The trends provide evidence of the reality of climate change, which in turn has a bearing on agricultural production.

Similarly, climate change's distortion of rainfall patterns consistently poses a threat to food and nutrition. It is common knowledge that rising temperatures and changes in rainfall patterns have a direct effect on agricultural productivity and

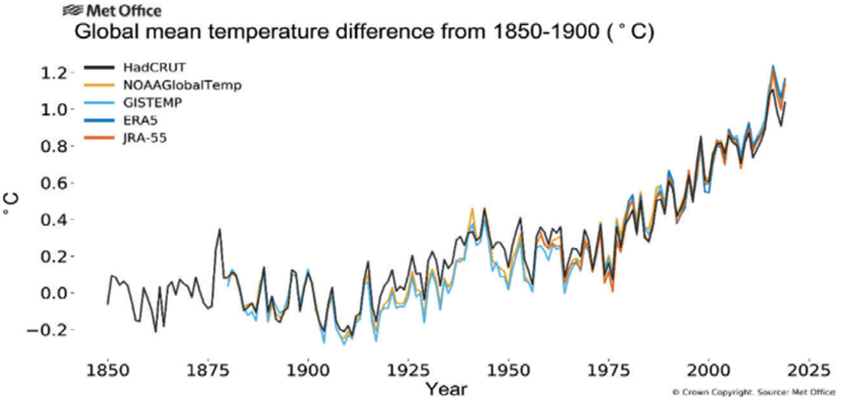

Figure 11.
Global mean temperatures 1850–1900 [35].

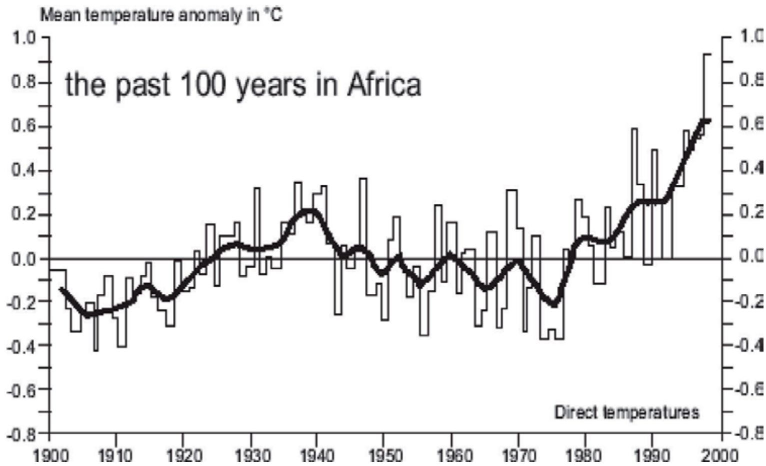

Figure 12.
Mean temperature anomalies in Africa (source UNEP, 2002).

food and nutrition security. However, the influence of these factors differs among various animal species, not to mention annual and perennial crops and agroecological regions of the world. Goat rearing as a sustainable and holistic approach to mitigating climate change and gender inequality is based on the notion that goats are relatively adaptable to the harshest agroecological regions and have the advantage of numbers. The largest share of goats is reared in rural agrarian systems, and their numerical distribution is vast because of their comparative advantages over other animal species in most agroecological zones in sub-Saharan Africa.

Climate change and variability are detrimental to general livestock production because they negatively affect the quality of feed crops and forage, water availability, animal and milk production, animal reproduction, and biodiversity, as well as lead to livestock diseases and parasites [36]. Despite all this, goats have emerged as an animal species of choice because of their ability to adapt to extreme and harsh climatic, geographical, and environmental conditions [37, 38]. Horst noted that goats have exceptional capacity to recover from drought because of their efficient reproductive behavior and variable body size [39].

One of the adverse effects of climate change on livestock rearing is grazing quality and quantity [40]. Under most rangelands where goats survive, forage has diminished over the years due to adverse climatic effects; therefore, the feeding behavior of animals has become critical. In this case, ruminants' energy requirements and digestive efficiency are vital criteria for selecting the most appropriate animal to rear in particular circumstances [41]. Aziz [42] observed that goats survive in differing ecological conditions, subsisting on different nutritional regimes under which they evolved and consequently sustaining their productivity. Principally, goat feeding behavior is intermediate and fixed, which favors both grazing and browsing, utilizing grasses in addition to shrubs [43]. In this venture, goats are extremely useful and effective in combating undesirable bush encroachment [44], which may be a dominant feature in most rural and poor communities.

Indigenous small stocks, such as goats, are much better adapted to local conditions than exotic stocks and require far fewer inputs for survival [45]. Of significance, goats have a greater capacity than other farm-reared ruminants to efficaciously convert poor feed resources into animal products such as milk and meat. The inherent complexity of goat structural, functional, and feeding behavior advantages has helped goat production under climate change-induced extreme environmental conditions. Principally, the structural, functional, and feeding behaviors of goats play a critical role in enhancing production, reproduction, and survival in adverse conditions.

Multiple environmental stressors are a frequent occurrence in most rural agriculture systems in sub-Saharan Africa and will presumably increase due to climate change variability, which may depress agricultural productivity and food security [9]. In the ranks of climatic change stressors, heat stress emerges as the primary component that adversely influences livestock production. In this regard, goat rearing becomes vital to sustain livestock production and enhance food security. This does not coincide with the proliferation of approximately 41.5% of the goat population existing in harsh semiarid/arid areas in tandem with the continued syndrome of poverty adaptation-fragile livelihoods [7], which explains the ability of goats to sustain their production under climate change-induced extreme environmental conditions.

The concentration of goat populations in the harsh tropical and subtropical agroecological regions of the world demonstrates that they are more heat tolerant than other ruminant animal species [46]. In most cases, black goats are prone to minimizing energy disbursement in winter; nevertheless, they experience a greater solar heat load in hot conditions. Therefore, there is a need for breeding lighter coats in goats, as ambient conditions might progressively become hotter and drier because of climate change variability.

Goats, through alterations in behavioral, morphological, or physiological responses to changing environments, have managed to survive in various agroecological zones. As such, goat adaptation mechanisms in response to climate change are important because they open the possibility of finding a solution to animal adaptability to climate change and addressing agricultural productivity and food insecurity.

It is important to note that the survival of animal species is dependent on the species' ability to cope with or adapt to prevailing harsh climate conditions. To preserve animal productivity levels in an environment impaired by climate change, it is necessary for animal species to be genetically adapted with the ability to survive in diversified, harsh environmental conditions. Goats are among the animal species that can adapt to environmental heat stress by virtue of a composite of physiological, morphological, behavioral, and genetic characteristics. Their inherent physiological mechanisms allow goats to evolve in extreme temperatures with limited water resources [47]. Goats can repress the effect of high thermal stress by stirring behavioral responses, namely, feeding, water intake, shade seeking, and increased frequency of drinking.

Ambient temperature is a determinant of the feeding behavior of goats; hence, nocturnal feeding has been observed in goats, enabling them to avoid high temperatures during the day. In a related study [48], goats that were both heat stressed and water deprived actually preserved their milk production for 48 hours, notwithstanding a 20% decrease in body weight. This observation concurred with [49], who reported that despite elevated temperatures, goats never displayed physiological stress, and the mean values of magnitude reported were at the level of the limits of tolerance to heat stress. This is the likely reason goats maintained milk production.

Desert goats reared in accordance with traditional resource-poor systems were watered only once every 3–6 days, when water was scarce [50], and did not show much physiological stress. Studies of water deprivation in goats and other animal species in harsh environments are numerous and indicate that goats in West Africa, [51] East Africa, [52] and Southern Africa are more tolerant to water deprivation [53]. Feed intake was less influenced by water deprivation in adapted pygmy goats than in non-adapted breeds [54]. A report from [55] explained that goat tolerance to water deprivation was ascribable to their ability to limit urine and fecal water excretion at high ambient temperatures. It is important to note that drinking behavior in animals is influenced by water restriction; in this case, there is a tendency of water deprivation in goats, predisposing animals to drink large volumes of water in one bout upon watering. This behavior is more distinct in goats than in sheep [56]. Such physiological behavior in goats will be critical in the advent of variability in temperatures due to climate change where temperature is expected to rise. This implies that to mitigate the effects of an increase in ambient temperatures due to climate change, promoting animal species with an efficient physiological response to heat stress is recommended. In this case, goats are inclined to tolerate heat stress better than sheep [57]. The tendency of most goats to have loose skin and floppy ears makes them more heat tolerant than other animals [58].

The morphological mechanisms that goats possess to minimize the effects of heat stress relate to their body shape and size, light hair color, lightly pigmented skin, and small amount of subcutaneous fat. Physiological means include increased respiration rate, increased sweating rate, reduced metabolic rate, and change in endocrine function [59]. This emphasizes the choice and use of adaptive animal species such as goats that preserve their production and are able to produce and reproduce in climatic-stressed environments. Hence, understanding how to confront climate change while protecting vulnerable rural communities through sustained agricultural production using adaptive species is essential to meet food requirements at the household level. This can only be attained through promoting adapted animals, and this is where the goat emerges as an ideal candidate.

An efficient reproductive system coupled with a small body size can easily adjust the flock size to correspond to scarce feed resources and water. It is important to note that it is easy to facilitate the integration or promotion of goats' rural communities because they are already embedded in the socioeconomic rural fabric. They can also be reared in limited space in addition to being popular with disadvantaged groups such as women.

Global climate change is primarily caused by GHG emissions that result in warming of the atmosphere [60]. The livestock sector contributes 14.5% of global GHG emissions; however, in ranking, goat production is known to emit relatively less methane than other domestic ruminants. Within animal production, the largest emissions are from beef followed by dairy and largely dominated by the methane produced during cattle digestion. The next largest portion of livestock GHG emissions is from methane produced during enteric fermentation in ruminants, a natural part of ruminant digestion where microbes in the first of four stomachs, the rumen, break down feed and produce methane as a byproduct. Methane is released primarily through belching. The status of goats relative to global GHG emissions will relatively address the challenge of maintaining a balance between productivity, household food security, and environmental preservation [61] in rural economies in sub-Saharan Africa. Indirect effects consider limitations on goat production from socioeconomic and environmental perspectives, which are mainly intended for decreasing GHG emissions, hence goat rearing has merits for rural economies' adaptation to climate change and addressing the pertinent issue of food insecurity.

Arguably, regarding mitigation, the improvement of animal nutrition and genetics is essential because enteric fermentation is a major GHG emitter in livestock production. Climate models predict that without substantial reductions in GHG emissions, global temperatures will continue to increase, causing major changes in our weather patterns, environment, and way of life. Therefore, in this case, selection of adaptable animal species such as goats that maximize feed efficiency, increase fertility, and improve overall flock health within the confines of adverse effects of climate change is recommended [59].

Worldwide, considerable efforts have been made by international organizations and governments to battle climate change and ensure food for needy populations [61]. The present discussion offers an overview of the impact of climate change on the livelihoods of rural farm households and the adaptation strategies used to cope with the effects of climate change on agricultural production and food security. To thoroughly explain the interlinkage between climate change and agriculture is a hypothetical matrix (**Figure 11**) where notable consideration has been paid to gender dynamics and climate change; the focus is to try and explain how gender issues and adaptation strategies are interrelated in rural households that are exposed to climate-related adversities that impinge on agricultural production and food security and nutrition. The discussion exposes a visible linkage between gender relations and climate change adaptation in rural agrarian communities.

Women are more vulnerable to the harmful effects of climate change than men, which has compromised agriculture and food and nutrition security. This is because women are the major players in rural agrarian agriculture. This trend is worsened by social norms and customary laws that promote gender inequality in rural agrarian households. The discussion proposes that goat rearing is an entry point for gender equality while protecting women from the effects of climate change on agricultural production and food and nutrition security. The discussion uses a hypothetical conceptual matrix, focusing on the interplay between gender relations and climate change adaptation as a subsector of the matrix. The overview concludes that adaptive capacity can be enhanced through the advancement of gender equality and women's empowerment through climate change knowledge and the promotion of goat rearing.

Poor resource livestock production systems, due to their reliance on specific climatic conditions, will in turn translate to the overall climate change effects impinging on productivity and food security. In this case, goats' adaptive features will provide an effective solution to livestock production systems as a way to mitigate climate change. As climate change emerges as pivotal in shaping future livestock rearing systems and their performance, it will have more influence on what livestock species to raise. In this case, the choice of agroecological zone-specific, climate-resilient, thermotolerant species to sustain livestock production and enhance food security is imperative in sub-Saharan Africa. This is based on the premise that the choice or selection of adapted livestock species such as goats will be part of a strategy to offset the adverse effects of climate change on livestock production while preserving animal productivity, which in the short or long term sustains food security. The development and promotion of goat rearing is a viable option in the context of climate change mitigation where other animal species seem to be relatively vulnerable.

There is the possibility that as adverse climate effects continue impinging on rural livestock production, goat rearing will assume a critical role due to goats' numerical strength and adaptive features such as feeding behavior and disease and heat tolerance, which gives them a comparative advantage for survival in harsh environmental conditions. In this regard, goats, due to their plethora of adaptive traits, emerge as a key facet in offsetting the destabilizing factors related to the uncertainties of climate change effects. Their ability to survive, reproduce, and produce in harsh environmental conditions is sufficient evidence for goats' capacity for sustainable utilization in resource-poor farming communities. As indicated by their numerical proliferation in sub-Saharan African's differentiated agroecological zones, goats have irrefutably proven that there are resilient livestock genetic resources that can be utilized to offset the effects of climate change and promote livestock production for increased food resources. Due to water scarcity, goats have the capacity to walk considerable distances in search of water and forage and make use of poor forage for their production and survival.

In view of this, rural, resource-poor production systems could be sustainable only in the long run if adaptive animal genetic resource species such as goats are promoted to offset adverse environmental effects and preserve performance levels. Goats' adaptation characteristics are embedded in their genetics, which implies that they are inheritable and favor the survival of goat populations in harsh environmental conditions. It is important to note that the climate resilient potential of goats is influenced by both phenotypic and genotypic characteristics, and there are several candidate genes that are highly associated with the adaptation of small ruminants to heat stress. Therefore, species and/or breed selection focusing on resilience is a worthwhile tool for sustaining animal production in an increasingly challenging environment [62]. Of interest is that some animal species tolerate heat better than others, which may be critical in the choice of species to raise in the harsh climatic conditions of rural economies. Goats are less susceptible to environmental stress than other domesticated ruminant species [57].

5. Goat rearing - a potential strategy in addressing gender inequality while sustaining animal production and enhancing food security in rural economies

Food and nutrition insecurity is a socioeconomic, environmental, and political subject; nevertheless, first and foremost, it is a gender issue that has resulted as a major cause and an outcome of compromised food production, food insecurity, and nutrition. Closing inequality gaps between females and males in food production systems will enhance women's ability to make themselves heard and direct the course of their own lives [63]. There is overwhelming evidence that indicates a strong correlation between gender inequality, agriculture, and food and nutrition insecurity [11]. Social and economic inequalities between men and women undermine food security and hold back economic growth and advances in agriculture [28]. It has been acknowledged that livestock production is one of the core sectors to address perpetual food scarcity and to bring future food stability to sub-Saharan Africa [64]. Microlivestock such as goats have emerged as integral livestock subsectors, apart from their adaptability to harsh environmental conditions induced by climate change, and have enormous potential for enhancing animal production, consequently enhancing food security in rural communities [65].

Goat rearing emerges as an appropriate conduit for enhancing food security and rural livelihoods, in addition to acting as an entry point for gender equality and the empowerment of rural women [63]. Turner [66] supported that women play major roles in rearing sheep and goats; hence, any developmental projects in this area will empower women in food production and nutrition. It has been noted that failure to identify agricultural subsectors where women are effectively engaged, such as goat production, has been the major reason for the unsuccessful nature of most of the development initiatives on food production and security in rural economies [67]. In the same study, it was observed that livestock development projects fail partially because the roles of women are neglected in the planning process.

The goat is the animal of choice for purposes that are within the domain of women's participation and responsibilities; hence, any goat-centered approach in rural development will consequently improve the lives of women in addition to enhancing food production overall. In most cases, due to increasing populations, the capacity for large ruminant animals, for example, cattle and buffaloes, has decreased; in this regard, shifting focus to micro livestock, such as goats, which are prolific and easy to manage, is recommended. Goat rearing in rural communities is one of the major components of livestock production systems in which women can be empowered and improve household agriculture, food, and nutrition. Goats have continued to play a significant role in the food chain and overall livelihoods of rural households, where they are largely the property of women and their children [45].

Goat rearing acts as an avenue to improve women's capacity to develop as productive members of society while elevating their economic empowerment. In this case, goat rearing acts as a gender-transformative intervention that is decisive in building resilience and coping mechanisms among women and helps reduce vulnerability and improve food security and nutrition [67]. Quinsumbing et al. [68] observed that a reduction in the gap between men and women with respect to ownership of resources, decision making, and control is necessary for attaining food security. Women's lack of participation in agricultural activities and general engagement with other community activities is symptomatic of entrenched norms and broader gender inequities. The shift in policy that acknowledges women's critical role in food production and nutrition security has resulted in increasing women's productive and economic capacity. However, there is a need to further examine the root cause of the entrenched gender inequalities that prevent women from fully participating, in agriculture and food production.

Gender inequalities in rural communities are prevalent and will persist because of a range of intertwined social, economic, and political factors that need to be addressed holistically. There is a proliferation of engendered development studies claiming the merits of focusing agricultural investments at women, especially in sub-Saharan Africa [69]. The argument is that increasing women's empowerment will translate into an overall increase in agricultural productivity, hence reducing poverty and food insecurity. This notion is based on the premise that addressing food security requires more than the initiation of opportunities for individuals to earn sustainable livelihoods; it also demands the creation of a conducive environment for men and women to acquire those opportunities.

Achieving gender equality and women's empowerment is critical to the success of addressing food insecurity. It has been proven that gender inequality has translated into a loss of opportunities or potential gains in livestock production and food security. Goat production, as a subsector of agricultural production, helps poor households increase their food security, reduce their vulnerability, and start a process that will move them out of poverty [70]. Regarding gender-cognizant perceptions of food security, it has been debated that gender-blind diagnoses of the challenges of food insecurity result in inadequate policy responses, which culminate in the perpetuation of food insecurity. Effective and promising strategies to address food insecurity need to be gender-just and environmentally sustainable in the long term.

Studies have proven that gender inequalities do not merely compromise not merely the capacity to produce and acquire food for good measurement of the nutritional security of that food, which is so central to household welfare [71]. Gender mainstreaming in agriculture has been proposed as an indispensable strategy for attaining gender equality and food security. However, this takes into account that agricultural growth is a key pathway toward addressing development issues such as food and nutrition insecurity and poverty, all of which climate change is already exacerbating [72]. There is conclusive evidence that when women are granted broader opportunities to participate in agricultural activity, the benefits expand far beyond themselves as individuals to their families and communities to societies and economies at large [28].

The development and promotion of goat production directs an ambitious path toward enhancing opportunities for women because it is critical to individual household welfare and socioeconomic development. Goat rearing as a strategy in addressing gender inequality builds on solid evidence that long-standing gaps between men and women impose real and significant disparities that need to be addressed. Since goat rearing is an important agricultural activity in rural economies of sub-Saharan Africa, its development and promotion is a promising intervention that can achieve tangible community results that can reorganize rural economies and positively address gender inequality.

There is overwhelming evidence that the provision of opportunities to women to partake in agricultural-related activities has positive effects on their families and communities in the form of improved household health, nutrition, and disposable income [63]. Advancing women's participation and control over micro livestock, which includes goats, supported by training in husbandry and animal health, in addition to increasing access to education, veterinary, and financial services, is essential to improving households' food security and nutrition.

6. Interconnectedness matrix: goat production, gender, climate change, and food security in rural economies in sub-Saharan Africa

Figure 13 models the interconnectedness of goat production and gender, climate. change, and food security in rural economies in sub-Saharan Africa. Responses to climate change tend to focus on scientific and economic solutions, disregarding the critical importance of human and gender dimensions. Gender relations are still largely absent from debates on climate change and animal production-related issues. Generally, all inequalities often contribute to environmental change, and transforming them is therefore an indispensable part of a more effective and sustainable strategy to build resilience. This implies that addressing gender differentiation in livestock production and disparities in climate change and response knowledge will facilitate sustainable community resilience.

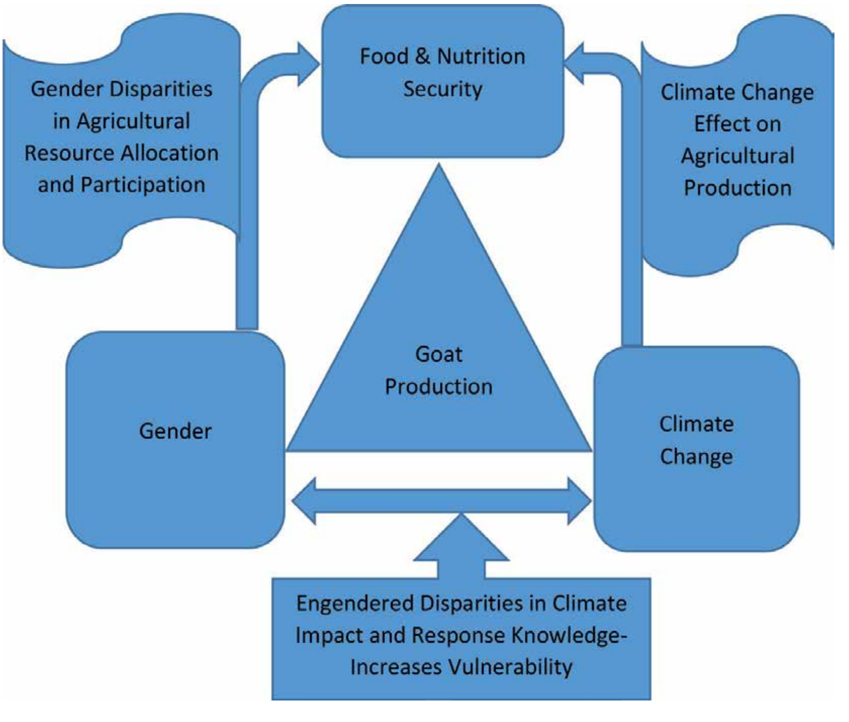

Figure 13.
Goat, gender, climate change, and food and nutrition security matrix. Source: Author.

This sustainable and broad-based approach to gender, climate, and food and nutrition security takes into account the complexity of social, economic, and ecological aspects of rural agrarian communities through adequately acknowledging the interrelationship of these factors. This understanding has a provision of the development of gender-sensitive goat production policies that fit with complex livestock livelihood strategies, especially for resource-poor livestock keepers' households. The matrix applies a gender perspective for understanding how goat production can be a pathway to food security possible through scrutiny of other elements such climate change and its impact on food security. Matrices are being modeled to explore different aspects of goat production, such as goat adaptability to adverse climatic conditions and less exposure to goat parasites, which makes goats an appropriate candidate for climate change mitigation strategies.

The two assumed goat production pathways out of food insecurity, climate change, and food security are (1) understanding disparities in livestock resource allocation and equal participation of men and women in goat productivity to address gender inequality and enhance food security, and (2) manipulating impact and response knowledge to reduce community vulnerability to climate change effects, thus increasing and sustaining goat productivity to address food insecurity and gender inequality. A general phenomenon is for men to own large livestock and particularly work animals, while women own micro livestock.

Strategies meant to enhance women's access to and control over agricultural resources or other assets have resulted in the enhancement of food security as well as the wellbeing of women themselves [65, 68, 73]. Men and women often manage different types of animals and are responsible for different aspects of animal care. Given women's traditional responsibility for household food security, their level of control over decisions about whether to sell or consume the family's animal products, as well as how to use any income obtained from the sale of animal foods, could greatly determine the nutritional wellbeing of household members.

For each pathway, the findings are organized around key questions about the role of women and lessons about interventions targeting women. Assembling this information is a first step toward identifying some of the main gaps in our evidence base as well as some of the kinds of research and development interventions made in which species and value chains are most likely to benefit poor women and their families. Women play an important role in livestock management, processing, and marketing, acting as care providers, feed gatherers, and birth attendants. Despite their considerable involvement and contribution, women's role in livestock production has often been underestimated, if not ignored.

There are potential effects of a goat-centered approach in shifting rural farm households toward gender-inclusive climate change adaptation to enhance food security and nutrition in sub-Saharan Africa. Regarding the matrix (**Figure 11**), the dependent factors of gender, climate change, and food security are deeply intertwined; hence, placing goat production as a redress factor, the matrix becomes an engendered livestock-based food security model that takes into account the adverse effects of climate change. The matrix is a departure from numerous previous hypothesized discussions that have focused on addressing gender inequality, food insecurity, and climate change adversity variables as isolated entities. This has posed challenges because these aspects of the socioeconomic and environmental nature of communities are interdependent, hence the need to establish a holistic approach in addressing these adversities. The matrix (**Figure 11**) is based on the understanding that goat rearing in rural economies will simultaneously curtail the risks of food insecurity and gender inequality and capitalize on the opportunities to offset adversities posed by climate change.

Gender differences in livestock production and disparities in climate change impact knowledge, and responses are the underlying root causes of vulnerability and food insecurity in rural communities in sub-Saharan Africa. Agriculture is a key livelihood activity, but it is vulnerable to climate change [1]. There is overwhelming documentation that climate change has a serious adverse impact on agricultural production and the livelihoods of millions of farmers, which has changed the lifestyle of rural people worldwide [74]. In recent decades, global awareness of the need to adapt agricultural systems and rural resource-poor livelihoods to the stressors emanating from climate change and variability has intensified. In tandem with this awareness, the importance of integrating gender aspects in climate change action in the agricultural sector has been recognized. Therefore, climate change discussion should afford adequate attention to gender-differentiated roles and vulnerability, in view of the fact that the impact of climate change has different implications for men and women. Lambrou and Piana [75] reported that women and men experience climate change impacts differently due to their socially constructed roles and responsibilities. Hence, it is imperative to design interventions that consider gender roles and guarantee protecting both men and women from the negative effects of climate change. This is based on the understanding that both men and women have a critical function to play in agriculture; hence, acknowledging gender distinctions facilitates appropriate, targeted interventions that offset vulnerability to climate change and contribute to gender equality and food security [74].

Assessment of adaptation, vulnerability, and resilience of communities against climate change and variability in rural communities can be applied using gender as a socioeconomic variable [76]. In most cases, there is a missing link to the scientific assessment of climate change impact through a gender integration approach to effectively mitigate and adapt to its impact. Consideration of the gender dimension in climate change is anticipated to culminate in effective interventions assisting both men and women in dealing with the impacts of climate change and bringing about resilient and comprehensive food security systems. Men and women can be effective agents of change with regard to environmental mitigation and adaptation only if they have equal access to information on climate change response. This implies that empowering men and women with climate change response knowledge can effectively advance sustainable agricultural production in rural communities as a result of offsetting the impact of climate change and enhancing food security. The provision of men and women with extensive theoretical and practical knowledge of climate change effects on agriculture should be given high regard. Broadening their role as agents of change in climate mitigation should be an integral part of the intervention strategy, and this aspect needs to be sufficiently exploited. However, the impact and response knowledge should be accurate and available to the general populace to accommodate anticipated changes.

Climate change is recognized as a global crisis, but responses tend to focus on scientific and economic solutions rather than addressing the vitally significant human and gender dimensions. Because of gendered social roles, women are in the front line of climate change impacts, such as droughts, floods, and other extreme weather events, yet they are the least responsible for environmental destruction. How then do we move toward more people-centered, gender-aware climate change policies and processes? How do we both respond to the different needs and concerns of women and men and challenge the gender inequalities that mean women are more likely to lose out than men in the face of climate change? The matrix helps to intervene through engendered climate change and food security perspectives to address the wider issues of voice, representation, and participation in general livestock production and decision making in rural communities.

The three pillars of this matrix are based on the acknowledgment of social, environment, and economic dimensions that influence rural communities, which are critical in discussions of gender inequality, food insecurity, and climate change vulnerability. The triple challenges seem to pose high social, environmental, and economic costs and lead to immense food insecurity in rural economies. The adoption of a goat-centered approach assumes that goat production is a predominant agricultural activity for livelihoods of rural communities in sub-Saharan Africa. The matrix provides avenues for pairwise analysis between subsectors such as gender and climate, gender and food security, and climate change and food security. Therefore, it is imperative that explicit attention be given to these relationships and how these dovetails affect goat production. An attempt to proffer a holistic approach that integrates scientific, technical, and economic aspects of goat farming with social and human dimensions is the major aim of this matrix.

Goats are deeply embedded in almost every sub-Saharan African rural economy and are a major agricultural subsector for most resource-poor farmers that can be exploited in addressing gender inequality, food insecurity, and climate change. However, it is important to note that the holistic perspective on these challenges is difficult to write about because of their direct and indirect connectedness. The matrix attempts to illustrate this phenomenon of the interconnection of gender, climate change, and food security.

The numerical status of goat species and composition in rural communities are critical to acknowledging trends in livestock ownership in rural economies and their impact on the vulnerability of resource-poor households to climate change and food insecurity. However, this matrix takes a holistic approach that is more difficult to achieve due to a variety of factors. Thus, it is imperative to improve our understanding of how the interaction of gender and climate change affects food security, particularly in resource-poor rural communities. It is also important to understand the pairwise relationships of different components of the framework. The understanding of gender differentiation in livestock production and disparities in climate change impact and response knowledge will lead to a more complete understanding of the influence of gender differentials in livestock production and disparities in climate change.

7. Conclusion

A goat-centered farming approach can help shift rural agrarian households and communities toward gender-inclusive climate change adaptation in agriculture to enhance food security and nutrition in sub-Saharan Africa. Gender inequality and climate change effects are compounding socioeconomic and environmental determinants that grossly compromise the stability of food production and food and nutrition security. Gender, climate change, agriculture, and food security are interrelated, and their dynamics are heterogeneous, complex, and rooted in social, economic, and institutional factors. The proposition in this chapter is that goat rearing can be a sustainable and holistic approach to addressing the triple challenges of gender inequality, climate change, and food and nutrition insecurity in rural communities of sub-Saharan Africa. This is grounded in the fact that goat rearing is an embedded integral component of a climate-smart livestock production strategy to increase rural agrarian resilience to climate change while improving food security and promoting gender equality. Apart from goats acting as an entry point for gender equality, they are a usable agro ecological, zone-specific, climate-resilient, thermotolerant animal species to sustain livestock production and enhance food and nutrition security. It is hypothesized that livestock production's susceptibility to the vagaries of climate change can be mitigated by promoting adapted livestock species such as goats, which possess an ample degree of adaptation traits in terms of physiological, functional, and adaptive feeding behavior. This is based on the premise that climate change-induced variables continuously impinge on livestock productivity, which in most cases is the major cause of food and nutrition insecurity in rural agrarian households. Over the decades, goats have inherently acquired distinctive diverse physiological, morphological, and reproductive attributes that comparatively advance their survival and proliferation in unfavorable harsh heterogeneous agroecological niches of sub-Saharan Africa. In this regard, goats, due to their plethora of adaptive traits, emerge as a key facet in offsetting the destabilizing factors related to the uncertainties of climate change effects, in addition to goats being women's animals. However, there is a need to develop mechanisms and promote the viability of goat production through various operational and institutional strategies. The challenge is that most sub-Saharan African countries do not provide adequate policy for, nor do they prioritize, goat productivity in rural communities. In conclusion, there is still significant prejudice and ignorance about the critical socioeconomic and environmental role of goats in farming. Despite the overwhelming evidence that goat rearing is hugely beneficial for resource-poor rural communities in sub-Saharan Africa.

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Section 8

Use of By-products

Chapter 12

Potential Liquid Fertilizer Made from Goat Feces to Improve Vegetable Product

Yacobus Sunaryo, Maria Theresia Darini, Vita Ratri Cahyani and Djoko Purnomo

Abstract

This study was carried out to examine the production of liquid fertilizer made from goat feces (LFGF) as well as the potency of LFGF for increasing plant growth and yield of vegetables. The study was conducted through 3 studies. The first study was begun with compiling a formulation for LFGF. The selected-raw-material was goat feces added with sugar and ZA, as well as EM (Lactobacillus sp., Actinomycetes sp., Streptomyces sp. and Yeast). The experimental results indicated that an increase in the concentration of ZA resulted in an increase in the total N and S content, as well as an increase EC of LFGF. Increased sugar concentration results in a decrease in pH and an increase in lactic acid content, whereas an increase in ZA decreases the formation of acetic acid. The use of sugar 25 g L^{-1} water and ZA 50 g L^{-1} water could produce the best quality of LFGF. The second study was to examine the selected LFGF combined with AB-Mix nutrient solution on the growth and yield of three types of leaf vegetables which were cultivated hydroponically. The results indicated that LFGF can potentially replace AB-Mix fertilizer by up to 50% in hydroponic vegetable cultivation. The third study was to examine the selected LFGF as nutrients availability of mustard that was cultivated in pots, given through planting media with a concentration of 1:40 L^{-1} water (EC 2300 μS cm^{-1}). It shows that LFGF has the potential to increase the growth and yield of mustard plants in pots.

Keywords: Liquid fertilizer, Goat feces, Lactic acid, Acetic acid, Foliage vegetables

1. Introduction

Goats are raised in addition to producing meat, they can also produce fur to be made into wool, and feces which are used as manure. Goat manure contains macro nutrients as well as micro elements that can be used as soil fertility amendments [1]. In sustainable agriculture, manure can be used as a potential soil ameliorant to increase soil organic matter and provide plant nutrients [2]. The traditional form of using goat manure is to spread it in its natural form over the land for growing crops and put it in the soil so that its nutritional content is available to plants. Furthermore, goat feces as manure can be made into quality liquid fertilizer [3] that can fertilize the growing media as well as a nutrient solution in hydroponics as modern plant cultivation.

Plant protected cultivation, the so-called, hydroponics and semi-protected cultivation, in particular in pots, is currently in great practices by Indonesian growers, however, the development of hydroponic and potting plant cultivation in Indonesia is still very limited. One of the difficulties of growers in hydroponic development and cultivation in pots is mainly due to the limited availability of quality liquid fertilizers.

One of the most important components in supporting the development of plant cultivation is fertilizer. Fertilizer is a source of nutrients which is one of the factors needed in plant growth. In geoponic plant cultivation, fertilizers are generally applied to the soil in the form of synthetic chemical fertilizers so that the nutrients contained in them can be quickly absorbed by plants. However, the application of synthetic chemical fertilizers can reduce soil fertility and productivity if given continuously. Soil productivity, among others, is determined by the condition of soil fertility, previous fertilization (fertilizer residue), the application of organic matter, and the type of plant cultivated [4].

The narrowing of fertile agricultural land in line with the increasing need for land for housing and offices and other public facilities, becomes a serious obstacle to crop production in the future. The decline in fertile agricultural land mainly occurred in developed and developing countries including Indonesia, encouraging the development of soilless cultivation technology (soilless culture) known as hydroponics. The discovery of liquid organic fertilizers can support the development of hydroponics because it can replace the availability of inorganic fertilizers which are increasingly difficult to obtain on the market in certain country like Indonesia.

To obtain high-quality organic fertilizers, the use of effectiveness microorganism (EM) as organic matter decomposer microbes during fermentation of the raw ingredients is the best way [5, 6]. In the manufacture of liquid fertilizers, urea, NPK, and molasses can be added to provide nutrients and energy sources to EM [7]. EM is a microbial inoculant used in the fermentation of organic matter to increase soil fertility, plant growth, and crop yield [8]. The quality of liquid organic fertilizers is determined not only by the nutrient content and pH of the fertilizer solution, but also the content of other phytochemical compounds such as growth regulators and other organic acids [9, 10].

Currently many quality solid organic fertilizers are offered in the market, such as vermicompost, which can increase crop yields [11, 12]. In addition, currently liquid organic fertilizers (LOF) are even created by the growers [13–15]. However, the availability of quality LOF on the market is still very limited. The current availability of LOF in the market in Indonesia has several weaknesses, such as expensive price, acidic pH, and low EC.

The formulation of the ingredients that are combined will determine the quality of the fertilizer made. Formulation is an important step in the manufacture of liquid organic fertilizers which determines the quality of the fertilizers made. However, in the manufacture of liquid organic fertilizers, there are not many reports that provide detailed formulations. ECHO West Africa Impact Center has conducted training in making liquid organic fertilizer for farmers with a formula consisting of: livestock manure, forage materials, namely green grass or green leaves, and water, each with a ratio of 1: 1: 1 (v/v), plus living earth and 2–3 shovel ash [16]. The ingredients are mixed and put in a drum, then fermented aerobically for 14 days. Every day, do the stirring for 5–10 minutes using a wooden stick. Likewise, the manufacture of liquid organic fertilizer "Herbafarm" by PT. Sidomuncul, with the raw material of liquid waste for making ethanol, the process of making fertilizer is reported in detail [17], while the comparison formula for raw materials and additives is not clearly detailed.

The use of organic fertilizers on the one hand gives a low quantity of crop yields but on the other hand is capable of producing high quality agricultural products. This low yield quantity is partly due to the low nutrient content of organic fertilizers [11, 12], so that in order to provide high yields it is necessary to look for quality organic fertilizers by increasing the nutrient content and the content of other chemical compounds.

It is not enough to carry out fertilizer quality tests in the laboratory to determine the content of nutrients and chemical compounds, but it needs to be done in the field to determine the potential or effect of fertilizers on plant growth and yield. In this study, tests were carried out on the dynamics of pH and EC, and the content of organic compounds of liquid fertilizer made from goat feces (LFGF) at the time of manufacture and storage, the effect of LFGF on the growth and yield of leaf vegetables cultivated hydroponically and in pots. The cultivation techniques used in this study include non-substrate hydroponics using nutrient solution planting media, cultivation techniques in pots using a mixed planting medium of sand, compost, and husk charcoal.

Fertilizer application to plants needs to be regulated in dosage. In the application of liquid fertilizer, the dose of fertilizer can be adjusted by adjusting the concentration, frequency or interval of application. In this study, the LFGF treatment interval was adjusted for planting mustard plants in pots.

2. Essential elements and organic acids content of LFGF

2.1 Research methods

Fermentation and incubation of liquid fertilizer were carried out in the laboratory of University of Sarjanawiyata Tamansiswa (UST). The materials are: air dried goat feces, sugar, ZA fertilizer, EM microbial solution, and sterile water. The tools used include: plastic buckets with lids of 30 liters volume, stirring bamboo sticks, 5 liter plastic jerry cans, plastic funnels, and a pH/EC/TDS meter.

Liquid fertilizers were formulated using a 3 x 3 factorial experiment arranged in a completely randomized design (CRD) with three replications. The first factor was the concentration of sugar, consisting of 3 levels: 12.5, 25, and 50 g L^{-1} of water coded S1, S2, and S3 respectively. The second factor was the concentration of ZA, consisting of 3 levels: 25, 37.5, and 50 g L^{-1} of water coded Z1, Z2, and Z3 respectively. There were 9 treatment combinations, namely: S1Z1, S2Z1, S3Z1, S1Z2, S2Z2, S3Z2, S1Z3, S2Z3, and S3Z3. Each treatment combination was fermented in 20 liters of water (see Appendix A). All combinations added 100 g of goat feces and 1 ml of EM liquid for every liter of water. Fermentation of the materials consisted of several steps [3, 18].

The fermentation was carried out for 3 weeks, for each combination formula of liquid fertilizer treatment was taken 5 liters of fertilizer solution, then collected in a plastic jerry can container and closed tightly. All plastic jerry cans containing fertilizer solution were placed in a storage room at room temperature for 5 months. Every month the pH and EC of the fertilizer solution were observed.

2.2 Results and discussion

There was no interaction between the sugar and ZA concentrations at the acidity (pH) of LFGF (**Table 1**). The variation of sugar concentration from the lowest to the highest indicates that the sugar concentration of 12.5 g L^{-1} of water produces the highest pH (6.4) close to neutral, if the concentration of sugar increases 2 to 4 times, the pH drops to 4.9–4, 3 and consistent from the first to the third week. In

Treatments	pH		
	Week I	Week II	Week III
Sugar concentration (g L^{-1} water)			
12,5 (S_1)	6,4 a	6,2 a	6,4 a
25 (S_2)	4,9 b	5,0 b	5,1 b
50 (S_3)	4,3 c	4,1 c	3,9 c
S (ρ > F)	< 0,0001	< 0,0001	< 0,0001
ZA concentration (g L^{-1} water)			
25 (Z_1)	5,3 a	5,2 a	5,3 a
37,5 (Z_2)	5,2 a	5,2 a	5,2 a
50 (Z_3)	5,2 a	5,0 a	5,2 a
Z (ρ > F)	0,6222	0,5218	0,2061

Note: The mean number in the column followed by the same letter shows no significant difference based on DMRT 5%.

Table 1.
Effect of sugar and ZA concentrations on pH of LFGF during fermentation.

contrast to the sugar concentration, the use of ZA concentrations of 25, 37.5, and 50 g L^{-1} water did not result in a change in pH (about 5.0–5.3) from the first to the third week (**Table 1**). This shows that sugar has an effect on the organic acid content of LFGF, the higher the sugar concentration the higher the organic acid content and the lower pH. Although the concentration of ZA did not affect changes in pH, ZA produced relatively acidic LFGF with a pH of about 5.0–5.3. Thus ZA also affects the organic acid content of LFGF but is not as strong as the effect of sugar (**Table 4**).

There was no interaction between the sugar and ZA concentrations on the electrical conductivity (EC) of LFGF (**Table 2**). The sugar concentrations of 12.5, 25, and 50 g L^{-1} water did not cause changes in EC, which was about 2600 μS cm^{-1} (after 20 times LFGF dilution) consistent from the first week to the third week. In

Treatments	EC (μS cm^{-1})		
	Minggu I	Minggu II	Minggu III
Sugar concentration (g L^{-1} water)			
12,5 (S_1)	2666 a	2713 a	2740 a
25 (S_2)	2648 a	2680 a	2698 a
50 (S_3)	2458 a	2528 a	2685 a
S (ρ > F)	0,1790	0,1500	0,2061
ZA concentration (g L^{-1} water)			
25 (Z_1)	1929 c	1909 c	1988 c
37,5 (Z_2)	2548 b	2621 b	2718 b
50 (Z_3)	3294 a	3391 a	3419 a
Z (ρ > F)	<0,0001	<0,0001	<0,0001

Note: The mean number in the column followed by the same letter shows no significant difference based on DMRT 5%.

Table 2.
Effect of sugar and ZA concentrations on EC of LFGF during fermentation.

contrast to the variation in the concentration of ZA, it shows that the ZA concentration of 25 g L^{-1} of water produces the lowest EC which is around 1900 μS cm^{-1}, if the ZA concentration increases to 37.5 g L^{-1} of water it results in an increase in EC to around 2500–2700 μS cm^{-1}, and when the ZA concentration was increased to 50 g L^{-1} water the result was an increase in EC to about 3300 μS cm^{-1} (**Table 5**). It can be understood that ZA which has the chemical formula (NH4)2SO4 as a nutrient provider (N and S) can stimulate the growth of microbial increase (EM) so that the breakdown of organic matter (goat feces) increases and results in an increase in the content of total dissolved solids (TDS) as well as EC of LFGF.

There was no interaction between the sugar and ZA concentrations on nutrient content (N, K, S, and Mn) of LFGF (**Table 3**).

The interaction between the use of sugar and ZA on organic acid content (lactic, acetic and citric acids) occurred (**Table 4**). High sugar concentration (50 g L^{-1} water) resulted in the highest lactic acid content both with low ZA concentrations (25 g L^{-1} water) and high (50 g L^{-1} water), namely: 7582 mg L^{-1} and 7270 mg L^{-1} respectively. This research is in line with research conducted by Yunus and Zubaedah [19] and Zubaedah et al. [20]. Sucrose provides energy and carbon for lactic acid bacteria for lactic acid metabolism, and the accumulation of lactic acid can lower the pH of the media. The results of Yunus and Zubaedah [19] research on the effect of sucrose concentration and fermentation time on the viability of *L. casei* during frozen storage of Ambon Banana Velva, showed that the use of 20% sucrose concentration resulted in 0.19% lactic acid and a pH of 4.89, while 40% sucrose results lactic acid 0.29% and a pH of 4.44. Fermentation by lactic acid bacteria is characterized by an increase in the amount of organic acid followed by a decrease in pH [20].

Low sugar concentration (12.5 g L^{-1} water) with low ZA (25 g L^{-1} water) resulted in the highest acetic acid content (2512 mg L^{-1}) (**Table 4**). The results of this study are different from the results of research conducted by Firdausni [21] and Priasty et al. [22]. Research by Firdausni [21] on the effect of sugar and yeast concentrations in vinegar from Rosella (*Hibiscus sabdariffa* L.) on the quality of Rosella vinegar, shows that 10% sugar concentration with 6 g of L^{-1} yeast produces 5.45% acetic acid, while sugar concentration 20% with yeast 6 g L^{-1} yield 14.80% acetic acid. Research by Priasty et al. [22] who studied the acid quality of Coconut

Treatment combination	N total (%)	K2O total (%)	S total (%)	Mn total (ppm)
S_1Z_1	0,44 d	0,17 b	0,06 e	21,34 e
S_1Z_2	0,66 c	0,13 cd	0,19 b	24,50 d
S_1Z_3	0,85 a	0,11 d	0,26 a	23,71 d
S_2Z_1	0,39 d	0,14 c	0,09 d	30,49 b
S_2Z_2	0,79 b	0,12 cd	0,24 a	37,54 a
S_2Z_3	0,81 ab	0,12 cd	0,20 b	27,95 c
S_3Z_1	0,44 d	0,19 a	0,06 e	29,55 cb
S_3Z_2	0,66 c	0,19 ab	0,15 c	38,03 a
S_3Z_3	0,85 a	0,21 a	0,20 b	29,44 cb
S * Z (ρ > F)	<.0001	0.0103	<.0001	<.0001

Note: The mean number in the column followed by the same letter shows no significant difference based on DMRT 5%.
S_1, S_2 and S_3: Sugar concentration of 12,5, 25, and 50 g L^{-1} water respectively.
Z_1, Z_2, and Z_3: ZA concentration of 25, 37,5, and 50 g L^{-1} water respectively.

Table 3.
Interaction between the sugar and ZA concentrations on nutrient content (N, K, S, and Mn) of LFGF.

Treatment	Organic acid content (mg L^{-1})		
combination	Lactic acid	Acetic acid	Sitric acid
S_1Z_1	49,37 d	2512,17 a	41,09 a
S_3Z_1	7582,52 a	373,89 d	35,80 b
S_1Z_3	17,20 d	915,38 b	29,39 c
S_3Z_3	7270,21 b	439,55 c	30,02 c
S * Z (ρ > F)	<0.0001	<0.0001	0.0012

Note: The mean number in the column followed by the same letter shows no significant difference based on DMRT 5%.
S_1 and S_3: sugar concentration of 12,5 and 50 g L^{-1} water respectively.
Z_1, and Z_3: ZA concentration of 25 and 50 g L^{-1} water respectively.

Table 4.
Interaction between sugar and ZA concentration on organic acid content of LFGF.

vinegar (*Cocos nucifera* L.) using the slow method, showed that the use of 3% yeast (*S. cerevisiae*) and 10% sugar (C6H12O6) produced 11% alcohol (C2H5OH), while the use of yeast with a concentration of 3% and 16% sugar produces 16.67% alcohol. Alcohol (ethanol) through the alcohol dehydrogenase process turns into acetaldehyde (CH3OH), then through the aldehyde hydrolase process acetaldehyde changes to hydrase acetaldehyde, finally through the aldehyde dehydrogenase process the hydrated acetaldehyde turns into acetic acid.

High citric acid content was produced in a combination of low ZA concentration (25 g L^{-1} water) with low sugar (12.5 g L^{-1} water) and high sugar (50 g L^{-1} water), namely 41.09 mg L^{-1} and 35.80 mg L^{-1} respectively (**Table 4**). In contrast to the research on the manufacture of citric acid conducted by Hamat and Sasmita [23] who studied the use of tapioca flour waste as a submerge culture in citric acid fermentation, the results showed that making citric acid from tapioca flour waste needed to be added with sugar with a concentration of 140 g L^{-1} of water., used *Aspergillus niger* bacteria, it takes 9 days of fermentation, 100 ml of tapioca waste can produce 1.54 g of citric acid with a pH of 5.

The higher the lactic acid content is due to the higher the sugar concentration used, resulting in lower LFGF pH, which can reduce the quality of the fertilizer. However, several studies have shown that lactic acid can stimulate plant growth. Giving lactic acid at a very low concentration can stimulate plant growth. Lactic acid can stimulate the growth of duckweed (*Lemna minor* L.) and corn (*Zea mays* L.) which is indicated by increasing plant biomass [24]. However, until now there has been no explanation of the mechanism of lactic acid stimulating effect on plant growth.

In the experiment on the germination of tomato seeds (*Lycopersicon esculentum* Mill) by Murthy et al. [25] showed that the treatment of lactic acid bacteria was treated with *L. paracasei* subsp. tolerant (LAB I) and *L. paracasei* subsp. *paracasei* (LAB II) resulted in the percentage of seeds germinated not significantly different from the control treatment, namely 78.13% (LABI), 79.76% (LAB II), and 76.10% (control). The three treatments resulted in a higher percentage of seeds germinating than seeds treated with wilt bacteria (*Ralstonia solanacearum*) strains 1–5 which resulted in an average seed germination of 35%. On the other hand, LAB I and LAB II treatments produced higher plant vigor index (sprouts), namely 1112.76 (LAB I) and 1130.20 (LAB II) higher than controls with plant vigor index 700.08, and *Ralstonia solanacearum* treatment with plant vigor index 196–216.83. This shows that the treatment of lactic acid bacteria can stimulate plant growth and produce a higher plant vigor index.

Lactic acid and acetic acid can make plants healthy. Both of these organic acids can reduce fungal infections in seeds, however at high concentrations they can have a negative effect on germination and reduce the vigor of Zinnia seedlings [26]. Compared to lactic and acetic acids, the content of citric acid of LFGF is very low. Citric acid can also stimulate plant growth. Talebi et al. [27] reported that citric acid is an environmentally friendly chemical, at a concentration of 300 mg L^{-1}, which can have a positive effect on the growth and development of Gazania plants.

Experiments examining the effect of organic acids on germination, vigor, and health of Zinnia plant seedlings [26], showed that 5% acetic acid treatment inhibited seeds from germinating, resulting in 14–26.3% germinating seeds, lower than the treatment of 1% acetic acid which produced 78.3–84% germinated seeds which was not significantly different from the control treatment (84–91% germinated seeds). However, the 5% acetic acid treatment resulted in the seeds being attacked by disease with the smallest percentage, namely 8.3–12.7% which was not significantly different from the 5 g kg^{-1} fungicide treatment (11.7–16.7%) which was lower than the control treatment (19.3–30.3%). While 1% or 5% lactic acid treatment did not inhibit seed germination, resulting in 85.7–86% germinated seeds for 1% lactic acid treatment and 73% for 5% lactic acid treatment. However, lactic acid treatment did not reduce the disease-stricken seeds compared to control.

Apart from lactic acid and acetic acid, citric acid also has a positive effect on plant growth. Experiments conducted by Marjenah et al. [28] who studied the effect of a mixture of beef bone with organic acids to increase available P and growth of maize in inceptisol soil, showed that citric acid was able to more strongly dissolve P-organic cow bone ash than acetic acid and lactic acid, so that P availability increased for plants.

The results of this experiment showed that the formula with a combination of 100 g goat feces +12.5 g sugar +50 g ZA produced a normal pH (range 6.0–6.5), the highest EC (range 3200–3400 μS cm^{-1}, after dissolving in water at a ratio of 1:20), and has the highest total N and S content, however, the formula produced the lowest lactic acid content and had an unpleasant odor. Observation of color and odor showed that the treatment of sugar concentration of 50 g L^{-1} produced yellow LFGF with a sour smell, sugar 25 g L^{-1} of water produced LFGF brownish yellow with slightly acid, while the treatment of sugar concentration 12.5 g L^{-1} water produced a blackish brown and unpleasant odor. The sour odor indicates the high organic acid content of the LFGF produced.

LFGF with the formula S2Z3 (goat feces 100 g L^{-1} water, sugar 25 g L^{-1} water, ZA 50 g L^{-1} water, EM 1 ml L^{-1} water), has a slightly acidic pH (5.0–5, 2), high EC, slightly sour smell, selected to be the LFGF tested applied to plants.

3. Mixture of LFGF and AB-mix on hydroponic leaf vegetables

3.1 Research methods

Fermentation of LFGF [3] is carried out at the Laboratory of the Sarjanawiyata Tamansiswa University. The manufacture of liquid fertilizer was carried out in the first week to the fourth week of February 2017. Experiments on using LFGF were carried out from March to August 2017 at Agricultural Technology Park, Nglanggeran Wonosari Yogyakarta.

The research materials included: the seeds of pakcoy mustard (*Brassica rapa subsp. chinensis*), lettuce (*Lactuca sativa* L), and red spinach (*Amaranthus tricolor* L), liquid fertilizer made from goat feces (LFGF), and AB-mix fertilizer. The tools used included: hydroponic installation shallow flow technique (SFT), digital pH/EC/TDS meter, calipers, scales, digital chlorophyll meters, and ovens.

Experiments on the use of LFGF on leaf vegetable plants used a 3 x 4 factorial arranged by completely randomized design (CRD). The first factor was the kinds of leaf vegetables, consisting of 3 levels: T1: pakcoy mustard, T2: lettuce, and T3: red spinach. The second factor was the combination of nutrient solutions, consisting of 4 levels: A1: LFGF + AB-Mix (v/v: 1:1), A2: LFGF + AB-Mix (v/v: 1:3), A3: LFGF + AB-Mix (v/v: 3:1), and A4: AB-Mix as controls. Each treatment combination was repeated 3 times so that there were 36 experimental units.

The seeds of pakcoy mustard, lettuce, and red spinach were sown in compost for two weeks until they grow into seedlings, then they were selected to obtain uniform seeds. The vegetable seedlings were then planted in a hydroponic installation with a series of 4-inch diameter PVC pipe using the shallow flow technique (SFT) method with a distance between the planting holes of 30 cm, and a vertical distance of 40 cm between the pipes (see Appendix B). Plants were fertilized with nutrient solution according to treatment. The concentration of the nutrient solution was adjusted in the range 1600–1650 μS cm^{-1}, and the pH was in the range of 5.5–6.5 (EC, pH, N and P content were observed in each combination of nutrient solutions). Nutritional solution replacement was carried out every 4 days when the plants were 1–12 days old, then once every 3 days until the plants were 21 days old, and once every 2 days until the plants were harvested (35 days old).

Five weeks after planting, observations were conducted on the variables of the number of leaves, shoot fresh weight, shoot dry weight, root dry weight, leaf chlorophyll content, and root/shoot ratio, on five sample plants from each treatment unit. Chlorophyll content was observed directly on the leaves without destructive, on the leaves that were located at the bottom, middle and top of the plant. Observation of chlorophyll content using a digital chlorophyll meter “CCM 200 plus Chlorophyll Content Meter”.

3.2 Results and discussion

The results of EC and pH observations of the nutrient solution from each mixture of LFGF and AB-Mix are listed in **Table 5**.

EC and pH of those various nutrient solution mixtures are ideal for the growth of leaf vegetable plants. Lettuce, carrots, strawberries, and onions require EC 1400 μS cm^{-1}, while broccoli, cabbage, tomato, cucumber, radish, and chili plants require EC 3000 μS cm^{-1} [29]. Spice plants require EC 2500 μS cm^{-1} and pH 5.5–6.5 [30]. Nutritional solutions with a pH of 5.8–6.5 are the most ideal for plant growth in hydroponic systems [31]. Ornamental plants *Gypsophila paniculata* require EC 1000 μS cm^{-1} for plant growth in the first month and 2000 μS cm^{-1} for the following month [32]. Lettuce requires EC 1200 μS cm^{-1} at 5 days of age, 2100 μS cm^{-1} at 10 days of age, and 1800 μS cm^{-1} at 15 to 35 days of age [33].

EC regulation of nutrient solution to make it stable was done by replacing the nutrient solution with short time intervals, namely when the plants were 1–12 days old, did once every 4 days, then once every 3 days until the plants were 21 days old, and once every 2 days until the plants were 35 days old. The results of experiments conducted

Nutrient solition	pH	EC (μScm^{-1})
P_1	5,85	1625
P_2	6,25	1636
P_3	5,54	1618
P_4	6,52	1650

Note: P_1: LFGF + AB-Mix (v/v: 1:1), P_2: LFGF + AB-Mix (v/v: 1:3), P_3: LFGF + AB-Mix (v/v: 3:1), P_4: AB-Mix.

Table 5.
EC and pH of ready-to-use nutrient solutions.

on hydroponic pakcoy [34] showed that the EC was too high (9600 μS cm^{-1}) or too low (0–600 μS cm^{-1}) causing low plant fresh and dry weight, leaf area narrow, low net photosynthesis rate, and decreased taste value. Based on growth and quality criteria, the optimal EC is 1800–2400 μS cm^{-1}. Too high or too low EC causes nutrient stress, increases antioxidant enzyme activity, and reduces plant growth and quality.

The results showed that there was no interaction between the combination of nutrient solution and kinds of leaf vegetables on the variables of leaf number, shoot fresh weight, shoot dry weight, root dry weight, and leaf chlorophyll content (**Table 6**). In mustard greens (**Table 6**), the nutrient solution treatment consisting of a mixture of LFGF + AB-Mix (v/v: 1: 3) (P2) resulted the highest canopy fresh weight, canopy dry weight, root dry weight as well as the highest chlorophyll content, while LFGF + AB-Mix (v/v: 1: 1) (P1) treatment and AB-Mix nutrient solution treatment without adding LFGF (P4) resulted in canopy fresh weight, canopy dry weight, and root dry weight not significantly different. The two treatments (P1 and P4) produced higher canopy fresh weight, canopy dry weight, and root dry weight than LFGF + AB-Mix treatment (v/v: 3: 1) (P3) (see Appendix C).

The results of field practice show that mustard greens are the most sensitive to changes in pH and EC of nutrient solutions compared to other leaf vegetables such as lettuce and spinach. In this experiment, the best growth and yield of mustard plants were obtained in the LFGF + AB-Mix (v/v: 1: 3) treatment, the LFGF + AB-Mix (v/v: 1: 3) treatment also produced the highest leaf chlorophyll content. This shows that the LFGF + AB-Mix (v/v: 1: 3) mixture produces the best nutrient solution for plant growth, the nutrient solution not only contains complete nutrients but also contains growth stimulants and growth nourishing (organic acids) in optimal concentration.

Plants	Treatments	Leaf number	Canopy fresh weight (g)	Canopy dry weight (g)	Root dry weight (g)	Chlorophyle content (%)
Mustard	P_1	16.44 ab	132.47 b	11.59 b	1.60 b	17.12 b
	P_2	18.44 a	155.23 a	14.63 a	2.08 a	20.00 a
	P_3	15.22 b	99.07 c	9.27 c	1.27 c	16.88 b
	P_4	17.67 a	125.20 b	11.13 b	1.56 b	16.69 b
$\rho > F$		0.0284	0.0031	0.0005	0.0006	0.0578
Lettuce	P_1	13.44 a	79.03 a	3.30 ab	0.47 a	4.50 a
	P_2	12.77 a	81.66 a	3.80 a	0.58 a	6.11 a
	P_3	13.11 a	66.72 a	2.51 b	0.45 a	4.90 a
	P_4	13.32 a	75.33 a	3.17 ab	0.58 a	4.80 a
$\rho > F$		0.9809	0.8799	0.0626	0.3101	0.2794
Red spinach	P_1	18.11 bc	108.61 a	16.44 a	2.01 a	15.39 a
	P_2	20.66 a	126.28 a	19.19 a	2.10 a	16.84 a
	P_3	16.78 c	83.31 b	12.69 b	1.56 b	15.27 a
	P_4	19.33 ab	106.51 a	16.23 a	1.86 ab	15.25 a
$\rho > F$		0.0011	0.0067	0.0064	0.0529	0.2935

Note: The mean number in the column followed by the same letter shows no significant difference based on DMRT 5%.
P_1: LFGF + AB-Mix (v/v: 1:1), P_2: LFGF + AB-Mix (v/v: 1:3), P_3: LFGF + AB-Mix (v/v: 3:1), P_4: AB-Mix.

Table 6.
Effect of mixture of LFGF and AB-mix on growth and yield of leaf vegetables.

AB-Mix is the most commonly used fertilizer for providing hydroponic nutrient solutions. The addition of LFGF to AB-Mix at a high ratio (v/v: 3: 1) could inhibit growth and reduced the yield of mustard greens, this was probably because the mixture of LFGF + AB-Mix (v/v: 3: 1) contained high organic acids so that it could inhibit plant growth. The experiment conducted by Szopińska [35] showed that 5% acetic acid treatment inhibited seed germination in *Zinnia elegans* plants, resulting in 14–26.3% lower germinated seeds compared to 1% acetic acid treatment which resulted in 78.3–84% germinated seeds no different real with control treatment with seeds germinated 84–91%.

LFGF + AB-Mix (v/v: 1: 1) treatment resulted in the growth and yield of mustard plants which was not significantly different from the control treatment (AB-Mix). Thus, this treatment can save the use of A/B- Mix fertilizer by 50%, so it can save costs because the price of AB-Mix fertilizer is expensive. To manufacture LFGF the cost per liter (unit cost L^{-1}) is not more than IDR 2,000 and to produce 1000 liters of ready-to-use solution (EC 1500 μS cm-1) requires LFGF 20 liters (costs IDR 40,000), while for preparing a ready-to-use AB-Mix nutrient solution 1000 liters (EC 1500 $\mu S\ cm^{-1}$) requires a package of AB-Mix (1 kg) for IDR 100,000.

In this experiment, LFGF was diluted by adding water with a ratio of 1:50 (v/v) to obtain an EC of about 1500–1600 μScm^{-1}. In hydroponic systems, the optimum EC for leaf vegetable plants such as pakcoy is 1.8 $mScm^{-1}$, too low or too high EC will cause nutrient stress, stimulate antioxidant enzyme activity, and inhibit growth and reduce plant quality [34]. Pakcoy can grow well in nutrient solutions with an EC of about 1.5–2.5 dSm^{-1}, while lettuce at EC is 1.6 dSm^{-1} [36].

In lettuce (**Table 6**), nutrient solution treatment only had a significant effect on the variable dry weight of the canopy. Treatment P2 resulted in a higher canopy dry weight than treatment P3 but it was not significantly different from treatment P1 and P4. Treatments P1, P3 and P4 produced the same dry weight of the canopy (see Appendix D).

In red spinach (**Table 6**), treatment P1, P2, and P4 produced canopy fresh weight and dry weight of the canopy were not significantly different (see Appendix E). The three treatments resulted in the fresh weight of the canopy and the dry weight of the canopy which was higher than that of the P3 treatment. As in mustard greens, LFGF + AB-Mix (v/v: 1: 3) treatment can produce better growth of lettuce and red spinach than LFGF + AB-Mix (v/v: 3: 1) treatment.

4. LFGF treatment on mustard plants in pots

4.1 Research methods

The experiment was carried out from March to July 2017 in the greenhouse of the Agricultural Faculty of UST. The experiment began with the manufacture of LFGF [3] and continued with the treatment of LFGF on mustard plants cultivated in plastic pots. Materials for the LFGF application test included: the seeds of Caisin mustard (*Brassica chinensis* var. parachinensis), polybags, husk charcoal, sand and compost. Tools that included EC/DHL/pH meters, scales, ovens, plastic pots with a diameter of 15 cm and watering cans.

The LFGF application experiment in the cultivation of mustard greens in pots was carried out with a single factor experiment which was designed in a completely randomized design. Types of treatment included the time interval for LFGF fertigation (watering): once a day (P1), two days (P2), three days (P3), four days (P4), and without the application of LFGF (P0). The experiment used 5 replications. Each experimental unit used 5 mustard plants grown in plastic pots.

The mustard plant seeding was carried out in a seedbed filled with a mixture of sand, compost and husk charcoal (v/v: 1: 1: 1). The mustard greens were sown by sowing the mustard seeds in a seedbed that had been filled with media. Spray the media twice a day in the morning and evening using a hand sprayer so that the nursery media was always moist. The mustard seedlings were allowed to grow in a seeding tub for 2 weeks, after which the mustard seeds were transferred to a black plastic pot filled with sand, husk charcoal and compost with a ratio of 1: 1: 1 (v/v) for treatment P0, and filled sand and husk charcoal with a ratio of 1: 1 (v/v) for treatment P1, P2 and P3. Filling the planting medium into the plastic pot was carried out to a height of 12.5 cm from the bottom of the plastic pot.

Plant maintenance included watering the plants with LFGF according to the treatment. LFGF was given by diluting with water with a ratio of 1: 40 (v/v) to obtain a concentration (EC) of 2,300 μScm^{-1}. Watering with LFGF was done in the morning on the plants and the potting media to field capacity (about 250 ml per plant) using a watering can. The control plant (P0) was watered only. In the afternoon all the plants were watered with water to field capacity.

Harvesting was done when the plants were 35 days old by removing the plants from the growing medium. The roots of the plants were cleaned from the planting medium, then observed growth variables including: root/stem fresh weight, leaf fresh weight, root/stem dry weight, leaf dry weight, and plant dry weight.

4.2 Results and discussion

LFGF fertigation treatment at intervals of 3 days (P3) and 4 days (P4) resulted in better mustard plant growth than LFGF fertigation at intervals of 1 day (P1), 2 days (P2), and without LFGF fertigation (P0) (**Table 7**) (see Appendix F). The P0 planting medium used in this experiment consisted of a mixture of sand + compost + husk charcoal (v/v: 1: 1: 1), a relatively fertile planting medium with a pH of 7.3, 25% organic matter content, N 1.97%, and P 1.35%, while the planting media P1, P2, P3, and P4 consisted of a mixture of sand + husk charcoal (v/v: 1: 1) having a pH of 7.5, 17% organic matter content, N 0. 25%, and P 0.09%.

Treatment	Leaf fresh weight (g)	Root/stem fresh weight (g)	Leaf dry weight (g)	Root/stem dry weight (g)	Plant dry weight (g)
P_0	57,60 c	41,4 b	5,07 c	5,11 b	10,18 b
P_1	128,4 b	38,8 b	11,11 b	4,87 b	15,98 b
P_2	127.0 b	44,0 b	11,52 b	5,52 b	17,04 b
P_3	202,4 a	65,6 a	18,22 a	8,25 a	26,47 a
P_4	175,6 a	70,8 a	15,19 a	8,55 a	23,74 a
P (ρ > F)	<0,0001	<0,0001	<0,0001	0,0018	<0,0001

Note: The mean number in the column followed by the same letter shows no significant difference based on DMRT 5%.
P_0: Without LFGF fertigation.
P_1: LFGF fertigation with interval 1 day.
P_2: LFGF fertigation with interval 2 days.
P_3: LFGF fertigation with interval 3 days.
P_4: LFGF fertigation with interval 4 days.

Table 7.
Average leaf fresh weight, root/stem fresh weight, leaf dry weight, root/stem dry weight, and mustard plant dry weight at 35 days after planting.

The planting medium in this experiment was half of sand, so it required more frequent fertilizer application. According to Relf et al. [37], sand soil requires more frequent fertilization than clay soil. Vegetables grown on porous growing media require more frequent fertilization, vegetables grown on clay require less fertilizer than vegetables grown on sandy soil [38]. Other factors that affect the frequency of fertilizer application include the type of plant, the plant growth stage, the frequency and amount of water given, and the type of fertilizer. Leaf vegetable plants require more nitrogen fertilizer [37]. Plants grown on organic soil require a little extra fertilizer. Liquid fertilizers are usually given with a frequency of once a week [38].

In this experiment LFGF was given with EC 2,300 μScm^{-1}. The application of liquid organic fertilizer to paprika plant seeds with liquid organic fertilizer made from shrimp and seaweed extract fermented using Trichoderma harzianum can improve the quality of plants fertilized 3 times a week with EC 1.5 $mScm^{-1}$ and watering every day as needed [39]. Experiments on elephant grass plants grown in pots showed that the treatment of liquid organic fertilizer from the *Centrosema pubescens* plant extract at a dose of 40 ml pot^{-1} resulted in a higher number of tillers and plant fresh weight than the lower dose treatment, namely 30, 20, 10 ml pot^{-1}. The lower the dose of liquid organic fertilizer, the less the number of tillers and the fresh weight of the plant [40]. Liquid organic fertilizer treatment can increase the ability of citrus plants to absorb macro and micro elements [41]. Furthermore, organic fertilizers have a positive effect on the carbohydrate content (fructose, glucose, and sucrose) of citrus fruits.

In this experiment, the planting medium used was limited in volume, accommodated in a plastic pot with a diameter of 15 cm. The planting medium used was a mixture of sand, husk charcoal and compost with a ratio of 1: 1: 1 (v/v) for control treatment, and a mixture of sand and husk charcoal with a ratio of 1: 1 (v/v) for other treatments. The limited volume of planting media resulted in limited availability of nutrients in the P0 treatment (control) despite the addition of compost, so that the growth and yield of control plants (without LFGF treatment) was not optimal. The size of the plastic pot (planting container) has an effect on the volume of plant roots, thereby affecting plant growth [42]. Pooter et al. [43] suggest that researchers be careful in determining the size of the pot in their research, as small pots can adversely affect the results of the study. However, the LFGF treatment (P1, P2, P3, and P4) gave better plant growth and yield than without LFGF treatment (P0). This indicates that the provision of LFGF can lead to more adequate availability of plant nutrients so that it does not require a heavier root volume.

Watering LFGF once every 3 days (P3) or once every 4 days (P4) resulted in higher plant growth and yield than watering LFGF once a day (P1) or once every 2 days (P2). This shows that the P3 and P4 treatments cause the availability of nutrients and organic acids in the optimum conditions for plant growth, while in the P1 and P2 treatments the availability of organic acids is too high so that it inhibits plant growth. At high concentrations it can have a negative effect on plant growth [35].

5. Conclusions

Increasing the concentration of ZA results in an increase in the total content of N and S, as well as an increase in EC of LFGF. Increasing the sugar concentration stimulates the formation of lactic acid at both low and high ZA concentrations, while an increase in ZA decreases the formation of acetic acid at both low and high sugar concentrations. Increasing the organic acid content decreases the pH of LFGF.

The combination of LFGF + AB-Mix (v/v: 1: 3) (P2) shows that the most ideal nutrient solutions, nutrient solutions not only having complete and optimum nutritional content, but also containing organic acids in optimum concentrations. It can produce the best growth and yield of pakcoy mustard plants are better than the control (AB-Mix), while the P2 treatment on lettuce and red spinach results in the same plant growth and yield as the control.

LFGF treatment with EC 2,300 μScm^{-1} and a time interval of 3 days on a mixed planting medium of sand + husk charcoal (v/v: 1: 1) can result the availability of nutrients and other compounds (organic acids) in optimal conditions for the growth of caisin mustard plants. It can produce the highest growth and yield of caisin mustard plants.

The non-traditional use of goat manure in the form of LFGF can increase the yield of leaf vegetables, both in potted and hydroponic cultivation, so that it can be economically profitable.

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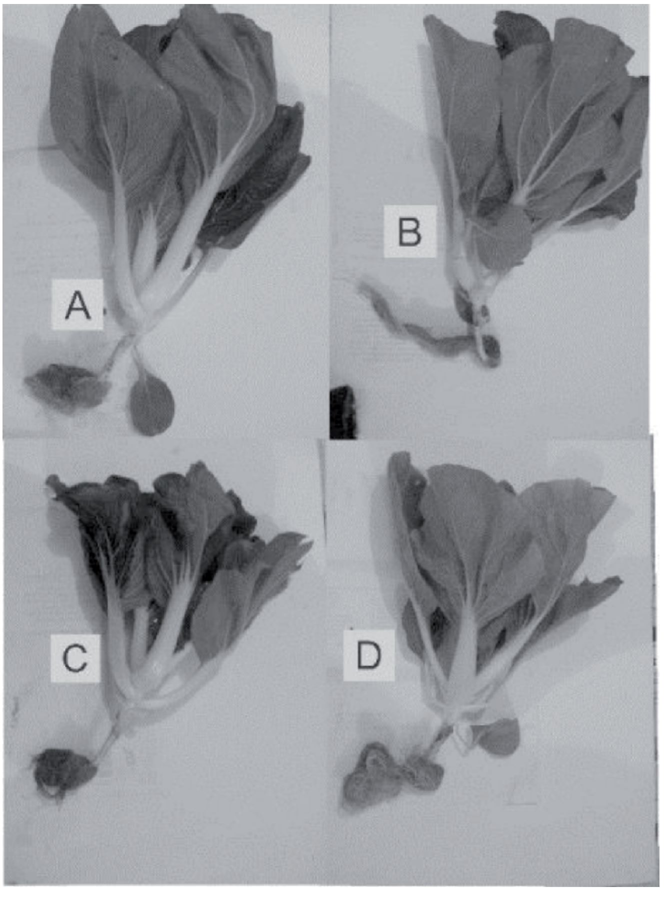
Conflict of interest

None.

Appendix A. Fermentation of LFGF

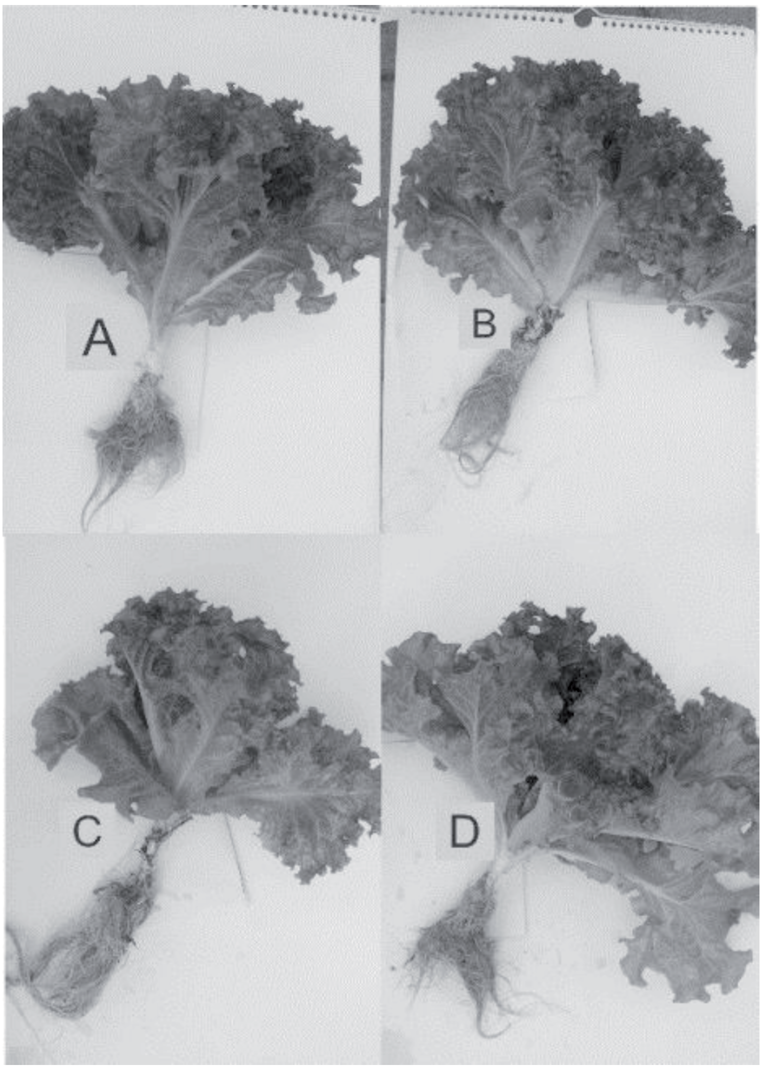
B. Hydroponic installation of Shallow Flow Technique (SFT)

C. Pakcoy mustard plants at 35 days of age



A: Plant treated with LFGF + AB-Mix (v/v: 1:1) (P1).
B: Plant treated with LFGF + AB-Mix (v/v: 1:3) (P2).
C: Plant treated with LFGF + AB-Mix (v/v: 3:1) (P3).
D: Plant treated with AB-Mix (v/v: 1:1) (P4).

D. Lettuce plants at 35 days of age

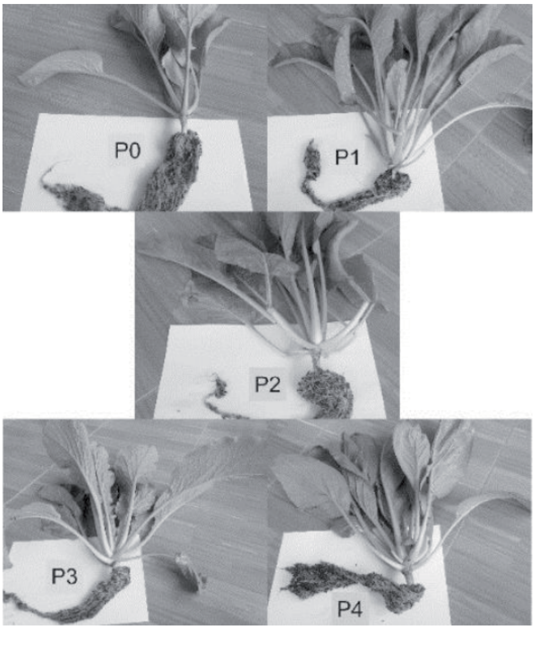


A: Plant treated with LFGF + AB-Mix (v/v: 1:1) (P1).
B: Plant treated with LFGF + AB-Mix (v/v: 1:3) (P2).
C: Plant treated with LFGF + AB-Mix (v/v: 3:1) (P3).
D: Plant treated with AB-Mix (v/v: 1:1) (P4)

E. Spinach plants at 35 days of age

A: Plant treated with LFGF + AB-Mix (v/v: 1:1) (P1).
B: Plant treated with LFGF + AB-Mix (v/v: 1:3) (P2).
C: Plant treated with LFGF + AB-Mix (v/v: 3:1) (P3).
D: Plant treated with AB-Mix (v/v: 1:1) (P4)

F. Caisin mustard plants at 35 days of age



P_0: Plant treated without LFGF fertigation.
P_1: Plant treated with LFGF fertigation with interval 1 day.
P_2: Plant treated with LFGF fertigation with interval 2 days.
P_3: Plant treated with LFGF fertigation with interval 3 days.
P_4: Plant treated with LFGF fertigation with interval 4 days.

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Section 9

Animal Health

Chapter 13

Bacterial Diseases of Goat and Its Preventive Measures

Kumaragurubaran Karthik and Manimuthu Prabhu

Abstract

Bacterial diseases of goats can cause huge economical loss to the farmers. Due to intensification of goat farming and poor hygienic practices there is increase in the number of bacterial diseases that affect the goats. Diseases like tuberculosis, Johne's disease and Brucellosis are chronic diseases that may be identified in the initial stages of infection during which they spread to other animals. Similarly, brucellosis, tuberculosis and also anthrax are zoonotic diseases hence due consideration has to be provided while handling animals suspected for these diseases. Use of vaccine before onset of the disease in endemic areas can prevent the disease outbreak and spread to other naïve population. Good hygienic practices and biosecurity measures at farm are essential to prevent disease spread. The present chapter deals with various bacterial diseases affecting goats and its preventive measures. This chapter can be a guide to field veterinarians, students and farmers as it highlights the important bacterial diseases of goats.

Keywords: Goat, Bacterial disease, Brucella, Anthrax, Preventive measures

1. Introduction

Due to intensification of small ruminant farming, there is increase in the number of disease outbreaks in the recent years. Among the various infectious diseases, diseases caused by bacterial pathogens contribute to severe economic loss to the goat farmers. Various factors like increase in herd size, reduced ventilation in farm and poor husbandry practices can predispose to diseases. Bacterial diseases like anthrax, enterotoxaemia, tetanus, gas gangrene, caseous lymphadenitis, listeriosis, tuberculosis, Johne's disease, dermatophilosis, pasteurellosis/mannheimiosis, brucellosis, foot rot, contagious caprine pleuropneumonia, colibacillosis, salmonellosis, etc., affect goats and can cause various ailments and some diseases can cause heavy mortality leading to huge economic loss to the farmer [1]. Different bacterial pathogens affect different organs of goat thereby eliciting various clinical signs based on which a tentative diagnosis can be made (**Figure 1**).

Antibacterial agents can be used to treat various bacterial diseases but these drugs should be used judiciously due to the risk of development of antimicrobial resistance. Vaccination is the best way to prevent infectious diseases and based on the pattern of the disease annual vaccination should be practiced to prevent disease outbreaks. Diseases like anthrax, brucellosis and tuberculosis pose threat to human since these diseases can be transmitted to human through direct or indirect route of transmission [2]. Due care should be taken while handling infected goats or dead goats in farm as the zoonotic diseases can cause severe aliments in human.

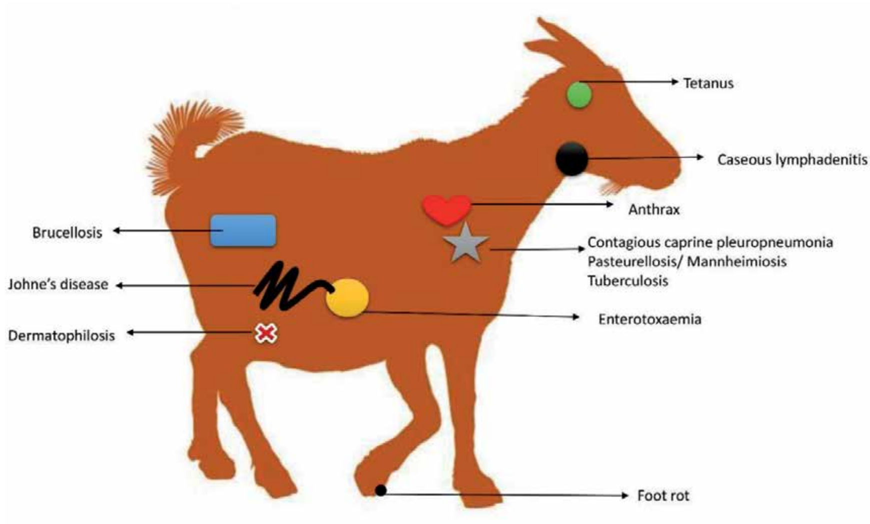

Figure 1.
Different bacterial diseases of goat and the organ/ tissues affected. Brucellosis affects reproductive tract, dermatophilosis affect the skin, johne's disease causes corrugation of intestine, pasteurellosis/ mannheimiosis, tuberculosis, contagious caprine pleuropneumonia affects the respiratory system, caseous lymphadenitis affects the lymph nodes and tetanus affects the nervous system. This figure is propriety of the authors.

2. Methods

This chapter is a comprehensive summary of important bacterial diseases of goats and this can be a guide to veterinary students, field veterinarians and goat farmers regarding the impact of these bacterial diseases. This chapter also highlights the preventive measures and zoonotic potential associated with the bacterial diseases of goats. Important bacterial diseases that are zoonotic and economically important like anthrax, brucellosis, tetanus, enterotoxaemia, Johne's disease, Pasteurellosis/ Mannheimiosis, caseous lymphadenitis, contagious caprine pleuropneumonia, dermatophilosis and foot rot are discussed. Each disease is delt with various subsections like definition of the diseases, etiology, epizootiology, transmission clinical signs, diagnosis, treatment, preventive measures and public health significance, if any.

3. Anthrax

Anthrax is a peracute, acute or subacute, often fatal disease of animals including goats. In goats the disease is mainly characterized by septicaemia, splenomegaly and gelatinous infiltration of subcutaneous or subserosal tissues. The disease is commonly known as woolsorter's disease, splenic fever, charbon, and milzbrand.

3.1 Etiology

The disease is caused by *Bacillus anthracis*, a gram positive, capsulated, non-motile, aerobic, spore-forming, rod shaped bacterium [3].

3.2 Epizootiology

The disease is worldwide in distribution and is endemic in some countries, while occurs in defined regions of other countries. It was reported to be associated with heavy mortalities in goats and sheep of sub-saharan region in 1960–70s and in other countries. In recent days, through strict vaccination procedures the incidence reduced in most countries, however, sporadic cases are still being reported. *B. anthracis* is widely distributed in the environment, as they produce highly resistant endospores. They can tolerate extremely adverse conditions such as desiccation, high temperatures and chemical disinfectants. When the vegetative bacteria are exposed to atmospheric oxygen under favorable temperature (20–40°C) and relative humidity (>60%), the spores are formed. Further, the calcium plays a role in spore formation and in combination with dipicolinic acid, enhances the spore survival. Hence, its survival is more in alkaline soil that is rich in calcium and nitrogen and with high moisture content, the endospores can survive for more than 50 years. Further, recurrent cycles of flooding and evaporation may concentrate spores in particular low-lying regions [3].

3.3 Transmission

Goats are infected by ingestion of food, water or soil contaminated with spores. The infection can also occur through inhalation or abraded skin and oral mucosa. Mechanical transmission by biting insects is also reported. Wild animals acting as carriers makes the control programme challenging as it is least possible to vaccinate all wild animals.

3.4 Clinical signs

The incubation period ranges from hours to days. The disease is usually fatal, especially in sheep and goats, after 1–3 days. The peracute case is characterized by sudden death without any premonitory signs. However, there may be fever, dysponea, congestion of mucous membranes, muscular tremors and terminal convulsions in few animals. In acute cases, fever, anorexia, labored breathing, increased heart rate, ruminal stasis and reduce milk production may be observed. There may be bloody discharges from orifices like mouth, nostrils, anus and/or vulva. Diarrhea or dysentery and oedema and swelling of the tongue, throat, flank and perineum (anus, vulva) may be seen. Pregnant animal abort and blood-tinged milk is produced. Animals then collapse with terminal convulsions and die [4].

Necropsy of suspected carcass is not recommended, as the vegetative bacteria may get transformed into spore and hence contaminate the environment. The pathological features such as absence of rigor mortis and rapid putrefaction and bloating of the carcass are common clinical features. Oozing of unclotted dark, tarry colored blood from orifices, soft and enlarged spleen, blood-stained fluid in body cavities and widespread ecchymotic hemorrhages are frequently observed post mortem findings.

3.5 Diagnosis

Though clinical signs are highly suggestive, the diagnosis based on clinical signs alone is difficult. Thin smears of blood from ear tip can be stained with polychrome methylene blue stain to reveal short chains of truncated blue color rods, surrounded by pink capsules (McFadyean reaction). The organism can be cultured on Sheep or Ox blood agar which shows flat, dry grayish colonies with 'ground glass' appearance after 24–48 hours of incubation (**Figure 2**). The selective media for the organism is PLET (Polymyxin-lysozyme-EDTA thallous acetate) medium. The Ascoli's thermo-precipitation test is also commonly used test to detect antigens of *B. anthracis*. Agar gel immunodiffusion, complement fixation test, ELISA and immunofluorescence

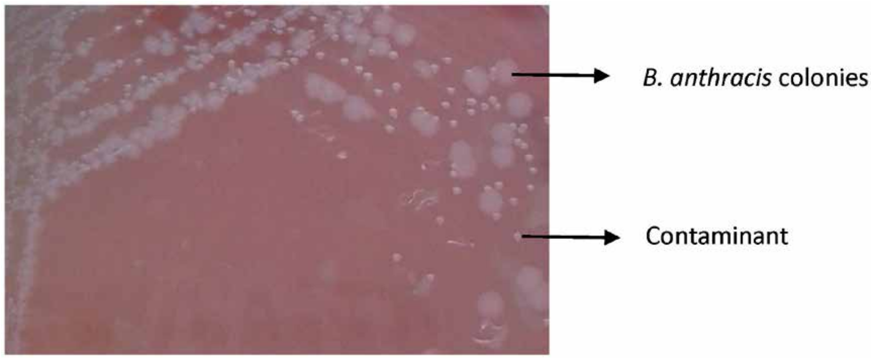

Figure 2.
Ground glass appearance Bacillus anthracis colonies on sheep blood agar. This figure is propriety of the authors.

tests though available are insensitive and not routinely used [4]. The PCR test can be used for direct detection of the organism from decomposed samples and can also be employed for targeting the pXO1 and pXO2 plasmids to confirm the virulence of isolates from the culture.

3.6 Treatment

Ailing animals in early stages of infection can be treated with penicillin or oxytetracycline or other long-acting antibiotics. An anthrax antiserum may result in recovery if used in early stages. Vaccination should follow 7–10 days after the conclusion of antibiotic therapy [4].

3.7 Preventive measures

In endemic areas, annual vaccination is advisable. The goat should be vaccinated with 'Sterne strain' live spore vaccine one month before the anticipated outbreaks. In non-endemic areas, movement of animals and their products should be restricted; feed and bedding materials etc., should not be transferred from affected herds. Disinfection of the premises with 5% formalin, 5% sodium hydroxide or 3% peracetic acid and placing foot-baths containing these sporicidal disinfectants at the entrances of the affected farms will help to control the spread of infection. Contaminated building should be fumigated with formaldehyde before removing the bedding materials [5]. Proper disposal of carcasses and the infected materials should be done either by deep burial or incineration.

3.8 Public health significance

B. anthracis is considered a bioterrorism agent. Three forms of disease occur in human beings. When endospores enter through abraded skin, the cutaneous form of anthrax (malignant pustule) develops. While, the pulmonary form (woolsorters' disease) follows inhalation route and intestinal form results from ingestion of infective material. The disease usually fatal if not treated early [6].

4. Brucellosis

Caprine brucellosis is an infectious zoonotic disease having substantial economic impact on both livestock and human. Caprine brucellosis is reported since ancient days; Hippocrates II first described the human brucellosis in 400 B.C. which was most likely to be associated with consumption of raw milk or derivatives of infected sheep or goats.

4.1 Etiology

The causative agent is *Brucella* species mainly *B. melitensis* that are small, non-motile, non-spore forming, gram-negative coccobacilli. Goats are also susceptible to infection by *B. abortus,* particularly when housed in close proximity with infected cattle; however, they do not sustain the infection in the herd [7].

4.2 Epizootiology

The disease is prevalent worldwide and it remains a major burden in parts of Mediterranean region, the Middle East, Central and Southeast Asia (including India and China), sub-Saharan Africa, and parts of Latin America [8]. Goat herds from USA, Canada, Colombia, Chile, and Uruguay are reported to be free from *B. melitensis* infection.

4.3 Transmission

Infection occurs primarily through ingestion of the organisms. Goats acquire infection by licking the aborted fetuses, placentas, newborn kids, vaginal discharges, or by consumption of feed contaminated with these infectious materials [9]. Milkers can also spread the infection through unsanitary milking practices.

4.4 Clinical signs

The disease is more severe in goats and is protracted than in sheep. Clinical manifestations include high abortion rates particularly during the fourth month of pregnancy and retained placentas, orchitis in bucks, arthritis and hygromas. In goats, mastitis and lameness may also be seen. The abortion rate can be high when this bacterium first enters a naive flock or herd [10]. The abortion rates are usually much lower once *B. melitensis* has become established in a herd and only a few animals abort repeatedly but affected animals shed bacteria during parturition. Healthy asymptomatic carriers become a potential source of infection. Other clinical signs include death of weak offspring, low weaning weight, decreased milk production, and epididymitis, and reduced fertility which is more common in sheep. In case of abortions, fetus might reveal excess of blood-stained fluids in the body cavities, with enlarged spleen and liver. Moreover, infected foetal membranes can show thickened and dull-gray color necrotic cotyledons [11].

4.5 Diagnosis

Diagnosis is made based on clinical signs, direct examination of MZN-stained smears of fluids or tissues, isolation and identification of *B. melitensis* from milk or an aborted fetus or by serum agglutination tests. The Rose-Bengal agglutination test and the complement fixation test are the most widely used methods for detecting *B. melitensis* infection and are approved for international trade. Indirect enzyme-linked immunosorbent assays (ELISA) have been developed and are also approved tests for the purposes of international trade [12]. Isolation and identification of *B. melitensis* from aborted foetal stomach contents, placenta and uterine fluids can be

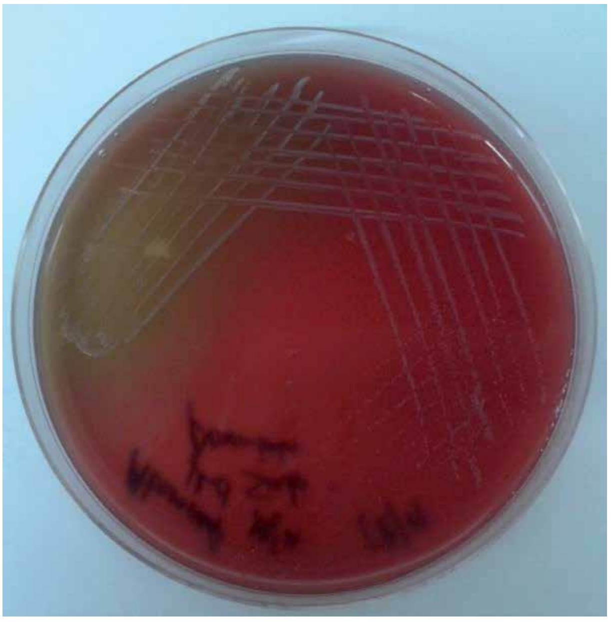

Figure 3.
Brucella melitensis colonies on sheep blood agar. This figure is propriety of the authors.

attempted and isolation is the gold standard technique for confirmation of brucellosis (**Figure 3**). Isolation should be carried out in biosafety cabinet class III as the organism is zoonotic.

4.6 Preventive measures

Test and slaughter policy of the infected herd is generally implemented in countries where the disease is considered exotic. This can also reduce the prevalence of disease in endemic areas. In most countries where *B. melitensis* is endemic, vaccination with the Rev. 1 strain is commonly employed [13]. It is a live attenuated strain of *B. melitensis*; administered by the subcutaneous or conjunctival routes and is used for vaccination of kids and lambs up to 6 months of age.

4.7 Public health significance

B. melitensis is highly pathogenic than other species of Brucella for human beings. The infection in human is characterized by fever, chills, headache, malaise, back pain, myalgia and lymphadenopathy, which may be accompanied by splenomegaly and/ or hepatomegaly. The patients may experience drenching sweats at night and nonspecific gastrointestinal signs such as vomition, diarrhea and/or constipation [14]. Localized manifestations such as arthritis, spondylitis, sacroiliitis, osteomyelitis, bursitis and tenosynovitis may be observed. Epididymo-orchitis, prostatitis and seminal vesiculitis can be seen in males, whereas abortion or premature births are seen in pregnant women. Deaths are usually uncommon except in infants caused by endocarditis or infections of the brain.

5. Tetanus

Tetanus (Lockjaw) is an acute, highly fatal intoxication of all domestic animals and humans caused by neurotoxin produced by the bacteria *Clostridium tetani* [15].

Though all species of livestock are susceptible, sheep and goats are more susceptible than cattle and horses being the most susceptible. It is characterized by hyperasethesia, tetany and convulsions.

5.1 Etiology

The etiological agent, *Clostridium tetani* is a strictly anaerobic, motile, slender, straight, spore forming ('drumstick appearance'), Gram-positive rod. Based on flagellar antigens, so far 10 serotypes of *C. tetani* have been described and all produce antigenically a similar neurotoxin called tetanospasmin. Though endospores are resistant to chemicals and boiling, they are destroyed by autoclaving.

5.2 Epizootiology

Tetanus is worldwide in distribution and occurs sporadically. The organism is normal inhabitant of intestinal tract of animals and persists as resistant spores in soil, manure [16].

5.3 Transmission

The toxemia in tetanus is caused by a specific neurotoxin produced by *C. tetani* in necrotic tissue. Spores are introduced into the tissue through wounds, specifically deep puncture wounds that provide the favorable anaerobic environment. Most outbreaks occur following mass contamination of animals during castration, vaccination, ear tagging, docking and other surgical procedures [17]. Grazing on rough and spiky pastures may injure the oral mucosa and hence may facilitate the invasion of the bacteria. The spores remain dormant in tissues and proliferate to liberate toxins under favorable conditions.

5.4 Clinical signs

The incubation period is usually of 4 days to 3 weeks. The initial signs include muscle stiffness, tremors and prolapse of the third eyelid. This is followed by rigidity and extension of the limbs leading to a stiff gait and abnormal flexion of the joints. Tetany of masseter muscles causes drooling of saliva (lock jaw) and regurgitation through nostrils [17]. The animals may exhibit bloat, an inability to chew, and hyperthermia. Retracted lips, hypersensitivity to external stimuli, and a 'saw-horse' stance are frequent signs. The spasms of alimentary and urinary tract muscle may cause constipation and retention of urine [17]. The abnormal muscular contracture may result in opisthotonus, curvature of the spine and bending of the tail. The disease is highly fatal and death occurs within 3–10 days with mortality nearing 100%, primarily as a result of respiratory failure. Necropsy features usually are nonspecific except for the inflammatory reaction associated with the wound.

5.5 Diagnosis

Diagnosis can be made based on clinical features such as muscular spasms, prolapse of third eyelid and based on history of trauma or surgery. The Gram-positive rods with terminal spores can be demonstrated in the smears prepared from necrotic tissue or wound [18]. Anaerobic culture of the bacteria from necrotic tissue may be attempted but is often unsuccessful. PCR and real-time PCR techniques can be employed for the detection of neurotoxin genes of the organism. Mouse inoculation test can be performed to demonstrate circulating neurotoxin from the serum of affected animals.

5.6 Treatment

Treatment mainly aimed at wound management, antibiotic therapy, antitoxin administration and vaccination. Wound management consists of surgical debridement of infected wounds and removal of debris, flushing with hydrogen peroxide to produce aerobic condition that helps to inhibit replication of the bacteria at the site of infection. The antibiotics (large doses of Penicillin) can be given both parenterally and flushed into the cleaned wound to prevent further replication of the bacteria and production of toxin [19]. Affected animals must be kept in a quiet and dark environment. Fluid replacement therapy, sedatives and muscle relaxants can minimize clinical discomfort and maintain vital functions. To neutralize unbound toxin, the tetanus antitoxin must be administered on time, either intravenously or into the subarachnoid space for three consecutive days. Vaccination with tetanus toxoid may be given subcutaneously to promote an active immune response even in those animals that are treated with antitoxin.

5.7 Preventive measures

Tetanus can be controlled by following good sanitation measures, aseptic surgical and management procedures and vaccination. Goats in a herd must be vaccinated routinely with tetanus toxoid which is very effective for stimulating long-term immunity. They can be vaccinated 2–3 times during the first year of life followed by booster vaccination before parturition to ensure colostral antibodies [20]. Further, a booster dose may be advisable if a vaccinated animal sustains a deep wound.

6. Enterotoxemia

6.1 Etiology

Enterotoxaemia in goats is caused by *Clostridium perfringens,* a gram-positive, non-motile, spore-forming bacilli that grows well in anaerobic or micro-aerophilic conditions. This disease condition tends to be associated mainly with sheep and is of less importance in goats and cattle. *C. perfringens* Type D primarily produce enterotoxamia and Type C sometimes causes sudden death in goats. Grain-fed kids (3–12 weeks old) on a high-concentrate diet are most susceptible, but adult goats may also be affected. Goats are commonly affected with a hemorrhagic form of enterotoxemia.

6.2 Epizootiology

C. perfringens is worldwide in distribution and is found in soil, feces, and in the intestinal tracts of animals and humans. *C. perfringens* types B, C and D may survive in soil as spores for several months. *C. perfringens* type A constitutes a part of the normal intestinal flora and is widely dispersed in soil. Overcrowding and prolonged confinement may increase the spread and severity of the condition.

6.3 Transmission

The *C. perfringens* type D is found as obligate parasite in the intestinal tract of animals [21]. The animals on a high grain diet or on succulent pasture are predisposed to this condition (hence described as ‘over-eating disease’). Thus, the disease is more common in well-fed animals in intensive feedlots.

6.4 Clinical signs

The peracute condition is characterized by sudden death of younger and healthy kids. This is occasionally preceded by other signs such as loss of appetite, lack of rumen activity and rumination, bloat, depression and a drunken appearance; the animals may show neurological signs such as incoordination, inability to stand, and convulsions. There may be watery diarrhea and glucosuria. In goat's acute disease is mainly characterized by dysentery, abdominal discomfort and convulsions.

In acute cases of goats, the necropsy findings include pulmonary edema, necrosis of intestinal walls and scattered hyperaemic areas of intestine. Intestinal contents may be green, blood-stained or mucoid, and fibrinous casts may be present in the lumen of the large intestine [22]. Mesentric lymph nodes may be edematous. Fluid accumulation in the pericardial sac, extremely necrotic, soft kidneys ('pulpy kidneys'), focal encephalomalacia, and petechiae of serosa of the brain, diaphragm, gastrointestinal tract and heart are common findings.

6.5 Diagnosis

Diagnosis of enterotoxaemia depends on epidemiological features, type of diet, clinical and pathological features. Gram positive rods can be demonstrated in the smears of intestinal contents or in the lesions of intestine. The culture of bacteria from fecal samples in cooked meat media may be suggestive of the disease (**Figure 4**). Organism on blood agar plates show double zone of hemolysis which is suggestive of *C. perfringens*. Demonstration of the epsilon toxin in the intestinal content is highly reliable method. Protection of mice injected with infiltrates of toxin from intestinal contents against specific antisera is diagnostic. Genotyping by PCR can be used to type isolates of *C. perfringens* as an alternative to in vivo toxin neutralization tests.

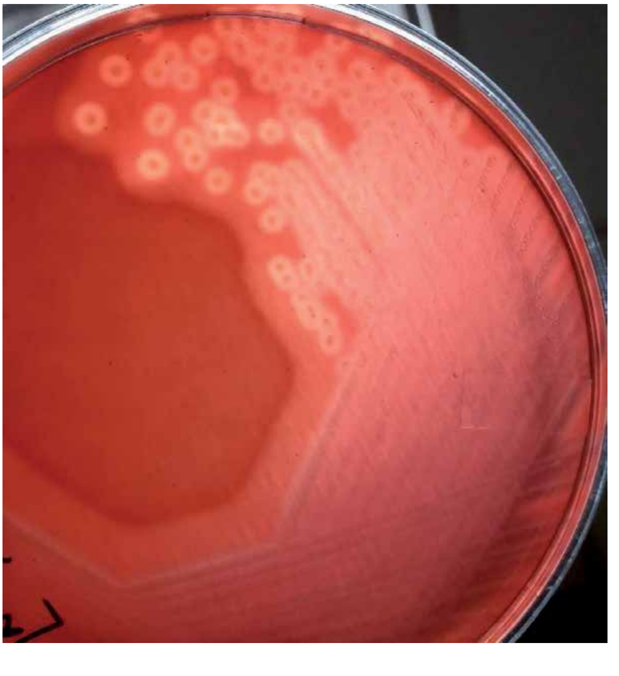

Figure 4.
Double zone hemolytic colonies of Clostridium perfringens on sheep blood agar. This figure is propriety of the authors.

Though ELISA tests can be performed, misdiagnosis may occxur as this test detects low levels of toxin in the intestinal contents of normal animals [23].

6.6 Treatment

Treatment generally is ineffective as most cases are acute in nature. A hyperimmune serum, if available, can be used and a combination of hyperimmune serum along with sulphadimidine has been found useful in goats. Chelating agents can be used to neutralize toxins [21].

6.7 Preventive measures

Vaccination before the anticipated outbreaks is the primary method of control. Alum precipitated formalin killed whole culture toxoid vaccines are commercially available. In ruminants, maternal antibodies last about 5–6 weeks postpartum and hence, the young animals must be vaccinated at this time. Kids are usually vaccinated twice at 4 weeks interval and then re-vaccinated at once in 6 months. However, several anaphylactic reactions have been reported in Sannen kids re-vaccinated with toxoids [24]. Sudden dietary changes and other predisposing factors to enterotoxaemias must be managed. Feeding regimens and feeding of concentrates even to adult goats should be monitored carefully.

7. Johne's disease (JD)

A chronic, contagious, granulomatous disease affecting small intestine of adult ruminants and the affected animals show weight loss and intermittent diarrhea [25].

7.1 Etiology

JD is caused by *Mycobacterium avium* subspecies *paratuberculosis*, a fastidious, acid-fast, gram-positive rod [25].

7.2 Transmission

The organism is present in the environment and animals at young are affected either through ingestion of contaminated milk or direct contact. Infected goats may excrete the bacteria in the feces thereby contaminating the environment [26].

7.3 Clinical signs

The incubation period is usually months to years. Chronic wasting is a characteristic sign in goat and at times pasty feces or diarrhea (in advanced cases) can be witnessed. In advanced cases the animals may lose weight rapidly and will have a hide and bone condition. During PM examination intestine of the affected animals have a corrugated appearance [27].

7.4 Diagnosis

Affected animals can be identified in the herd by intradermal skin testing using Johnin purified protein derivative (PPD). Alternatively, Interferon gamma assay (IGRA) can also be used to assess the cellular immunity. Lymph nodes (Ileal and ileocecal) aspirates, intestinal scrapping can show acid fast bacilli in staining

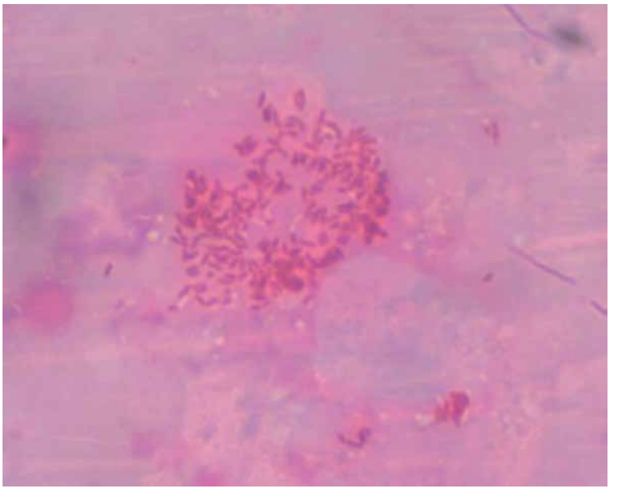

Figure 5.
Acid fast bacilli in intestinal scrapping. This figure is propriety of the authors.

(**Figure 5**). Organism my shed intermittently in feces and hence, bacilli can be found by acid fast staining [27]. Organism can be detected intestinal tissues, lymph node and feces by culture and PCR. Detection of antibody in the later or final stages of the disease can also be attempted for diagnosis.

7.5 Treatment

Treating animals with antimycobacterial agents are not fruitful.

7.6 Preventive measures

Due to its chronic nature, it is difficult to identify the disease early hence, it is advised to test a newly purchased animal before letting into the farm. Test and cull policy is better to break the chain of infection. Suspected animals should be separated from the herd and affected animals milk should not be fed to neonates [25]. The organism may survive longer in the pasture hence, once an animal is found positive it is best to change the pasture land.

7.7 Public health significance

A similar condition in human named as Crohn's disease has been suspected to be caused by *Mycobacterium avium* subspecies *paratuberculosis* still there is no clear evidence for zoonotic transmission of the pathogen [28].

8. Pasteurellosis and Mannheimiosis

Pasteurellosis and Mannheimiosis is an acute fatal disease characterized by pneumonia and septicemia.

8.1 Etiology

Pasteurella multocida and *Mannheimia haemolytica* are aerobic, bipolar, nonmotile, non-spore forming gram-negative rods [29].

8.2 Epizootiology and transmission

P. multocida and *M. haemolytica* are ubiquitous and even present in respiratory tract of healthy animals. Young animals are prone to infection than adults. Stress including weaning, transportation (hence termed as shipping fever), change in diet/weather and overcrowding are the predisposing factors for the condition. Viral diseases can also predispose Pasteurellosis and Mannheimiosis and the organism can be transmitted directly or indirectly through inhalation or ingestion [30].

8.3 Clinical signs

Acute rhinitis or pharyngitis is the common sign noticed in animals. Animals may have high fever, anorexia, and rapid breathing along with profuse mucopurulent nasal/ocular discharges. Kids are more susceptible than adult goats and death may occur without any clinical signs [30]. PM changes include marbling of lungs, pleural adhesion, sero-fibrinous fluid in the thorax, frothy exudate in trachea and also in bronchi.

8.4 Diagnosis

Bipolar organisms of *P. multocida* can be noticed in the impression smears from dead animals (**Figure 6**). Isolation of the organism on selective media and biochemical confirmation is the standard diagnostic procedure. *M. haemolytica* produces hemolytic colonies on blood agar and it can grow on MacConkey agar which are the differentiating features from *P. multocida*. Molecular diagnosis can be carried out by PCR [31].

8.5 Treatment

Use of antibiotics based on antimicrobial susceptibility testing can be used to control the bacterial propagation and anti-inflammatory agents can be used to control fever [30].

8.6 Preventive measures

M. haemolytica and *P. multocida* bacterins can be used as vaccines to prevent the occurrence of the disease [32]. Other measures like reducing overcrowding thereby improving the ventilation in enclosures and also reducing the stress during transportation can prevent the occurrence of the disease.

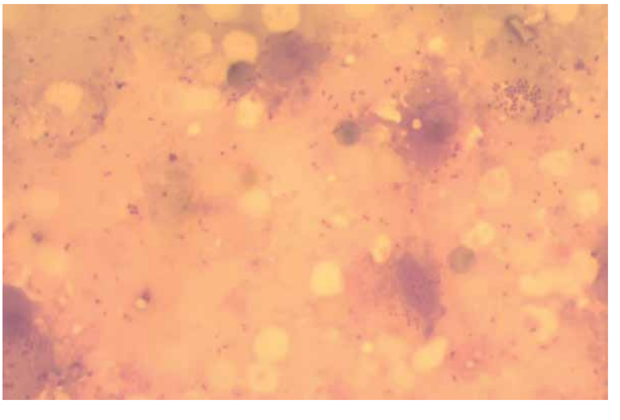

Figure 6.
Bipolar organism in lung impression smear. This figure is propriety of the authors.

9. Caseous lymphadenitis

Caseous lymphadenitis (CLA) is contagious, subclinical and chronic suppurative condition of sheep and goats, occasionally in cattle and is characterized by the formation of abscesses in lymph nodes and visceral organs [33].

9.1 Etiology

CLA is caused by *Corynebacterium pseudotuberculosis*, small, non-motile, non-spore forming, pleomorphic, Gram-positive bacteria which may occur in curved, coccoid, club and rod forms (coryneform morphology) [33]. Two biotypes of *C. pseudotuberculosis* are recognized; ovine/caprine biotypes that lack nitrate-reducing capacity mainly affect sheep and goats, causing superficial and visceral abscesses. The second equine/bovine biotype usually reduce nitrate and mainly affects horses and cattle, causing ulcerative lymphangitis.

9.2 Epizootiology

CLA is worldwide in distribution and the probable dissemination of the disease throughout the world occurred through importation of infected animal [34]. This disease is found in parts of North and South America, Australia, New Zealand, the Middle East, Asia and Africa and is being reported more often in Britain and other European countries.

9.3 Transmission

The bacteria can survive in the environment for about 6 months or more. Transmission can occur either through direct or indirect contact or through wounds contaminated with pus from the abscesses of infected animals. The organism enters through contamination of skin wounds arising from castration, ear tagging or tattooing, docking or shearing operations. Arthropod bites or contaminated dips can also be the source of infection [34]. Goats having traumatized buccal mucosa have more chances of taking the bacterium from contaminated feed. The organism has also been isolated from the milk of affected goats.

9.4 Clinical signs

The incubation period varies from weeks to months; usually is about 3 months. CLA may be manifested in two forms: in its superficial form it is characterized by infection of peripheral lymph nodes, such as the submandibular, parotid, prescapular and supramammary lymph nodes (**Figure 7**). These peripheral lymph nodes enlarge, may erode and eventually leads to formation of abscess in chronic cases. Visceral form is characterized by abscessation of internal organs, such as lungs, liver, kidneys, uterus, spleen and internal lymph nodes (mainly mediastinal and bronchial lymph nodes) that may not be detectable antemortem [35]. These two forms can co-exist; however, the visceral form is more common among sheep, while superficial form is more frequent among goats with external abscesses in the lymph nodes particularly of the head and neck regions.

Eventually, the affected animal become exercise-intolerant, anorectic, ill-thrift and debilitated (often known as thin-ewe syndrome in sheep). Fever, increased respiratory rates, and pneumonia may also be noticed. Morbidity up to 15% is common, and morbid animals will often eventually succumb to the disease. The infection can also lead to abortion in doe and orchitis and/or epididymitis in bucks.

Figure 7.
Lymph node enlargement in goats noted in caseous lymphadenitis. This figure is propriety of the authors.

Though less common, orchitis can be acute in which the buck develops fever, reduced appetite, lack of walking ability and loss of libido. The infected testes appear swollen, hot and painful to touch.

9.5 Diagnosis

Diagnosis is based on clinical signs and lesions and abscessation of both superficial and visceral lymph nodes is typical. Radiographs may be useful in identifying affected central nodes which also must be confirmed by culture of tracheal washings. Gram and Giemsa staining can be used for identification of the bacteria. Isolation of organism from purulent material from abscessed lymph nodes in case of live animals and /or from abscesses of internal organs from dead animals. ELISA tests which detect antibodies directed against either cell wall antigens or the exotoxin (Phospholipase D - PLD) are available [34]. Further, the detection of INF-γ by ELISA, an indicator of cell-mediated immunity, has also been potentially used for demonstration of CLA in eradication programs. Molecular techniques such as PCRs targeting 16S rDNA, *rpo* and *pld* genes have also been used in the recent years for the diagnosis of caseous lymphadenitis.

9.6 Treatment

Though *C. pseudotuberculosis*, in vitro is susceptible to antibiotics, the antibiotic therapy is usually not much effective in animals. The chronic nature of infection, the intracellular location of the bacteria and the formation of biofilm in natural infections reduce the antibiotic efficacy, making them useless. Draining of abscesses, followed by cleansing and chemical cauterization with 10% iodine may be helpful or the localized abscesses may be removed entirely from valuable animals [34].

9.7 Preventive measures

As CLA is contagious in nature, the animals with draining and punctured lesions should be kept isolated until healed. Reducing the environmental contamination, proper sanitation and biosecurity of facilities and instruments and safety measures to prevent injuries are all important in control. The causative agent is sensitive to common disinfectants such as hypochlorite, formalin and cresol; however, the surfaces should be cleaned before disinfection, as organic matter usually interferes with the action of these agents. The control measures vary with the prevalence of infection. In countries with a high incidence, rigorous sanitary procedures must be implemented, along with vaccination. Disease eradication can be achieved in endemically-infected herds by test and disposal policy [36].

Most of the commercially available vaccines contain inactivated PLD of either *C. pseudotuberculosis* or of other pathogens, such as *Clostridium* species. Glanvac vaccine (Vetrepharm, Inc. London) is licensed for use in sheep and goats in Canada, Australia and New Zealand. However, the use of PLD toxoid in goats may result in some adverse consequences such as reduction in milk, fever, ventral edema, ataxia and convulsions; therefore, its use is restricted [34]. On the other hand, live vaccines targeting the attenuation of PLD gene, confers the best and longest-lasting immune response, due to its similarity to natural infection.

9.8 Public health significance

Human beings are rarely affected, some cases of human infections have been documented as occupational infection in veterinary doctors and assistant as well as farm experts.

10. Contagious caprine pleuropneumonia

Contagious caprine pleuropneumonia (CCPP) is a highly contagious and rapidly spreading mycoplasmal disease of goat, occasionally sheep and wild ruminants. CCPP is characterized by severe sero-fibrinous pleuropneumonia, very high morbidity (100%), and mortality (80–100%) and results in heavy economic losses.

10.1 Etiology

CCPP is caused by *Mycoplasma capricolum* subspecies *capripneumoniae* (Mccp), which was earlier known as *Mycoplasma* biotype F38. It belongs to the class *Mollicutes* that lack cell wall. *M. ovipneumoniae*, *M. mycoides* subspecies *capri*, and *M. mycoides* subspecies *mycoides* (Large Colony Type) are also considered as etiological agents of caprine pneumonia in the United States [1].

10.2 Epizootiology

CCPP is becoming a novel emerging and rapidly spreading disease in most parts of the world and at present, goat populations in more than 40 countries are affected with CCPP and sporadic cases of CCPP are also being reported from many more countries [37]. It mostly occurs in countries of Africa, Middle East and Asia.

10.3 Transmission

The disease is highly contagious and main mode of transmission is through inhalation of infected aerosols. The direct contact with affected animals is the main source of transmission. Airborne transmission can result in distant spread of about 50 m distance. However, the shorter survival time (3–14 days) of the organisms in external environment limits transmission of Mccp [38]. Yet under cold, moist and overcrowded environment these bacteria can persists for longer durations and may lead to severe outbreaks mostly in winter.

10.4 Clinical signs

CCPP is strictly a respiratory illness and is characterized by severe dyspnea, nasal discharge, cough, and fever. This can occur in peracute, acute and/or chronic forms in endemic areas. In peracute form, affected goats may die within 1–3 days without premonitory clinical signs. In acute infection, the initial signs are high fever (41–43°C), lethargy and anorexia, followed within 2–3 days by coughing and laboured breathing. The cough is frequent, violent and productive. In the final stages of infection, the goat may not be able to move and stands with its front legs wide apart and its neck stiff and extended [37]. Saliva can drip continuously from the mouth, and the animal may exhibit grunt or bleat in pain. Frothy nasal discharge and stringy saliva may be seen terminally. Pregnant goats may abort. Acutely affected goats generally die within seven to 10 days. In the chronic cases, there is chronic cough, nasal discharge and debilitation. These forms with resembling clinical signs in goats were also reported from captive wild goats.

Pathological features during necropsy are also limited to respiratory system. Acute form is characterized by unilateral pneumonia and sero-fibrinous pleuritis with straw colored fluid in the thorax. The lung is granular with copious straw-colored exudates oozing out on cut section. Pea-sized, yellow-colored nodules may be noticed in lungs and these nodules are surrounded by areas of congestion. Varying degrees of lung consolidation or necrosis may also be noticed [37]. The regional lymph nodes mainly bronchial lymph nodes are enlarged. Some long-term survivors reveal chronic pleuropneumoniae or chronic pleuritis, with encapsulation of acute lesions and numerous adhesions to the chest wall. The interlobular septa are not usually thickened in domesticated goats.

10.5 Diagnosis

CCPP can be diagnosed based on cultural, biochemical, serological, and molecular methods following a tentative clinical diagnosis. Ultrasonography and X-rays may help in diagnosis and CCPP-associated changes may be evident in lungs, pleura, thorax, and associated structures. Cultural isolation and identification ('fried egg-like appearance' of the colonies under microscope), though is conventional but is still considered as standard method for detection of Mccp from lung tissue and/or pleural fluid at necropsy. Due to the difficulty in isolation, PCR is the technique of choice for the diagnosis of CCPP. The agglutination tests, ELISA, FAT, CFT (most widely used), passive or indirect haemagglutination tests (IHT) are the immunological methods employed for diagnosis of CCPP [38]. Latex agglutination test is being increasingly used in diagnostic laboratories as a pen side test. It can used to test whole blood as well as serum.

10.6 Treatment

Tylosin is considered the drug of choice against Mccp. Further, oxytetracycline is also found effective when administered in early stages of infection. However, some infections are slow to resolve.

10.7 Preventive measures

In endemic areas, proper care should be taken while introducing new goats into the flock. Flock testing, slaughter, and on-site quarantine may be helpful in controlling the spread of disease. Vaccines available in some areas may help in prevention of the disease. The commercially available CCPP vaccine containing inactivated Mccp suspended in saponin provides protection for over 1 year [37].

11. Dermatophilosis

Dermatophilosis is a chronic, exudative and sometimes proliferative dermatitis occurs in domestic ruminants, wild animals and occasionally in human beings. Also known as Cutaneous streptothricosis, Strawberry foot rot or Lumpy wool.

11.1 Etiology

Dermatophilosis is caused by *Dermatophilus congolensis*, which is a gram positive, nonacid-fast, facultative anaerobic actinomycete that produces motile zoospores.

11.2 Epizootiology

The disease occurs worldwide and is more common in tropics and subtropics. The organism is believed to be a saprophyte of soil and persists in dry scabs and crusts, to survive for up to 42 months. It has been reported from many countries, but occurs particularly in humid climates and areas where ticks of the genus *Amblyomma* are endemic [39].

11.3 Transmission

Transmission occurs by direct contact with infected animals. The infection can be transmitted indirectly by mechanical vectors (ectoparasites) and also through intradermal inoculation by contaminated thorny bushes. The pathogenesis may be influenced by factors such as mechanical injury to the skin, rainfall, tick infestation, concurrent diseases and/or stresses that compromise the host's immune system.

11.4 Clinical signs

The disease is painful but non-pruritic, and is characterized by exudative, proliferative or hyperkeratotic dermatitis, accompanied by the production of crusts and folliculitis. In sheep, it may be seen in two forms: mycotic dermatitis (lumpy wool) and strawberry foot rot. While in goats and cattle, similar signs of crusty, suppurative dermatitis are seen and are often referred as cutaneous streptothricoses. The skin lesions appear raised, thick, yellow-brown colored discrete or confluents crusts containing matted hair. Sometimes may be seen in nodular form also with discrete encrustation of scab. The whole body may be affected but less hairy parts such as ears, axilla, scrotum, prepuce, ventral abdomen, limbs etc., show severe lesions [40]. Lesions in younger goats are mostly seen along the tips of the ears and under the tail. Most affected animals will recover within 3–4 weeks and lesions have little effect on overall health. In severe generalized infections, the animals often loose condition. If there are lesions at the feet, lips and muzzle, the movement of animals and eating become difficult.

11.5 Diagnosis

Diagnosis of dermatophilosis is mainly based clinical signs particularly based on the appearance of the characteristic skin lesions. The same can be confirmed by the demonstration of the organism from the lesions beneath the scabs. The softened scab materials stained by the Giemsa method, reveal the characteristic branching filaments containing zoospores. The organism can be cultured on blood agar at 37°C under 2.5–10% CO_2 for up to 5 days and Haalstra technique based on chemotaxis of the zoospores to CO_2 can be employed for efficient recovery of the organism.

11.6 Treatment

Animals can be treated with antibiotics such as high doses of penicillin or long acting tetracyclines. Topical applications alone are ineffective. Antibiotic therapy is augmented by topical treatment with lime sulfur as well as control of ectoparasites and biting flies. Povidone iodine shampoos or chlorhexidine solutions also help in clearing the disease.

11.7 Preventive measures

Control measures are based on minimizing the effects of predisposing factors and prompt treatment of affected goats. Animals with skin lesions must be isolated and treated at the earliest. Minimizing moist conditions (such as providing shelter during rainfall) is helpful in control and prevention. Grazing management especially removal of thorny bushes in pasture land that damages skin will also help. Prophylactic antibiotic therapy can also be given.

11.8 Public health significance

D. congolensis is a zoonotic organism and rare human infections have occurred from handling diseased animals.

12. Foot rot

A contagious, either acute or chronic dermatitis of the hoof and its underlying tissues leading to lameness [41].

12.1 Etiology

Foot rot is caused by *Dichelobacter nodosus* and *Fusobacterium necrophorum*, anaerobic, non-spore forming, gram negative rods.

12.2 Epizootiology

The organism *F. necrophorum* is ubiquitous in nature while *D. nodosus* is obligate pathogen, can be present in skin and hoof of animals and cannot survive much longer in environment. Moist environment, humid condition, wet grounds and overcrowding are the predisposing factors for foot rot [42].

12.3 Clinical signs

Interdigital region will be moist and will have a foul odor due to necrosis (**Figure 8**). Lameness is the common sign of foot rot. Based on the severity of the infection animals may lose weight due to anorexia and there will be decrease in production [43].

Figure 8.
Moist, necrotic interdigital region seen in foot rot condition. This figure is propriety of the authors.

12.4 Diagnosis

Diagnosis is based on clinical signs and isolation of organism from the foot lesions. Since the organisms are anaerobic isolation is tricky and hence molecular diagnosis like PCR can be used for diagnosis.

12.5 Treatment

Hooves of the animals should be trimmed so as to remove the necrotic material thereby eliminating the anaerobic environment. Local antibiotics may be applied to the affected hoof after trimming. 10% zinc or copper sulfate or 10% formalin can be used for footbath [44].

12.6 Preventive measures

D. nodosus, though present in epidermal tissues of the hoof, survives for less than 7 days in the environment and hence, affected animals should be separated from the herd to prevent spread to other animals. Regular hoof trimming and cleaning should be practiced. Bacterins can be used as vaccines to prevent the infection.

13. Conclusions

Goat is called as poor man's cow but there are various bacterial diseases that cause economic loss to the goat farmers. Serval bacterial diseases cause acute infection hence there will be sudden onset of infection leading to huge mortality. Measures like use of vaccines before onset of disease, good management practices, etc., are essential to prevent the disease outbreaks. Animals with infection or clinical signs should be separated from rest of the animals so that infectious pathogens do not transmit to naïve animals and it is also recommended to quarantine newly purchased animals before admitting them into the farm. These practices can curtail the spread of infectious agents. It is also advisable to screen for diseases before purchasing the animals to the farm. Diseases like TB, JD and brucellosis should be screened before the purchase since these diseases are chronic in nature hence can remain undiagnosed. Animals infected with diseases that can affect human like anthrax, brucellosis, etc., should be handled carefully and better bio-security measures should be followed to prevent spread of disease within herd and also to human beings. Most of the bacterial infection can be treated with antimicrobial agents but these agents should be used judiciously because in the recent times antimicrobial resistance is a major problem.

Conflict of interest

The authors declare no conflict of interest.

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Chapter 14

Management and Control of *Eimeria* Infection in Goats

Saw Bawm and Lat Lat Htun

Abstract

Coccidian parasites of the genus *Eimeira* cause coccidiosis in farm animals, which develop in both the small and the large intestines. Coccidiosis is a major economic concern in many livestock, especially in young animals, as a result of losses caused by clinical infection (diarrhea) and subclinical (poor weight gain in particular) and the required treatment costs. Herein, we summarize geographical distribution of *Eimeria* parasites, their life cycle, pathogenesis, clinical signs, economic losses due to coccidiosis, diagnosis, recent information on control and prevention, and anticoccidial drugs for *Eimeria* infection in goats. With regard to poverty alleviation in most developing agricultural countries, it is important to maintain and develop goat-related industries. Proper management should be used to prevent losses and reduce the productivity from coccidiosis in young animals by: reducing the level of environmental contamination by infectious oocysts; minimizing stress; and avoiding overcrowding.

Keywords: *Eimeria* infection, goats, management, control, anticoccidial drugs

1. Introduction

The world populations of 2.3 billion small ruminants (goat and sheep) which comprise 1.09 billion goats [1] provide vital milk, meat and fiber. Goats (and sheep) are particularly important in Asia and Africa where they account for more than 90% and nearly 70% respectively of the world stocks [2]. Coccidian parasites of the genus *Eimeria* cause coccidiosis in small ruminants, which develop in both the small and the large intestines and specifically affect young animals [3]. In many livestock, especially in young animals, coccidiosis is of great economic importance as a result of losses due to clinical infection (diarrhea) and subclinical (poor weight gain in particular) and the required treatment costs. In goats, the majority of *Eimeria* infections are asymptomatic; notwithstanding, a few species have been linked to diarrhea and hindered growth [3, 4]. The coccidian are intracellular parasites, members of the protistan phylum Apicomplexa, subclass Coccidiasina. The genus *Eimeria* and *Isospora* are homoxenous, they develop both sexually and asexually in the same host [5]. Various *Eimeria* spp. are known to be involved in different ruminant hosts (bovine, ovine, caprine), however, because of the strict specificity of the host, no cross infection take place [3]. The *Eimeria* species do not transmit from animal species to another.

Studies in some countries such as Sri Lanka [6], Iraq [7], Jordan [8], Austria [9], Turkey [10], Saudi Arabia [11], China [12], Brazil [13] and Iran [14, 15] have shown that coccidiosis in goats is an important clinical and subclinical disease that may be linked to serious economic losses, especially under intensive breeding conditions with high animal density and high productivity [16]. Of the 16 *Eimeria* species identified in goats worldwide, *E. arloingi, E. ninakohlyakimovae, E. christenseni*, and *E. caprina* were considered being the most pathogenic species [17–20]. According to reports [3, 21], the common species of *Eimeria* in goats are listed in **Table 1**.

1.1 Geographical distribution

In temperate areas including Europe, *E. ninakohlyakimovae*, *E. arloingi, E. christenseni, E. jolchijevi, E. alijevi, E. caprina and E. caprovina* are the most prevalent *Eimeria* species in goats [22]. In semi-arid zones (Gran Canaria, Spain), the most common *Eimeria* spp. are *E. ninakohlyakimovae, E. arloingi* and *E. alijevi* [4]. In USA (mid-western states), *E. arloingi* (98.8%), *E. christenseni* (58.2%), *E. ninakohlyakimovae* and *E. parva* (33.3%) are the most frequent *Eimeria* spp. found in goats [23]. In dry tropical areas such as Senegal, the common coccidia species are *E. arloingi* (64%) and *E. ninakohlyakimovae* (56%) [24]. Similar findings have been reported in Ghana [25], Nigeria [26], Kenya [27, 28] and Zimbabwe [29]. In dry areas of Sri Lanka, *E. ninakohlyakimovae* (31%) *E. alijevi* (29%) and *E. arloingi* (21%) are the three most prevalent coccidia [6]. In Myanmar, the most common species of *Eimeria* found in goats are *E. arloingi* (25.4%), followed by *E. hirci* (20.7%) and *E. christenseni* (13.9%) [30]. High prevalence of *Eimeria* species infections, *E. arloingi* (64–80%) and *E. christenseni* (60%), have been reported in dry tropical areas of Africa (Senegal) [24], Nigeria [26], and Zimbabwe [29]. The occurrence of mixed-species infection was higher than single-species infection [12, 26, 31]. Coccidia of small ruminants, therefore, exist globally, and it appears difficult to say that there is any specific geographical distribution for one or the other species of coccidia.

1.2 Life cycle

Eimeria usually needs only one host in which to complete their life cycle. Within a host's intestinal cells, two stages, schizogony/merogony and gamogony grow up.

Organism	Distribution	Remark	Reference
E. ninakohlyakimovae	USA, European countries	Pathogenic	[3, 21]
E. arloingi	USA, Australia, Asia	Pathogenic	[3, 21]
E. caprina	USA, Spain, Africa	Pathogenic	[3, 21]
E. christenseni	US, Africa, Asia, Australia	Pathogenic	[3, 21]
E. parva	Africa, Asia	Benign	[3, 21]
E. hirci	Africa, Asia, Australia	Benign	[3, 21]
E. jolchijevi	Australia	Benign	[3, 21]
E. apsheronica	Africa	Benign	[3, 21]
E. alijevi	Asia	Benign	[3, 21]
E. caprovina	Africa	Benign	[3, 21]
E. capralis	-	-	[21]
E. charlestoni	-	-	[21]
E. masseyensis	-	-	[21]
E. pallida	-	-	[21]
E. punctata	-	-	[21]

Table 1.
Common species of Eimeria *in goats.*

Sporogony/sporulation, on the other hand, takes place outside of the host within an oocyst protecting infectious sporozoites. The life cycle involves an extracellular oocyst maturation stage (sporogony) as well as a parasitic intracellular stage inside the host with a sexual reproduction accompanied by an asexual [16].

When the unsporulated oocysts pass through the feces, after 2–7 days they become infected depends on *Eimeria* species and environment. The first single cell is divided into four sporoblasts, each of which grows into single sporocyst with two sporozoites [32]. The sporulated oocysts are resistant to adverse environmental conditions. They are able to live for several months or even over a year. Extreme desiccation, direct exposure to the sunlight, however, limits the survival of the oocysts, and temperatures below −30°C or above 63°C are lethal for the oocysts. The oocyst has thick-wall and usually ovoid form [16].

After ingestion by the host, the walls of the oocyst break down, releasing sporozoites from the sporocysts. The sporozoites penetrate the small intestine through an epithelial cell and develop into schizont of the first generation. The schizonts release motile merozoites, which may either initiate a second generation of schizonts or develop into gamont, gametes and then non-sporulated oocysts, which are released with the feces. The schizogony of second generation in the large intestines usually occurs with another generation of merozoites invades epithelial cells and develops the sexual stages, the gametocytes, male (microgametocytes) and female (macrogametocytes). Second-generation schizogony and fertilization of the gametocytes (gametogony) cause functional and systemic lesions of the large intestine [16]. In general, prepatent period for *Eimeria* species in goats is approximately 19 days [33]; however, the prepatent period is 20 days, 14–23 days, 10–13 days and 17–20 days for *E. arloingi*, *E. christenseni*, *E. ninakohlyakimovae* and *E. capria*, respectively [34]. Life cycle of *Eimeria* spp. in goat is shown in **Figure 1**.

1.3 Pathogenesis and pathology

The pathological and clinical outcomes are influenced by a number of factors such as the present *Eimeria* species, infection dose, its replication potential, inflammatory immune and concurrent infections by other pathogens as well as management and related stress. Due to the intracellular localization of all internal

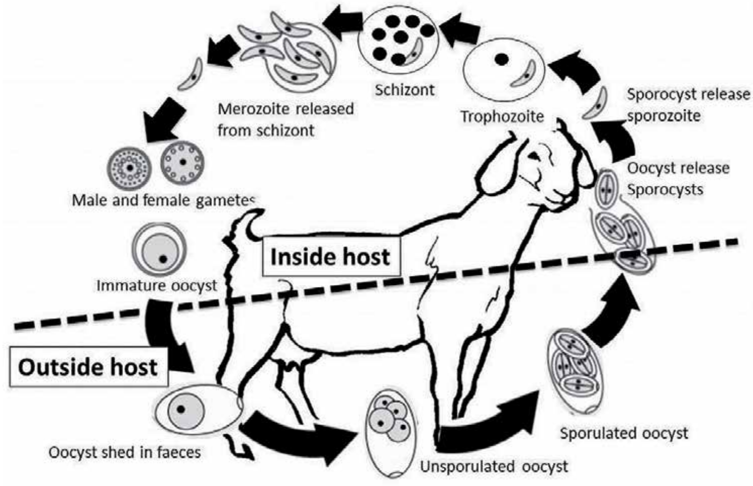

Figure 1.
Life cycle of Eimeria *species in goat. This figure was redrawn based on the picture in Taylor et al. [21].*

developmental stages, significant damage to the intestinal mucosa occurs. The outcome of *Eimeria* infections can vary greatly by parasite species as well as by individual host animal and farm. The damage caused by the parasite infection and replication occurs most during the late schizogony and gamogony [35]. This is due to the multiplication that the parasite undergoes during its first schizogony, leading to an exponential increase in the number of intestinal cells during subsequent multiplication. As a result, most of the damage occurs shortly before oocyst excretion starts in affected animals.

In early infections with *E. ninakohlyakimovae* or *E. caprina* in goat kids are characterized by haemorrhagic enteritis [36]. Polyps in the small intestine may develop as a result of *E. arloingi* infections [18], and *E. apsheronica* induce formation of white nodules in the mucosa that are visible from the serosal surface [37].

1.4 Clinical signs

Eimeria ninakohlyakimovae and *E. caprina* are highly pathogenic species capable of inducing watery to bloody diarrhea [13]. The infections with *E. arloingi* can also lead to watery diarrhea [38]. Acute symptoms may not exist in older animals at all or only in a small numbers of the affected goats following reinfection. Subclinical coccidiosis following infection with pathogenic species can be expected to produce subacute to chronically adverse impacts on the health, feed efficiency, and prolonged productivity [28]. Coccidia can invade and kill hosts' intestinal cells that cause anemia, loss of electrolyte and poor absorption of nutrients.

Most affected goats show diarrhea, poor growth rate, weakness and rough hair coat [12]. The feces are soft, watery and have clumps of mucus and color shifts from brown to yellow or dark tarry [18]. Loss of weight and dehydration are noted. Because the appetite is decreased, the animals' general condition is worsened. In some cases, sudden deaths occur in young animals between 2 and 4 months old without preceding digestive signs [3]. Diarrhea with or without mucus or blood, dehydration, emaciation, fatigue, and death are common clinical signs. But in fact, some goats are constipated and die acutely without diarrhea.

Impairment of growth is the major sign in subclinical form of coccidiosis. Early signs in acute cases include decreased appetite, listlessness, fatigue and abdominal pain which can be manifested by crying and repeated rising up and lying down. First, the feces may be unpelleted, then pasty, and eventually watery yellowish-green or brown diarrhea. The typical characteristics associated with coccidiosis are diarrhea that may be mucoid or bloody, abdominal pain, tenesmus, loss of appetite, fatigue, weight loss, rough hair coat, dehydration and anemia. Fever, ocular and nasal discharges can occur in the acute disease. Clinical coccidiosis is common in lambs 4–6 weeks old. Acute, bloody diarrhea can occur in severe cases, as a result of extensive damage to the intestinal epithelium [39].

While coccidiosis is self-limiting, the clinical presentation can be exacerbated further by other enteric pathogens. Exposure to low-grade challenges results in development of a strong immunity against to the disease. Successive infections in young animals might lead to the excretion of a large numbers of oocysts in animals, which leads to heavy contamination of houses, pastures or watering places [34].

2. Materials and methods

The present chapter intends to give a comprehensive approach of the importance of *Eimeria* parasite in goats, pathogenesis, clinical signs, diagnosis and economic losses due to coccidiosis. In addition, this chapter aims to explore the recent information on control and prevention, and anticoccidial drugs for *Eimeria* infection in goats. The databases were searched from PubMed and Google Scholar search. Search terms were "*Eimeria* in goats" and "coccidiosis in goats". A total of 130 articles were retrieved from the search. These studies were conduct in different regions of the world with different breeds of goats. Findings of anticoccidial studies carried out in the author's laboratory were also included.

3. Economic impact

Some assumed parameters for estimation of economic losses are summarized in **Table 2**. There are not well documented economic impacts of coccidiosis in small ruminants and no published data for economic losses due to subclinical or clinical disease in tropical regions are available. While subclinical coccidiosis might not be of great importance, it cannot be compared to other infections [5]. Where the high density of animals with high productivity can cause coccidiosis to become an infection of great economic significance in small ruminants [16]. In the case of a mild infection, these losses can be attributed to reduce productivity with no clinical signs.

Global sheep and goats production was being estimated to lose up to $140 million per year [40]. Losses result from mortality, treatment costs for animals with diarrhea, enhanced sensitivity to secondary infections in infected animals, and reduced production efficiency. Beside the acute impacts, a prolonged effect was suggested as regards a lower feed efficiency, less final growth performance, and a reduced reproductive performance for life [41]. Subclinical coccidiosis is believed to cause higher production losses than clinical coccidiosis, since animals are infected and are affected for long-term [42].

No.	Parameters	Possible impact	Reference
1.	Poor feed conversion rate	Poor weight gain	[3, 41]
2.	Poor body weight gain	Poor weight gain	[3, 41]
3.	Weight loss	Poor weight gain	[3, 41]
4.	Intercurrent or concurrent diseases	Secondary infections, the cost of treatment	[16]
5.	Reduced productions (milk, wool, hair)	Reduced income	[3]
6.	Losses due to mortality	Production loss	[16]
7	Reduced carcass quality	Reduced income	[3]
8	Reduced fertility	Production loss	[41]

Table 2.
Assumed parameters for estimation of economic losses due to coccidiosis in goats.

4. Diagnosis

There are different diagnostic methods available for specific identification of *Eimeria*. They are based mainly on clinical observations. The most direct, definitive, and cost-effective method of diagnosis continues to be the microscopic examination of diarrhoeal or bloody feces from young animals [42]. Traditional methods are primarily based upon microscopic oocysts morphological features, parasite biology, clinical signs in animals affected, and typical macroscopic lesions assessed by lesion scores [44]. In general, fecal samples are collected and analyzed

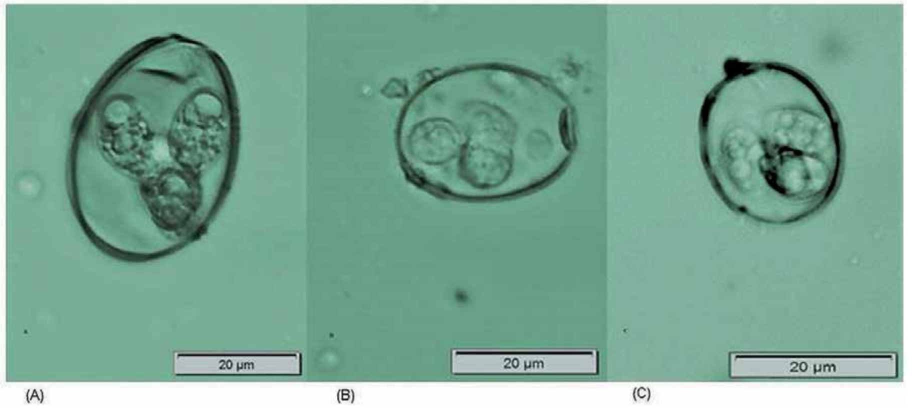

Figure 2.
Oocysts of E. christenseni *(A),* E. arloingi *(B) and* E. hirci *(C) from goats in Myanmar identified by Bawm et al. [30].*

for the presence of *Eimeria* oocysts (**Figure 2**). Fecal flotation enables oocysts to concentrate and increases their sensitivity significantly. Moreover, species-level identification should be performed. As many of the *Eimeria* species are either not or mildly pathogenic, it is possible to determine whether the *Eimeria* oocysts found are associated with a clinical disease or only an accidental finding and whether the cause of this disease requires more study. Pooled fecal samples can be used for monitoring purposes, while clinically ill should be individually sampled so that the excreted amount of *Eimeria* oocysts can be easily estimated. Accurate quantification of oocyst excretion in individual samples from animals in the focus groups can be helpful. There are several quantitative flotation methods available, with the McMaster counting technique being the most common method one [8].

However, the morphological approach is not entirely accurate due to the prevalence of intraspecies heterogeneity, as natural *Eimeria* infections are typically mixed with more than one species and some species have confounding characteristics [43, 44]. In addition, morphological observations are very labour-intensive in conjunction with fecal analysis and require a professional method of classification. In order to overcome the limitations of conventional methods [45–47], molecular techniques have been identified as useful for species identification or classification of this genus and have further demonstrated the phylogenetic location of each *Eimeria* species and phylogenetic clades [48, 49]. Molecular characterization of *Eimeria* goat species has been recorded in Australia [50], India [51], Iran [52] and Myanmar [30].

5. Prevention and control

Coccidiosis in ruminant is usually controlled by a combination of good management and treatment with anticoccidial drugs or prophylactics [42]. In general, effective control of coccidiosis is not based on the complete removal of *Eimeria* from the affected premises. It is considered neither possible nor useful to avoid contact between the naïve hosts and *Eimeria* for the operation of this parasite. Low-dose infections are generally not linked to disease, and low-dose infections are beneficial to the host because they allow the host to develop a protective, non-sterile immunity and protect against future infections. Therefore, instead of pathogen eradication, the emphasis of ruminant coccidiosis management lies in reducing the infection burden to uncritical levels and endemic stability [42].

Prevention is mainly based on the management of herds, including hygienic measures, since no vaccine is available. Coccidiosis outbreaks are a herd-level problem that is driven by stress. Infected animals need a responsive immune system to prevent severe disease. Therefore, minimizing or eliminating stressors like diet changes, harsh climate conditions, crowding, frequent shipping, animal grouping and exposure to other disease pathogens is a crucial part in preventing disease [16]. It is important to ensure adequate nutrition and appropriate uses of anticoccidial drugs. Colostrum uptake is important for newborn ruminants as it protects them from pathogens. Although the protection against *Eimeria* is not efficient, the protection from other pathogens supports and prevents problems in the animals' immune system.

Proper hygiene and minimizing predisposing factors in the environment are important for the control strategies of coccidiosis [53]. Pens for lambing and kidding should be kept clean, and bedding should be disposed when old or infested with oocysts. The washing and disinfecting of the buildings must be done with boiling water under pressure and gaseous ammonia [54].

All steps that minimize the amount of fecal contamination on hair coats should be routinely applied. Feed and water troughs should be high sufficient to prevent heavy fecal contamination. Feeding animals on the ground should be avoided, particularly when overcrowding. The regular rotation of pastures for parasite control will also assist in the controls of coccidial infection [53].

6. Anticoccidial drugs

With respect to available anticoccidials, they are usually supplied as feed additives, in drinking water, or in feed supplements such as salt. As a result, their use is often most feasible in weaned animals. However, anticoccidial prevention may need to start in the first weeks of life depending on the procedure [3]. In general, coccidiostats and coccidiocidal drugs are available. The development of internal coccidia stages is inhibited by coccidiostats, while coccidiocidal drugs kill the parasites. Drugs of both modes of action are currently available on the market. The best time to administer a prophylactic treatment would allow for the infection to develop but not for full parasite development. An appropriate treatment given following or prior to infection by the onset of oocyst release and appearance of symptoms is known as metaphylaxis. Anticoccidial therapy would therefore be optimally applied after infection, for the most important ruminant *Eimeria* species, approximately 14 days after infection, when the first and second merogonies develop. The main advantage of metaphylaxis over prophylaxis is the development of immunity and protection against reinfection, which is unlikely to make any subsequent anticoccidial treatments necessary. In general, it is important to apply prophylactic and metaphylactic treatment on the basis of a herd or animal group, as infected animals cannot be determined and all animals living in the same contaminated environment would be exposed to *Eimeria* infections. Continued use of coccidiostats reduces the number of oocysts passed through the feces over time, but may also lead to selection for resistance and therefore a regular monitoring of the treated animals is needed [16].

Anticoccidial drugs belong to one of two categories [55, 56, 63]:

1. Polyether antibiotics or ionophores produced by the *Streptomyces* spp. or *Actinomadura* spp. Ion gradients across the parasite cell membrane are interrupted by these drugs:

    a. Monovalent ionophores (monensin, narasin, salinomycin)

b. Monovalent glycosidic ionophores (maduramicin, semduramicin)

c. Divalent ionophore (lasalocid)

2. Synthetic compounds produced by chemical synthesis with a particular mode of action, which are often referred to as "chemicals":

a. Inhibition of parasite mitochondrial respiration (decoquinate, clopidol)

b. Inhibition of the folic acid pathway (sulfonamides)

c. Competitive inhibition of thiamine uptake (amprolium)

d. Inhibition of respiratory chain enzymes and nuclear division of protozoan (e.g., diclazuril, halofuginone, nicarbazin, robenidine)

Polyether ionophores inhibit the growth of sporozoites by increasing the concentration of intracellular Na^+ ions. They also accelerate the activity of Na+/K+/ATPase [57] and affect merozoites by inducing the breakup of the cell membrane [58]. Monensin was the first antibiotic to show an anticoccidial effect at reasonable concentrations, allowing it to be used in feed [59]. It can act as an effective anticoccidial agent for coccidiosis caused by *E. crandallis*, *E. christenseni* and *E. ninakohlyakimovae* in goats kept in confined space [60].

Monensin fed prophylactically at 20 g per ton of feed for 28 days decreases shedding of oocysts and improves feed conversion. However, high monensin levels make the feed unpalatable and toxic [53, 60]. It is believed that toxic effects in the horse, cattle, dogs, cats, rats, avian species and goat are mediated by interference with cell membranes ion gradients, inducing mitochondrial disruption and thus depleting of cellular energy [61, 62]. The documented toxic effects include heart toxicity, muscle degeneration and neuropathy, the latter is shown by myelin and ataxia [62].

Quinolones, pyridones, alkaloids, guanidines, thiamine analogues, and triazine derivatives are examples of synthetic anticoccidial drugs. Triazines inhibit nuclear division of protozoan thus interfere with the development of schizonts and gametocytes [63]. Decoquinate (0.5 mg/kg BW) and lasalocid at a dose of 25-100 mg/kg feed can be used to treat coccidiosis from weaning to market [53]. Sulfonamides at dosage rates of 25 to 35 mg/kg BW for at least 15 days are effective against coccidiosis in small ruminants. The combination of chlortetracycline and sulfonamide has provided protection in lambs. Other drugs include monensin (20 and 16 g/ton of feed for sheep and goats, respectively), toltrazuril (20 mg/kg BW as a single oral dose) and diclazuril (2 mg/kg BW as a double oral dose) [34, 53, 64].

Amprolium in feed is also used to treat the disease in goats (100 mg/kg BW for 21 days) and sheep (50 mg/kg BW for 21 days) [53]. Amprolium is structurally related to thiamine, and it is believed to be associated with a competitive inhibition of successful transportation of thiamine into parasite [65]. The production of oocyst in lambs has proved to be decreased when given as an in-feed medicine and clinical coccidiosis outbreaks have been successfully controlled by single drenching [66]. Young *et al.* [65] also stated that reductions in oocyst production have been detected in goats.

Diclazuril and toltrazuril have shown in several studies to decrease production of oocysts in natural and artificial *Eimeria* infections when orally given to young cattle, pigs, or lambs prior to the onset of clinical signs [67–71]. The molecules of decoquinate, toltrazuril, and diclazuril act on the whole coccidial cycle and allows curative as well as preventive action [53, 72]. According to our recent study [73], among the treated group of goats with monensin, toltrazuril, and amprolium, the percentage reduction in the number of fecal oocyst in the toltrazuril- treated group was found to be observed the highest (92%).

Resistant problems have been reported for some anticoccidial drugs, such as arprinocid and quinolone buquinolate [74]. In the field trials, toltrazuril resistance did not exist in at least five consecutive drug exposures [75]. The polyether ionophores became the drug of choice in 1972 and, as of today, are now the most commonly used drugs in poultry. Although ionophores resistance is likely to develop slowly due to their specific mode of action, resistance development in synthetic drugs with a specific mode of action appears to be faster, involving genetic mechanisms [76].

7. Conclusion

In this review, we highlight the management and control of *Eimeria* parasite in goats, the causative agent of coccidiosis, which is of great economic importance as a result of losses due to clinical diseases (diarrhea) and subclinical (poor weight gain) and the required treatment costs. We summarize the geographical distribution of *Eimeria* parasites, their life cycle, pathogenesis, clinical signs, economic losses due to coccidiosis, diagnosis, recent information on control and prevention, and anticoccidial drugs for *Eimeria* infection in goats. With regard to poverty alleviation in most developing agricultural countries, it is important to maintain and develop goat-related industries. Proper management should be used to prevent losses and reduced productivity from coccidiosis in young animals by reducing the level of environmental contamination by infectious oocysts, minimizing stress, and avoiding overcrowding [3]. It is essential to be aware of the problem and to implement control strategies, such as the maintenance of hygienic conditions and use of anticoccidial drugs.

Conflict of interest

The authors declare no conflict of interest.

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Chapter 15

Sustainable Utilization of Indigenous Plants to Mitigate Ticks and Tick-Borne Diseases amongst Selected Rural Households of KwaZulu-Natal Province, South Africa

Mbusiseni V. Mkwanazi, Sithembile Z. Ndlela and Michael Chimonyo

Abstract

The objective of the study was to explore IK used to control ticks and associated diseases. A structured questionnaire (n = 250) were administered randomly to collect IK amongst the households active in goat production. Challenges on the use of ethno veterinary plants were also captured using focus group discussions. There was an association between goat ownership and gender, males used IK (70%) more than their female counterparts. Ticks were ranked as the major ectoparasites affecting goat productivity. Amongst ticks, *Amblyomma* species were ranked as the most important. *Cissus quadrangularis. Lin* (32%), *Gomphocarpus physocarpus E. Mey* (27%) and *Portulaca pilosa L.* (25%) plants had the highest FL values for their use to control ticks. Four plant species were identified to treat goats against tick-borne diseases. *Pittosporum viridiflorum Sims* and *Boophane disticha* were reported to treat heart water. *Aloe marlothii A.Berger* and *Erythrophleum africanum (Benth.) Harms* plants cure anaplasmosis. Livestock farmers hold substantial knowledge of ethno-veterinary plants to control ticks and their associated challenges. More research is required to affirm the acaricidal properties claimed to promote and optimize sustainable use of these medicinal plants.

Keywords: animal diseases, heart water medicinal plants, skin damage, treatment, wounds

1. Introduction

The production of goats is increasing in the developing countries due to several key drivers of change in the livestock production sector [1]. One of which is the unforeseeable drastic effect of changing climates. Thus, addressing the issues of climate change in the context of livestock intensification involve rearing of species that are robust and adaptable to changing extreme conditions such as severe drought, increase temperatures and water scarcity issues [2] faced in the world. Goats are, therefore, more appropriate under such environments. Goats are inexpensive to raise and are, thus, a viable option for resource-limited households. Their high fecundity and relatively small space requirements and exceptional ability to produce under marginal environments such as mountainous and degraded lands are other attributes. The importance of goats is even higher in drier agro ecological zones where crop production is unreliable due to low and poorly distributed rainfall patterns coupled with droughts. Goats are also able to feed on grasses, bushes, shrubs, tree leaves and crop residues which would otherwise go to waste.

Although, goats are suitable under marginal lands, their productivity is still low owing to several constraints such as infectious diseases and parasites [3]. Communal production systems are characterized by poor management and low productivity. Farmers in communal production systems hardly use drugs to treat goats, consequently, diseases and ectoparasites are rife and major threats to goat production. Surveys have indicated that ticks are one of the constraints that limit goat productivity [4]. Ticks cause substantial losses such as diseases, reduced productivity through high mortalities and they are economically the most important ectoparasites of goats. Ticks suck blood, which damages the quality of the skin and hides and introduce toxins into goats [5]. In goats, skin lesions, particularly between the hooves, lead to secondary infections and may cause lameness [6].

The most common methods used to control ticks are through commercial acaricides. In developing countries, however the supply of acaricides are inconsistently available or not available at all [1]. Goats owned by resource-limited farmers are reared on communal rangelands where they browse extensively in mixed pastures with cattle. During dipping of cattle, goats are often ignored yet these species graze together. Many resource-limited farmers cannot afford acaricides and depend extensively on indigenous knowledge (IK) and practices. Indigenous knowledge is critical in goat health and it enhances cost-effective management of ticks [1]. Over centuries, resource-limited communities have learnt how to survive in difficult environments. They know appropriate varieties of crops to plant, when to sow, which plants are poisonous, which can be used for control of diseases in livestock [7]. Though such knowledge is valuable, however government veterinary services are an impediment to the development and use of IK as they regard it as based on mythology due to lack of scientific validation. As such, farmers are exposed to modern veterinary services leading to infrequent application due to failure to purchase the acaricides and at times under dosing, thus contributing to the development of resistance of ticks to acaricides.

The use of ethno-veterinary plants, which is part of IK is, however, important because it is easily accessible and locally available [1]. The study, therefore, will assist through the use of IK and its practices to eradicate ticks in goats, thereby enhancing global food security through provision of healthy chevon. Information obtained can also be used to design cost effective control programmes, which are locally available and affordable to farmers. Indigenous knowledge could also be blended with conventional knowledge (CK) to strengthen veterinary livestock care. Gathering IK could also increase the choices for farmers to control ticks and associated challenges in goats without only depending on CK. Indigenous knowledge could be useful because it controls even parasites that have developed resistant to acaricides. The objective of the study was to explore the use of IK used to control ticks and tick-borne diseases in goats.

2. Materials and methods

2.1 Ethical clearance consideration

The respondents' rights, religions, culture and dignity were respected. The respondents were assured that no confidential information would be disclosed, and they had a right to stop the interview whenever they did not feel comfortable. The experimental procedures were performed according to the ethical guidelines specified by the Certification of Authorization to Experiment on Living Humans provided by the UKZN Social Sciences – Humanities & Social Sciences Research Ethics Committee (Reference No: HSS/0852/017).

2.2 Study site

The study was conducted at Jozini municipality of uMkhanyakude district in the KwaZulu-Natal Province of South Africa. Jozini lies at 27º 24' 06.9' S; 32º 11' 48.6 E, and covers about 3 082 km^2, with an altitude ranging from 80 to 1900 m above sea level. Jozini experiences subtropical climate, with an average annual rainfall of 600 mm. Although the area receives rainfall throughout the year, most rains are received between January and March, with the months of June and July being dry and cool. Highest mean monthly temperature is recorded in January (30°C) and lowest in July (11°C). The average daily maximum and minimum temperatures at Jozini are 20 ºC and 10 ºC, respectively. The vegetation type of the area is mainly coastal sand-veld, bushveld and foothill wooded grasslands [8]. Agricultural practices in this district include production of field crops, vegetables and extensive livestock farming.

2.3 Study design and data collection

Eight communities were visited across the Jozini Area. Scheduled meetings with local authorities such as chiefs and local headmen were arranged to gain access to communities. The visited communities were Biva, Nyawushane, Mkhonjeni, Gedleza, Mkhayane, Makhonyeni, Mamfene and Madonela. They were randomly selected amongst communities active in goat production. Households were identified by the local chiefs and selected based on their personal experience on indigenous knowledge systems (IKS) to control ticks. The sampling technique involved approaching participants with extensive knowledge on the use of ethno-veterinary plants in goats. Enumerators were obtained from the local villages to ensure that farmers are comfortable to participate during the study. The questionnaire was pre-tested for accuracy and clarity of questions. Structured questionnaires were used to collect data from 250 households.

Data collection included household demographic information such as gender, age, source of income and employment status. Effects of ticks in goats, tick species and tick-borne diseases prevalent in the study area. Factors that limit the use of IK were also captured. Indigenous methods and practices used to control ticks and associated tick challenges were also captured. Information such as the (1) Local names of plants (2) part of the plant used (3) method of preparation and dosage were also captured during the survey. Apart from the questionnaires, further information on challenges with ethno-veterinary plants was collected through focus group discussions (FGD) with knowledgeable persons from the communities.

2.4 Plant collection and identification

Following the survey with the selected key respondents, 13 plant specimens were identified and collected. During collection of plant parts, leaves and bark were collected to ensure that plants continues to grow. The specimens were harvested, prepared, packaged and stored according to the herbarium rules and regulations. Plants specimens were then pressed and transported to the University of Kwa Zulu–Natal for botanical identification. For each plant species collected, a voucher specimen was prepared by The Bews Herbarium of the University of KwaZulu-Natal, Pietermaritzburg, South Africa.

2.5 Statistical analyses

All data were analyzed using SAS [9]. The PROC FREQ procedure for chi-square was used to compute association between households' demographic profile and IK use and challenges of IK. Mean rank scores for the effects of ticks on goat productivity, reasons of keeping goats, goat production constraints, common external parasites and common ticks and tick-borne diseases in the study site were determined using PROC MMEANS of SAS [9].

Fidelity level (FL) values were determined to capture the most used ethnoveterinary plants, as this could demonstrate their possible efficacy. Fidelity level is the percentage of respondents who use a certain plant for the same function [10] and was calculated as:

$$\frac{Na}{N}\times 100 \quad (1)$$

N_a - is the number of respondents who claim the use of a plant species to treat a particular ailment; N - is the number of respondents who use the plant as medicine for any ailment.

3. Results

3.1 Household socio-demographic information of respondents

Table 1 shows the association between household socio- demographic information and IK use of the farmers in the study site. There was an association (P < 0.05) between

Household demographic parameters		IK use	χ^2	Significance
Goat ownership	Male	69.7	5.96	**
	Female	30.3		
Marital status	Married	35.9		
	Not married	64.1	3.89	*
Educational status	Informal education	59.9		
	Formal education	40.2	1.20	*
Religious belief	Tradition	55.6		
	Christianity	54.4	1.25	ns
Sources of income	Salary	10.3		
	Livestock farming	23.4		
	Crop farming	20.0	4.06	ns
	Government grant	46.3		
Employment status	Employed	20.0		
	Unemployed	45.9	3.45	ns
	Self-employed	34.1		

NS: not significant (P > 0.05);
*P < 0.05;
**P < 0.01.

Table 1.
Socio-economic characteristics of respondents and association with indigenous knowledge use (n = 250). This result originated from the authors own work.

goats' ownership and gender, males were using IK (70%) more than females. The association between marital status and IK use was ($P < 0.05$). Farmers that were not married used IK more than those that are married. There was an association ($P < 0.05$) between educational status and IK use in the study area. Farmers that did not receive formal education were found to depend on IK more than those that received formal education. Unexpectedly, there was no association ($P > 0.05$) between IK use and religious belief. Although farmers that believed in tradition were using IK (56%) more than Christians. There was also no association between sources of income and IK use ($P > 0.05$), however farmers that depended on government grant (46%) used IK more. Even though there was no association ($P > 0.05$) between IK use and employment status, however farmers that were unemployed were more (46%) likely to use IK.

3.2 Livestock inventory and effects of ticks on productivity of goats

As expected, households owned different types of livestock (**Figure 1**). Livestock species owned by respondents consisted of cattle, goats, sheep, chickens, pigs, ducks and donkeys. Cattles (89%) were the most kept livestock species in the study area, followed by goats (80%), chickens (61.3) and sheep (51%) in that chronological order of importance. Ducks (28%), pigs (24%) and donkeys (10%) were least important species in the study area.

Table 2 shows the effects of ticks on goat productivity as ranked by farmers. Wounds were ranked the first. The loss of body condition due to ticks were reported as the second effect of ticks that thwarts goat productivity. Challenges of limping were ranked the third, followed by transmission of tick-borne diseases (**Table 2**). Skin irritation, destroying teats and anemia were least important.

3.3 Constraints to goat production

The most important external parasites constraining goat productivity are shown in **Figure 2**. Farmers ranked ticks as the most important external parasites affecting goat productivity. Lice were ranked the second and mites as the third constraint. Whilst the flies were ranked the least external parasites affecting goats productivity. **Table 3** shows the mean rank scores of different tick species

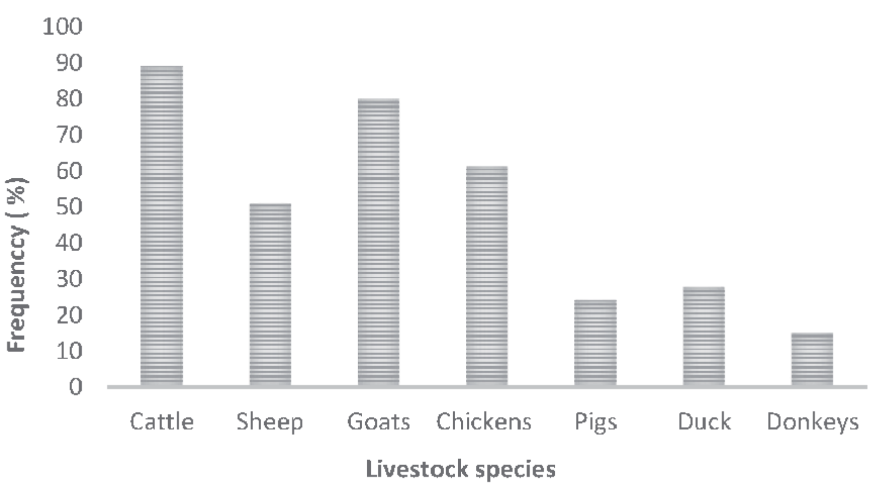

Figure 1.
Livestock numbers kept per household in the study site (N = 250). This result originated from the authors own work.

Conditions	Mean rank scores
Wounds	1.84 (1)
Limping challenges	1.90 (3)
Skin irritation	2.21 (5)
Destroyed teats	2.29 (6)
Loss of body condition	1.86 (2)
Anemia	3.10 (7)
Tick-borne diseases	1.95 (4)

The lower the 1 mean ranked score (rank) of a use the greater its use. Values in parentheses indicates means ranks.

Table 2.
Effects of ticks on goat productivity. This result originated from the authors own work.

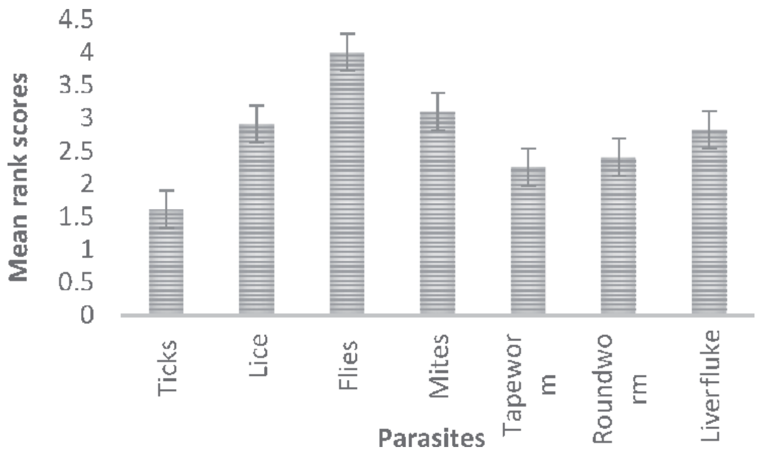

Figure 2.
Common parasites prevalent in the study site. This result originated from the authors own work.

Ticks	Mean rank score
Amblyomma	1.5 (1)
Hylomma	2.5 (3)
Rhipicephalus evertsi evertsi	2.0 (2)
Tick-borne diseases	**Mean rank score**
Heart water	1.8 (1)
Anaplasmosis	2.7 (2)
Babesiosis	3.3 (3)

The lower the 1 mean ranked score (rank) of a use the greater its use. Values in parentheses indicates means ranks.

Table 3.
Mean rank scores of ticks and tick-borne diseases. This result originated from the authors own work.

and associated tick- borne diseases affecting goat productivity in the study site. *Amblyomma* species were ranked as the most important amongst the ticks, followed by *Rhipicephalus evertsi evertsi* ranking the second and the least being the *Hylomma* species. Amongst tick-borne diseases, heart water was ranked as the most important, followed by anaplasmosis and babesiosis in that descending order.

Scientific name	Family name	Local name	Accession No	Parts used, preparation, dosage, and effectiveness	Conditions treated
Cissus quadrangularis L.	Vitaceae	Inhlashwana	NU0068142	Fresh leaves grind and mix together and apply on the body parts of the goat, every effective	Ticks, wounds
Stapelia gigantea N.E.Br.	Apocynaceae	Uzililo	Yet to be identified	Crush fresh leaves and apply paste topically on the skin, moderately effective	Ticks
Portulaca amilis Speg.	Portulacaceae	Ushisizwe	Yet to be identified	Crush fresh leaves and topically apply paste on the goat skin, very effective	Ticks
Gomphocarpus physocarpus E. Mey	Apocynaceae	Phehlachwathi	NU0068162	Crush fresh leaves and topically apply paste on the goat skin where there are ticks, very effective	Ticks, wounds
Drimia altissima (L.f.) Ker Gawl.	Asparagaceae	Umahlanganisa	Yet to be identified	Crush fresh leaves or roots and apply treat on the wound, very effective	Wounds
Spirostachys africana Sond.	Europhorbiaceae	Umthombothi	NU0068154	Crush fresh leaves or roots and apply the paste on the wound, very effective	Wounds
Achyranthes aspera L.	Celastraceae	Isinamane	NU0068139	Crush fresh leaves and feed solution to goats, effective	Ticks
Aloe marlothii	Asphodelaceae	Inhlaba	NU0068166	Crush the leaves and collect the juice apply on the wound	Wounds
Maytenus acuminata (L.f.) Loes	Celastraceae	Isinamane	Yet to be identified	Crush fresh leaves and feed solution to goats, effective	Ticks

Table 4.
Ethno-veterinary plants used to control ticks. This result originated from the authors own work.

3.4 Ethno-veterinary control of ticks and tick related conditions in goats

Nine plant species belonging to eight families were identified to control ticks and related tick challenges. Six medicinal plants were used as tick repellents from goats namely, *Cissus quadrangularis. Lin, Stapelia gigantea N.E. Br., Portulaca pilosa L., Gomphocarpus physocarpus E. Mey, Achyranthes aspera L and Maytenus acuminata (L.f.) Loes.* **Table 4** shows methods of plant preparation and dosages used. In addition, three ethno-veterinary plant species were identified to treat tick wounds: *Cissus quadrangularis. Lin, Drimia altissima (L.f.) Ker Gawl.* and *Spirostachys africana Sond.* Other plant species are broad spectrum, for example *Cissus quadrangularis. Lin,* which is used to control ticks can also be effectively used to treat wounds. The use of plant leaves was most prominent in the study area, followed by barks. *Cissus quadrangularis. Lin* mixture is smeared on the wound to prevent maggot development. Leaves from *Aloe marlothii A.Berger* are applied on the wounds.

The juicy liquid from *Aloe marlothii A.Berger* is then applied topically on the wounds to prevent the development of maggot. The wound was cleaned before the prepared mixture of *Drimia altissima (L.f.) Ker Gawl.* is applied (**Table 4**). Fidelity level values were determined to estimate the ethno-veterinary plants use values (**Table 5**). *Cissus quadrangularis. Lin* (32 %), *Gomphocarpus physocarpus E. Mey* (27 %), *Portulaca pilosa L.* (25 %) were the plants having the highest FL values for their use to control ticks. *Maytenus acuminata (L.f.) Loes* had the least FL value of 17 %, followed by *Stapelia gigantea N.E. Br* (3 %), respectively. Leaves were the most frequently used plant parts, constituting (55 %), followed by barks (25 %). Roots had a frequency of (13 %) and lastly the fruits constituting (7 %).

3.5 Ethno-veterinary plants used to treat tick-borne diseases in goats

Table 6 shows ethno-veterinary plants, methods of preparation and dosages used for treatment of tick-borne diseases in goats. The *Boophane disticha* is administered orally to kill the *Ehrlichia ruminantium* bacterium *spp* that causes heart water. *Pittosporum viridiflorum Sims* is widely used to treat heartwater in the study area. *Aloe marlothii A.Berger* plant is used to cure anaplasmosis.

3.6 Challenges of using indigenous knowledge

During group discussions, farmers acknowledged that there are numerous challenges pertaining to the use of ethnoveterinary plants. Farmers attributed some of the challenges to lower rainfall patterns that have led to the limitation of ethno-veterinary plants used to make remedies for both ticks and other associated challenges

Plant species	Condition	Na	N	FL in % [(Na/N)]
Cissus quadrangularis. Lin	Ticks	11	34	32. 3
Stapelia gigantea N.E. Br	Ticks	1	36	2.77
Portulaca pilosa L.	Ticks	1	4	25
Gomphocarpus physocarpus E. Mey	Ticks	60	225	26.7
Maytenus acuminata (L.f.) Loes	Ticks	1	6	16.6

Na – Indicates the number of respondents who claim a use of plant species for a particular ailment, N – indicates the number of informants who use the plant as medicine for any ailment, FL – Fidelity level.

Table 5.
Fidelity level indices of ethno-veterinary plant species used to control ticks in goats. This result originated from the authors own work.

Scientific name	Family name	Local name	Voucher No	Parts used, preparation, dosage, and effectiveness	Disease
Boophane disticha	Amaryllidaceae	Ingcotho	NU0068143	Fresh crushed leaves mixed, add water to form a solution and drench ¼ cup to kids, every effective	Heart water
Erythrophleum africanum (Benth.) Harms	Fabaceae	Umkhwango	NU0068159	Dry bark and fresh leaves are used, add water and mix, feed solution to goats, very effective	Anaplasmosis
Aloe marlothii A.Berger	Asphodelaceae	Inhlaba	NU0068166	Crush the leaves and collect the juice oral administration 1 cup/goat, very effective	Anaplasmosis
Pittosporum viridiflorum Sims	Pittosporaceae	Umfusamvu	NU0068132	Boil fresh bark and wait for it to cool and feed goat 0.5 L 1×day for 2-3 days, very effective	Heart water

Table 6.
Ethno-veterinary plants used to treat tick-borne diseases. This result originated from the authors own work.

including tick-borne diseases. For example, ethno-veterinary plants such as *Croton sylvaticus Hochst.* (Ugibeleweni), *Leonotis leonurus (L.) R.Br* (umhlahlampethu), *Erythrophleum lasianthum Corbishley* (Umkhwango), *Pittosporum viridiflorum Sims* (Umfusamvu) are found in the wild. Due to lower rainfall patterns coupled with increased drought occurrence, ethno-veterinary plants are becoming scarce. The scarcity of plants is also exacerbated by increasing human population, overharvesting and deforestation. The exorbitant increase in the human population that are using IK has two limitations to ethno-veterinary plants. Firstly, the number of settlers in the area is increasing and they remove important plants during preparation and building of shelters. Secondly, as the number of people who uses IK increases, some of the people harvest plants inappropriately whereby one uproots the whole plant, which then destroys plant growth.

4. Discussion

Ethno-veterinary knowledge and practices contribute gigantically to the veterinary management of goats and the use of IK is capturing much popularity. For example, about 80% of farmers living in sub-Saharan Africa today depend on ethno-veterinary plants for their livestock health [11]. Indigenous people do not reveal IK effortlessly as it is a source of their livelihood [12]. Indigenous knowledge is normally transferred and passed to the next generation through oral conversations. As a result, a vast of IK remain undocumented. Indigenous knowledge is also restricted to the elderly generation, thus with the demise of older generation, there is fear and danger that IK will rapidly vanish while not promoted to enforce policies for sustainable development of livestock veterinary care, hence the need for the current study. The observed association between goat ownership and gender, with males using IK more than females was anticipated. This finding corroborates with that of Mkwanazi et al. [1]. The probable explanation could be that in resource-limited areas men are usually the head of households and therefore, culturally obligated to take decisions on livestock including goats. Women are culturally not allowed to enter livestock kraals, thus making it difficult for women to participate and make purposeful decisions. In addition, there is a belief that ethno-veterinary plants should not be collected by menstruating women as this would reduce the healing power of the plants [13]. Women, however, should not be deprived of such a privilege, because in the modern society men are scantly at home as they migrate to seek for better opportunities in urban areas, as a result woman remain behind and enforce decisions. Moreover, most households nowadays are headed by women, therefore, men should be encouraged to educate women on IK and livestock management.

The finding that most unmarried household heads used IK more could be influenced by the lack of additional household income, resulting in farmers opting to use IK so that the negligible remittances that they receive could be used to purchase essential things such as food and paying school fees for children. The observation that farmers with informal education used IK more was not surprising because most of them grew up using IK to control tick and associated challenges in goats, hence their high dependency on ethno-veterinary plants. The observed finding that traditionalists were using IK more as opposed to Christians is not surprising. Christian converts associate IK use with demons. This is rather worrisome given that young people are easily lured to Christianity as opposed to learning African ways of living. Therefore, this presents a threat of disappearance of IK for the future generations. The observation that unemployed farmers use IK more could be linked with the nature of the sources of income in resource-limited areas, most unemployed farmers are old and therefore, depend on sales from farming and government grant incentives for survival. This observation resonates with that of Sanhokwe et al. [4].

The observation that cattle were the most popular livestock species is influenced by social status, since in resource-limited areas cattle are an emblem of wealth. Therefore, cattle are considered very important because of the economic roles they perform [14]. They perform multiple roles such draught power, slaughtered during burial of chiefs, kings and generally men who are heads of households and in wedding ceremonies. Although goats are an alternative for farmers who do not afford to keep cattle, but they are usually referred as poor man's cow [15]. The finding that chickens were the third livestock species kept by farmers deviates from the work of Nyahangare et al. [14], who reported chickens as the most populous species kept by resource-limited farmers. Chickens have low input requirements, which makes it easier for farmers to accommodate them in their homesteads. Despite the lowly rank of other species such as ducks, pigs and donkeys, however but they still contribute substantially. The study area experiences frequent droughts; therefore, donkeys occupy a very important niche of transporting water during water shortages.

The observation that the primary reason for keeping goats was to perform cultural ceremonies resonates with Mdletshe et al. [16]. In resource-limited areas, goats are used to communicate with ancestors and are scantly slaughtered outside the context of traditional ceremonies. Keeping goats for sales confirm the notion that farmers sell their goats in times of need and generate cash income, which is generally used to purchase food and other essentials. The observation that milk ranked the least concurs with Mahanjana and Cronje [17] and Masika and Mafu [18]. Most farmers do not milk goats for human consumption, hence the need to educate farmers on the importance of goat's milk as it has therapeutic properties and is more digestible than cow milk. Thus, dissemination of information to farmers on goat milk can ensure continued access to high quality protein by the less fortunate and those allergic to lactose, particularly young children.

The observation that experts showed awareness and could identify the effects associated with ticks suggest that these challenges are evident in the study area. The observation that farmers ranked wounds as the major effect of ticks on goat productivity could be influenced by that ticks gouge through the skin leading to the development of wounds. In resource-limited areas farmers use traditional practices such as the use of thorns and scissors to remove ticks from goats, however such practices tend to destroy the stomach part of the tick only while leaving the head inside the skin. Therefore, goats would rub themselves trying to appease the pain, thus causing the wound. The finding that ticks cause loss of body condition demonstrates the seriousness to include goats in tick control programs. This is important to consider because availing resources to goats will help improve their productivity and hence their contribution to livelihood. The loss in body condition could be due to that ticks suck blood, thereby denying goats adequate nutrients. Subsequently, making goats vulnerable to diseases. The observed challenge of limping in goats could be due to that ticks attach between the hoofs, causing wounds that may lead to hoof rot. Eventually making goats to limp and unable to reach mountains and grazing areas for browsing. Jongejan et al. [6] recorded 89% of goats suffering from lameness due to predilection of ticks between their feet. The observation that tick-borne diseases ranked the fourth should not be taken light, because in the past goats, especially Nguni breeds have been assumed to be resistant tick-borne diseases. Hence, there is a need for further research to be done on tick-borne diseases in goats.

Farmers can identify different tick species in their goats using color patterns [19, 20]. The finding that ticks were ranked as the most external parasites affecting goats agrees with Mkwanazi et al. [1]. The probable explanation could be that goats are hardly dipped in resource-limited areas and much priority given to cattle, although these species graze together in communal rangelands [1]. High infestation of ticks could also be due to that during the cool-dry season, where water and feed resources are deficient, goats travel far to mountains and valleys where ticks are abundant [21]. Ticks were scored high and perceived as a major cause of mortality in kids under communal farming conditions in South Africa [22]. The observation that lice were ranked the second contradicts findings by Sanhokwe et al. [4] who reported mites to be second challenge after ticks on goats. It should be alluded that prominence of external parasites in the study area could be influenced by poorly managed rangelands where parasites burden is rife. The observation that *Amblyomma* tick species were ranked as the most important amongst the ticks agrees with Jongejan et al. [6] who reported *Amblyomma* as the predominant adult tick species on goats with a relative proportion of 66%.

Goats in resource-limited areas have been found to be infested with a large population of *Amblyomma* and *Rhipicephalus evertsi evertsi* [1]. The observation that farmers mentioned the presence of *Hylomma* infestation on goats in the study site was rather befuddling because Horak et al. [23] reported that *Hyalomma* species are not present in the study area as farmers suggested. In particular areas where the *Hyalomma* has been spotted, goat infestation is very low; less than 2 ticks per goat. Secondly, *Hyalomma* that infests dogs are not common in the study area [23] suggesting that although farmers have knowledge on ticks, they often confuse different tick species. Perhaps the most striking finding was that most of the IK experts did not directly connect ticks with the spread of tick-borne diseases. Farmers, however, were able to define tick-borne diseases using clinical symptoms, but it should be borne in mind that some diseases exhibit differential diagnosis. Thus, affecting the accuracy of the diagnosis.

The observation that heart water ranked the first amongst tick-borne diseases could be influenced by the high prevalence of *Amblymma* species in the study area that is known to be the carrier of *Ehrlichia ruminantium* bacteria transmitting heartwater in goats. The observation that farmers could rank anaplasmosis the second was surprising, considering that anaplasmosis in goats is a subclinical and non-pathogenic disease of little economic importance [23]. Infected animals show few clinical signs of the disease. Consequently, the correlated symptoms such as slimy mucous around the nose, lying down, weakness and shivering of goats form part of a range of signs by which heart water can be identified.

Nine common ethno-veterinary plant species were identified to be used by farmers to control ticks and related challenges. These plants are from different families *Vitaceae, Asphodelaceae, Apocynaceae, Portulacaceae, Apocynaceae, Asparagaceae, Europhorbiaceae* and *Celastraceae.* Other plant species have a broad-spectrum nature. For example, *Cissus quadrangularis Lin* from *Vitaceae,* is used to control ticks and treat wounds. Similarly, *Aloe marlothii A.Berger* is used to treat anaplasmosis and tick wounds. Plants from the genus *Aloe* have been successfully used throughout the world due to their biologically active ingredients [24]. *Cissus quadrangularis. Lin* has many biological activities, including antioxidant, anti-bacterial and anti-inflammatory activity. *Drimia altissima (L.f.) Ker Gawl.* plant is known to have various biological activities such as antioxidant, anti-bacterial, anti-inflammatory activity, anti-fungal and cytotoxic effects. In addition, the plant has been reported to have insecticidal activities with properties including L-azatidine-2-carboxilic acid and bufadienolides, scillirosidin and proscillaridin A [25].

The effects against ticks from other plants including *Stapelia gigantea N.E. Br*, *Portulaca amilis Speg.* and *Achyranthes aspera L.* have not been reported in literature, however, farmers indicated that their leaves are excellent tick repellents. Therefore, there is a need of in-depth research on their potential efficacy as tick repellents. The observation that FL values of *Cissus quadrangularis. Lin*, *Gomphocarpus physocarpus E. Mey* and *Portulaca pilosa L.* (25%) were high, showed that most farmers in the study area generally prefer these plants and they constantly utilize them to control ticks. The observation that *Maytenus acuminata (L.f.) Loes* had the least FL value disagrees with Mkwanazi et al. [1]. Some of the medicinal plants have low FL values because some farmers did not know their preparation methods and dosages. Acaricidal validation of these plants is essential to isolate their active ingredients and thus, used to produce drugs.

The four plants; *Boophane disticha, Erythrophleum africanum (Benth.) Harms* and *Pittosporum viridiflorum* Sims. *Boophane disticha* were identified to treat goats against heartwater and have intensive usage in the traditional medicine practice of indigenous people around the world. For example, *Boophane disticha* has been widely used in cattle to treat babesiosis, however in this study it is used against heartwater. This is possibly due to its antimicrobial and anti-inflammatory activities [26]. *Pittosporum viridiflorum* Sims is reported to repel ticks [27, 28] and to have acaricidal properties against larvae of *Rhipicephalus appendiculatus* [27]. In the current study, however, it is reported to treat heartwater. Multiple properties including wound healing, anti-inflammatory, antibacterial and low toxicity [29] have been found in *Pittosporum viridiflorum* Sims.

The observation that leaves and bark were common plant parts used to prepare these remedies agrees with Maroyi et al. [29]. The high use of leaves could presumably be due to strong seasonality of rainfall that hinders the growth of many plant species during the dry season. Leaves are also readily available. Leaf harvesting does not inhibit the growth and survival of the whole plant species [30] as compared to roots, which could be another plausible reason for their greater usage in remedy preparations. The most common preparation method used was boiling the plant in water. This could possibly because boiling allows time for the active compound to infuse to the water through detaching the chemicals and making the solution potent.

The limited plant availability because of lower rainfall patterns could mean that different plant species respond differently to changes in climatic conditions [31]. Some plant species are still available in the same place, however, have adapted to new climatic conditions through selection. Other plant species moved to greater latitudes or altitudes. This could be the case with some medicinal plants such as *Croton sylvaticus Hochst*, *Pittosporum viridiflorum Sims* and *Erythrophleum africanum (Benth.) Harms* that are now found in far areas. *Croton sylvaticus Hochst* was reported to be found in far-away mountains and no longer widely accessible. This could be attributed to climate change, causing some plants to migrate to higher areas until there are no further places to inhabit.

Despite the use of these ethno-veterinary plants, however majority are threatened by anthropogenic disturbances [32]. The extensive use of medicinal plants is the most common threat to its availability. The most serious issues or threats with regards to extracting medicinal plants is habitat degradation and over harvesting. As a result of over harvesting, for example, many of these plant species with fewer exceptions are now harvested from the wild habitat. In addition, plant materials are being lost due to lack of systematic conservation, hence the need of conserving the erosion of the remaining plant species. Proper conservation strategies for plants that are widely used such as *Aloe marlothii A.Berger* and *Cissus quadrangularis. Lin* should be done.

5. Conclusions

The study showed that there is still a considerably strong use of IK of plant-based remedies to control ticks and associated tick challenges in livestock, including goats. Nine plant species were identified to control ticks and related challenges such as wounds, using *Cissus quadrangularis. Lin*, *Gomphocarpus physocarpus E. Mey* and *Portulaca pilosa L.* being populous across. Heartwater was a major disease of economic importance. Heartwater is more of a recent introduction to the area, hence experts had a more scientifically informed understanding of the disease, gleaned from veterinarians and animal health technicians. The high dependence on ethno-veterinary remedies and practices on ticks and their associated challenges highlights the need to support IK in veterinary care. There is a need, for government institutions to collaborate with IK experts to identify and standardize IK practices in wider use for effective control of ticks and diseases in livestock.

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Conflict of interest

The authors declare that there is no conflict of interest.

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Section 10

Goat Milk and Human Health

Chapter 16

Angiotensin Converting Enzyme Inhibitory Peptides Derived from Goat Milk

Iqra Aslam, Amsha Hoor, Munazzah Meraj and Sadia Javed

Abstract

Today hypertension has become a threat to the human lives. Different factors like sensitivity to sodium, obesity, alcohol consumption, sedentary lifestyle and smoking are responsible for the development of hypertension. Hypertension can be of major risk factor to cardiovascular diseases (CVD). Because of their small molecular mass, bioactive peptides have an important role in the digestion and absorption of proteins. Angiotensin converting enzyme inhibitory (ACE-I) peptides are one of the most widely used bioactive peptide in the field of medicine and food processing. Thus, these inhibitors are applied to regulate the blood pressure and prevent hypertension. Synthetic ACE inhibitors have various side effects and that is why scientists nowadays, are focusing on the natural alternate of ACE inhibitors with promising health properties. Two types of proteins found in milk are casein and whey proteins which are a good source of the bioactive peptides having a positive impact on body functions. ACE inhibitory peptides derived from the goat milk proteins are considered to be used in nutraceuticals and pharmaceutical products to reduce the hypertension ultimately reducing the risk of CVD and other related diseases.

Keywords: Hypertension, Bioactive peptides, Goat milk, ACE-I peptides, Health benefits

1. Introduction

1.1 Hypertension

Up to 30% of the adult population in most of the countries, hypertension is considered as a major risk factor for cardiovascular disease [1]. In the human body the regulation of BP is done by cardiac output and peripheral resistance. Heart rate and stroke volume are the two factors which adjusts the cardiac output, while the changes in the smooth muscles in arteries and arterioles adjusts the peripheral resistance [2].

Hypertension can be categorized as primary hypertension and secondary hypertension. Primary hypertension is mainly found in the adults, it can develop over years and do not possesses distinct identifiable cause so it is named as primary hypertension. Various underlying causes or effects of certain medication leads to the development of hypertension, that is secondary hypertension [3].

Although no distinct cause is found for primary hypertension, but there are many factors which are responsible for setting of primary hypertension. The factors which leads to the development of primary hypertension are: obesity, sodium sensitivity, smoking, extreme consumption of alcohol, sedentary lifestyles. All these factors are supposed to be associated with the chronic elevation of BP in primary hypertension [4].

Hypertension is observed as distinct disease and can be regarded as major risk factor to the CVD; it contributes directly to the renal failure, peripheral arterial disease, stroke, artery disease and congestive heart failure. If successful BP reduction is achieved then the risk of CVD and incidence of coronary mortality particularly with the elderly having multiple risk factors, can be dramatically reduced. In the later age that is older than 60 or also in the middle ages BP leads to the incidence of CVD. As the age increases the BP lowering drugs becomes most prescribed drugs for older than 60. Among all the CVD risk factors, hypertension is the most common risk factor for CVD [3].

Some factors are considered important in the development of hypertension. These factors include variation in genetic makeup, aging, style of living, overweight and nutrition. Diseases like Pheochromocytoma, Diabetes, Cushing syndrome, Kidney disease, Congenital adrenal hyperplasia are also involved in creating hypertension. Along with the factors mentioned above, some medications like hormone therapy for menopause, oral contraceptives, and excessive intake of alcohol are contributor in developing hypertension [5].

A number of pathophysiological factors have been involved in the genesis of essential hypertension which includes increase in the sympathetic nervous system activity possibly related to increase exposure to psychological stress. Other factors involved in the genesis of hypertension includes inadequate intake of potassium and calcium, increase in the production of sodium retaining hormones and vasoconstrictors, long term intake of sodium intake, increases or inappropriate secretion of enzyme renin which results in the increase production of Ang II and aldosterone [6].

1.2 ACE inhibitors

Recently, bioactive peptides have become an interesting research topic in the field of food and medicine. Due to the small molecular mass of these peptides, they allow easy digestion and absorption of proteins by the human body. These biological active peptides are involved in the regulation of physiological functions of the body, help in the development and growth for humans by providing nutrition, and play an important role in prevention and treatment of diseases [7].

As a functional ingredient, bioactive peptides with hypertensive activities can be used in food to deliver to consumers [8]. Within the proteins structure, the bioactive peptides are inactive, different methods are used to release them [9].

In humans, ACE act as a metalloproteinase with zinc catalytic active sites, resulting in raising the blood pressure by converting angiotensin to angiotensin-II. Thus, ACE inhibitors are applied in the regulation of the blood pressure for the protection of the organ targeted [10].

2. Mechanism of action of ACE inhibitors

As far as mechanism of ACE is concerned, inactive decapeptide is converted into potent vasopressor octapeptide AngII by the action of ACE enzymes which also inactivates the formation of bradykinin [11]. Currently the focus of research is the study of the underlying processes related to ACE inhibition. ACE enzyme is zinc protease which plays essential role in the regulation of BP because it is responsible for the conversion of Ang I to Ang II. As a result of this C-terminal dipeptide and aldosterone is released which leads to the constriction of blood vessels as result the BP rises Furthermore, sodium ions also accumulates in the human body and cause rise in in the SBP [12, 13]. In addition, bradykinin which is a potent vasodilator is also hydrolyzed by the action of ACE which becomes responsible for further increase in BP, so, the inhibition of this ACE is supposed to lower the BP [14].

3. Angiotensin II blockage

Renin is an enzyme produced in the juxtramedullary cells of the kidney and secreted in blood circulation. Renin converts its substrate angiotensinogen into Ang I. The zinc metallo peptidase Ang I is converted ino Ang II when His-Leu is removed from Ang I by the action of the ACE. This Ang II is very potent vasoconstrictor and endorses the sodium retention by rising tubular reabsorption of sodium (**Figure 1**).

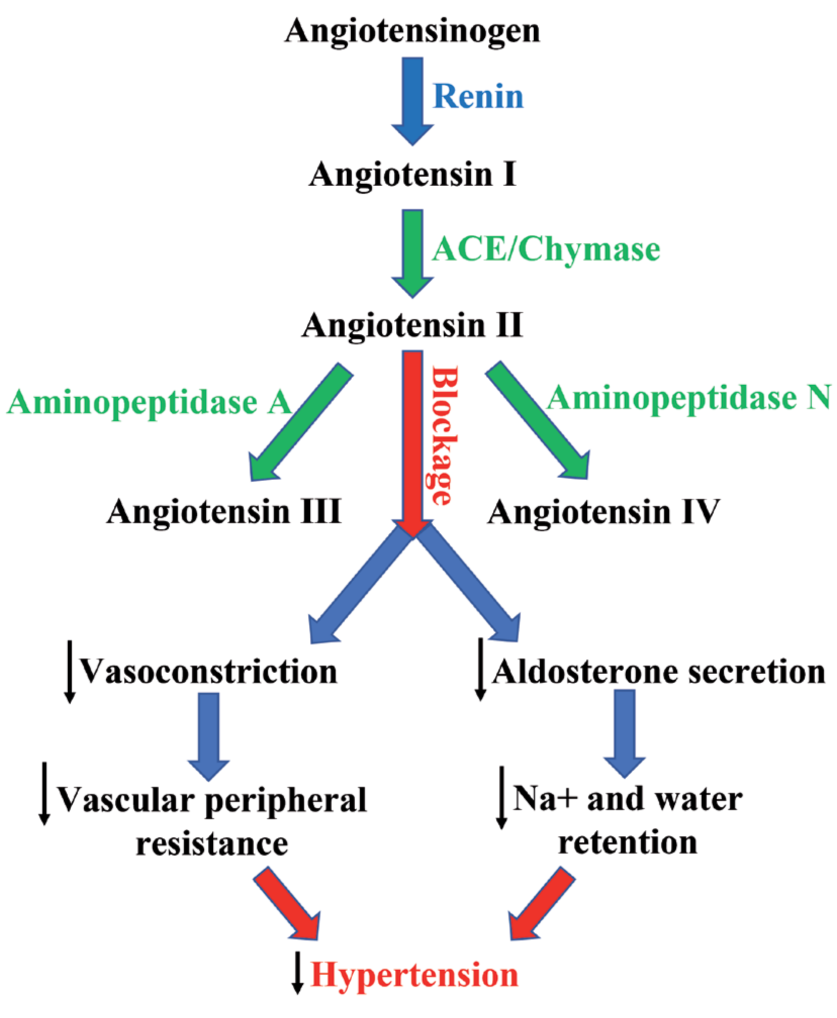

Figure 1.
Effect of Ang II blockage on BP reduction.

The presence of RAAS tissues is detected in various tissues of the human body. The organs of the human body where the presence of ACE is detected includes brain, heart, kidney and vessels, the angiotensin in these tissues expresses in two ways either locally or enter in the circulation. ACE inhibitors causes in the reduction of BP by decreasing the local Ang II devoid of the ACE in plasma [15]. Conversion of Ang I into Ang II is blocked by ACE-I and also the cleavage of bradykinin to inactive metabolites is prevented. ACE enzyme also cleave other peptides, but the majority of pharmacological properties of inhibitors can be credited to decrease of Ang II and maintenance of bradykinin [16]. In humans, ACE inhibitors lower BP in all forms of hypertension. ACE inhibitors are generally effective across all age classes, but show greater probability of efficacy in white rather than black patients. After prolonged dosing ACE maintain their effectiveness, even though Ang II levels in plasma may return to pretreatment levels [17]. This phenomenon, termed "angiotensin escape," may be the result of Ang II formation by enzymes other than ACE, or by increased transcription of ACE [16].

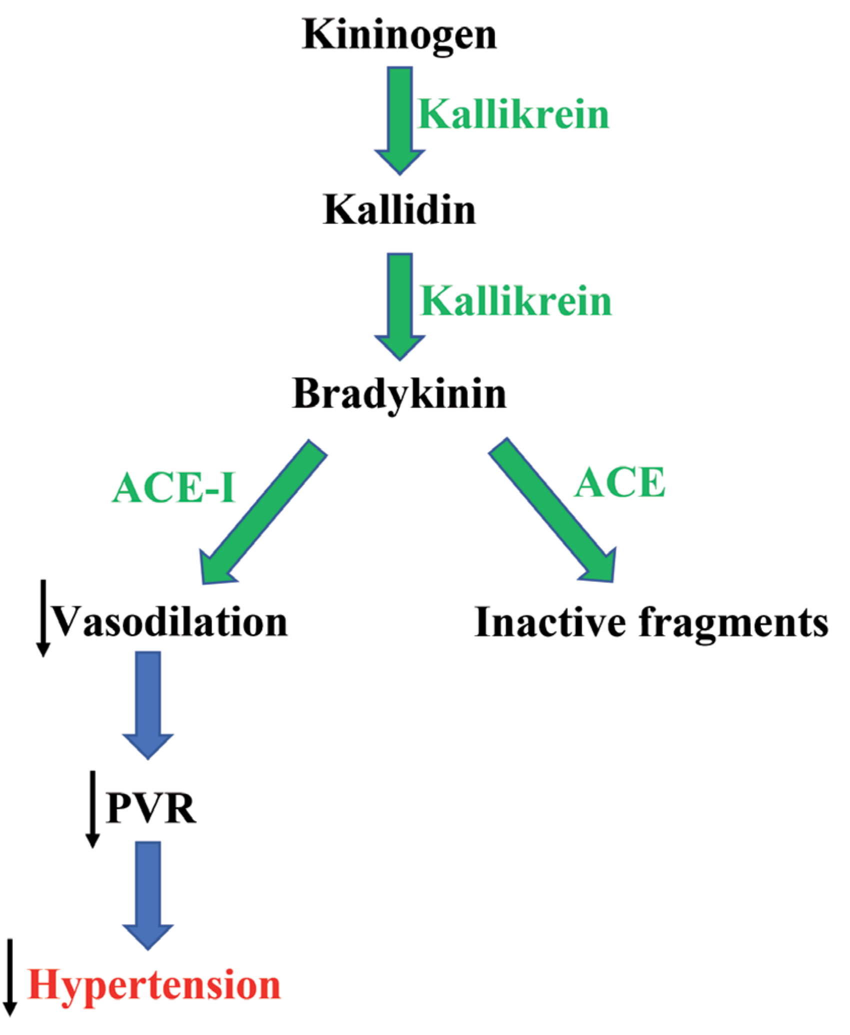

Figure 2.
ACE-I lowers the incidence of hypertension by vasodilation, while formation of inactive fragments raises the BP by vasoconstriction. PVR; peripheral vascular resistance.

3.1 Bradykinin potentiating

The pharmacological effect of bradykinin potentiation activity first shed light on the therapeutic potential of ACE inhibition because it occurs in parallel with RAAS blockade after administration of ACE inhibitors (**Figure 2**).

Kininogen is precursor of bradykinin. The two enzymes, plasma and tissue kallikrein acts on kininogen and convert it into bradykinin. The hormone acts through the B2 receptor present in the endothelial cells and are responsible for the release of vasodilator substances such as nitric oxide and prostaglandin I_2. Pharmacological blockade of this receptor has been shown to blunt the antihypertensive properties of ACE-I [18]. While reduced renal kallikrein activity may be associated with hypertension, a causal relationship between this phenomenon and elevated blood pressure has not been established. Therefore, while bradykinin may contribute to the antihypertensive pharmacology of ACE-Is, the significance of the kallikein-kinin pathway in cardiovascular disease is outdone by the many actions attributable to angiotensin II.

4. Pharmacological approach

Frequently, synthetic inhibitors are used to minimize the extremity of hypertension. These include enalapril, lisinopril, ramipril, fosinopril, captopril but these have some side effects. Therefore, exploring the ACE inhibitors from natural sources with health promoting qualities is the need of hour [5, 19].

5. Non-pharmacological approach

Non-pharmacological approaches include alternate to pharmacological approach. This includes life style modifications. In the prevention and management of CVD, diet plays a vital role. Intake of low fat containing dairy product, maximum usage of vegetables, and maximum intake of fruits is suggested to reduce sodium intake so that hypertension can be controlled. If required, weight drop and exercise is also suggested [3].

5.1 Natural alternate

The famous Dietary Approaches to Stop Hypertension (DASH) diet decreased systolic blood pressure (SBP) and diastolic blood pressure (DBP) by 5.5 and 3.0 mmHg, respectively [20]. Diet containing fruits and vegetables alone caused BP reduction roughly half of the DASH diet, which in addition to fruits and vegetables also contain low-fat dairy products [21].

However, the greater reduction in SBP cannot be ascribed to milk products only because other dietary alteration e.g. reduced saturated fat was also incorporated into DASH diet. Nonetheless, the relationship between the intake of milk products and reduction in BP is demonstrated by many other intervention studies [22].

As an alternative to ACE-I synthetic drugs, for their ability to reduce toxic effects of chemically synthesized drugs in humans and prevention of hypertension, ACE-I peptides from natural sources like food proteins have attracted great attention [8].

Other than source of essential amino acids, proteins from milk also are a great source of the bioactive peptides having various benefits of health. The benefits of peptides derived from the milk protein include antioxidant effects, activities of immunomodulators, ACE-I and antihypertensive effects [9].

6. Methodology

A study conducted in 2016 by Bao et al. compared four types of commercial proteases. These included neutral protease, alcalase, flavourozyme and proteinase K because of their higher ACE inhibitory activity in skimmed goat and cow milk. Alcalase and proteinase K showed much higher degree of hydrolysis (DH) than neutral protease and flavourozyme for both skimmed goat and cow milk. The results showed that ACE inhibitory peptides from goat milk produced by alcalase was the best having ACE inhibitory activity of 95.31%. While ACE inhibitory peptides from the hydrolysis of cow milk by proteinase K, showed 81.28% ACE inhibitory activity [23].

In the year 2017, the experimentation of Ibrahim et al. on the digestion of isolated whey and casein proteins of goat milk by the gastric pepsin paved the way as a candidate for antihypertensive bioactive peptides. The gastric pepsin produced soluble hydrolysates which exhibited the inhibition of ACE. The fractionation of hydrolysates was carried out into four fractions (F1 ~ F4) by size exclusion chromatography, Sephacryl S-100 column. Peptides in both whey and casein F4 fractions were isolated by RP-HPLC. The hydrophobic peptide peaks showed the most potent inhibitor of ACE. The results from this experiment, for the first time, introduced new potent ACE inhibitory peptides which can be derived from the goat milk whey and casein and are released by gastric pepsin [19].

Another study was conducted by Tagliazucchi et al. which involved a newly developed harmonized static in vitro digestion model, with mass spectrometry (MS) for the identification of bioactive peptides. The main objective of the study was the identification of ACE inhibitory peptides from the skimmed goat milk which are released after the gastro-intestinal digestion. By using ultrafiltration peptides were extracted from the post pancreatic digest and by RP-HPLC followed by MS these peptides were isolated. The sequences which were identified, there were 18 identical to bioactive peptides with ACE inhibitory activities. During in vitro gastro intestinal digestion of goat milk protein, the antihypertensive tripeptides VPP and IPP were released. Thus, to study the release of short bioactive peptides during gastro intestinal transport, the research outlines the appropriateness of the harmonized digestive model system [24].

In 2018, a study conducted by the Shu et al. the hydrolysis of cow and goat milk were performed by four commercial proteases which include trypsin, papain, alkaline protease and bromelain. The comparison between the ACE inhibitory activity of cow and goat milk was measured. The hydrolysates which were treated by alkaline protease showed the highest degree of hydrolysis DH. Moreover, the ACE inhibitory activity of the hydrolysates derived from goat milk was higher than that of hydrolysates derived from cow milk. Therefore, a proper enzyme is required for the development of functional milk products like ACE inhibitory peptides [7].

In another study, Chen et al. used a novel wild strain *L. plantarum* 69 which was genetically identified. This novel strain was used for the fermenting of goat milk having high ACE inhibitory activity. The response surface methodology was used to maintain the optimal fermentation condition. The fermented product reached the ACE inhibitory activity to 88.91% close to the 91.68% which was predicted. By using ultrafiltration, macroporous resin DA201-C, gel chromatography and RP-HPLC purification was operated, which finally exhibited the ACE inhibitory activity of 91.62%. Thus, the goat milk which was fermented by L69 maintained highe ACE inhibitory activity and showed the successful survival in the gastro intestinal tract [1].

Experiment conducted by Parmar and fellows showed that the goat milk fermented with *L. casei* (NK9) exhibited a sequence of peptide AFPEHK having ACE inhibitory activity, matched with goat milk protein databases of AHTPDB. However, *L. casei* (NK9) and *L. fermentum* (LF) could be explored for the production of ACE inhibitory peptides from fermented goat milk [25].

The research of Aslam et al. showed the hydrolysis of goat milk protein with *Lactobacillus Helveticus-cicc22171.* The purification of ACE inhibitory peptides from the fermented goat milk was done by ultrafiltration. Then size exclusion chromatography was performed by having a molecular cut off 10,000 Da (PM-10) membrane. By applying Nin Hydrin reaction and SDS-PAGE analysis, the sample with 24 h incubation time was best considered as compared to others. Moreover, Q executive Hybrid Quadrapole-Orbitrap MS was used for the determination of molecular structure and sequence of ACE inhibitory peptides. Groups of proteins containing PVP, VVP and VPP, were identified with highest ACE inhibitory activity. These novel bioactive peptides from fermented goat milk can be used as ACE inhibitory peptides and control hypertension [5].

Last year, the research of Parmar et al. reported the study of five different cultures of *Lactobacillus* i.e. *L. rhamnosus* (NK2) (KR080695), *L. casei* (NK9) (KR732325), *L. fermentum* (M5) (KU366365), *L. paracasei* (M16) (KU366368), *L. fermentum* TDS030603 (MTCC 25067) (LF). These were studied for their ACE-inhibitory activities, peptides production from fermented goat milk (*Capra aegagrus hircus*), growth behavior and PepX. Peptides obtained from the fermented goat milk were purified, isolated and their characterization was done by profiling of amino acids, by searching on Protein Information Resource (PIR), Database of Antihypertensive Peptides (AHTPDB) and BIOPEP database. Furthermore, the exploration of *L. fermentum* (M5) and *L. paracasei* (M16) couldlead to the production of ACE inhibitory peptides from the fermented goat milk. Thus, the goat milk which is fermented by the *Lactobacillus* cultures can be considered as a novel source for the production of ACE inhibitory peptides [26].

Methodology	Technique	Enzyme	Peptide Sequence	References
	Ultrafiltration size exclusion chromatography SDS-PAGE Q executive Hybrid Quadrapole-Orbitrap Mass Spectrometry	—	VLPVPQKAVPQ VLPVPQKVVPQ TQTPVVVPPFLQPEIMGVPKVKE	[5]
Fermentation by *L. plantarum* 69	Response surface methodology (RSM) ultrafiltration gel chromatography RP- HPLC	—	—	[1]
Enzymatic hydrolysis		Alcalase, flavourzyme, neutral protease proteinase K	—	[23]

Methodology	Technique	Enzyme	Peptide Sequence	References
Enzymatic Hydrolysis	Centrifugation Spectrophotometry	Alkaline protease trypsin bromelain papain	HHL	[7]
Enzymatic Hydrolysis	MALDI-TOF MS RP-HPLC	Pepsin	HHL	[19]
Enzymatic Hydrolysis	Centrifugation UV/Visible Spectrophotometry	Protease Trypsin Pepsin papain	HHL	[8]

7. Milk and BP

Milk is a fluid that is secreted from the female mammary glands of mammalian species, and its primitive function is to meet the complete nutritional requirements of infants. Proteins present in milk consists of 80% caseins and 20% whey proteins [27].

Milk is rich in calcium, potassium and magnesium. A number of studies have showed the importance of calcium and its effect on BP. A meta-analysis of 40 studies, which includes 2492 subjects showed that the calcium supplementation decreased SBP and DBP by 1.9 mmHg and 10 mmHg respectively [28].

7.1 Molecular properties of milk proteins

Various systems of proteins are synthesized through the formation of monomer subunit associations. Those associations have a fixed structure, and they contain several identical or different subunits or many identical subunits. Casein and whey proteins make up the protein system of milk. Whey protein molecules comprises of globular structure with a relatively high content of helical structures and a balanced distribution of acidic and basic amino acid residues and hydrophobic and hydrophilic amino acid residues along the polypeptide chain [29]. In contrast to standard globular proteins such as whey proteins, casein is characterized by a unique, amphiphilic structure.

Proteins from the milk are a precursor of different biologically active peptides, but many peptides in milk are inactive, therefore, require hydrolysis for their release [7, 30].

One of the good source of the bioactive peptides which have a positive impact on body functions is from the caseins and whey proteins of the milk. The release of these inactive peptides present within the precursor protein sequence is done by the enzymatic hydrolysis or by fermenting with lactic acid bacteria, in vivo or in vitro. Other methods which include DNA recombinant technology, chemical synthesis and extraction from the natural foods have also been confirmed for releasing bioactive peptides [7].

In a nine year's follow up study of 6912 white, non-hypertensive men and women showed that the subjects consuming less than one serving of low- fat milk per day have risk of getting hypertension while those subjects consuming low-fat milk per day had lower increase of high BP. Similarly, a potential study of 3,157 young adults having age between 18 and 30 years surveyed for 10 years found that the frequency of elevated BP was inversely associated with total intake of dairy products, if subjects had body mass index (BMI) ≥ 25 but not in normal weight subjects [31, 32].

8. Goat milk

Because of the presence of all the essential amino acids without a high concentration of fats and mucus producing substances, goat milk is considered to be a perfect food [27]. Because utilization of bovine milk has become the cause of food allergy in infants, the importance of goat milk is constantly increasing. Therefore, when there is a shortage of human milk, goat milk proteins are highly recommended because of their property of being more digestible [19].

Goat milk is different from cow or human milk in capacity of buffer, alkalinity, and digestibility but have various health benefits. In the maintenance of health and nutrition of young and elderly, goat milk has played an important role [25]. The amino acid composition of goat milk protein is closer to that of human breast milk than to bovine or caprine milk [1].

All over the world, the production and consumption of goat milk and dairy products is increasing. Goat milk has a unique advantage to other milk. The immunoglobulins are more abundant in goat milk than breast milk [33] Also, the amount of proteins, fats, minerals, vitamins, and other nutrients of goat milk are much higher than other milk [10]. In the production of ACE-I peptides after fermentation, goat milk is considered a better choice among other dairy species [5].

8.1 ACE-I peptides from goat milk

In processed dairy products (cheese, milk etc.) antihypertensive peptides have been found without any intended functional role. Valine-Proline-Proline (Val-Pro-Pro) and lactotripeptides Isoleucine-Proline-Proline (Ile-Pro-Pro) have been obtained from sour milk. Although casein and whey have shown effect in decreasing the BP but nowadays research is focused on their degradation products called as peptides [24, 34, 35].

Different studies reported that ACE-inhibitory peptides can come from different sources like animal products, marine organisms, and plants. And are derived by hydrolyzing enzymes such as pepsin, chymotrypsin, and trypsin and microbial enzymes such as alcalase, thermolysin, flavourzyme, and proteinase K [36].

Some findings reinforced the possible beneficial effects by consuming fermented goat milk. It helps in the prevention of cardiovascular diseases in association with oxidative stress and hypertension [37].

For the development of products of pharmaceuticals and nutraceuticals, bioactive peptides derived from the milk proteins are considered. As a suitable source for the generation of bio-functional ingredients to prevent and treat hypertension, a study provided a theoretical base for the development of goat milk derived proteins [27].

Among the sequences identified after the in vitro gastro intestinal digestion of skimmed goat milk, 18 were the bioactive peptides with ACE-I activity [24].

Fermented goat milk produced by *Lactobacillus* cultures could be a novel source of ACE-inhibitory peptides [26]. In a study conducted by Yuliana, it is seen that for the proteolytic degradation of milk proteins and production of different peptides Lactic acid bacteria (LAB) is used. *Lactobacillus kefiri* YK4 and JK17 are used as a potential starter culture for the production of ACE-I peptides [30].

8.2 Biochemical aspects of milk derived ACE-I peptides

As far as the biochemical aspects of milk derived ACE-I peptides are concerned, the endothelial ACE contains two homologous domains which are named as N-terminal and C-terminal, both domains are catalytically active, ACE domain bind to any of the domain or may prefer to both. However, C-terminal is dominant angiotensin converting site as well as it seems necessary for BP regulation. The molecular mass of majority of ACE-I peptides is low while they possess short chain. These are consistent with the findings of Aslam [5].

Although ACE-inhibitory effect of a hypotensive peptide could be verified *in vitro*, question on the true antihypertensive mechanism may still remain e.g. lactotripeptide obtained from fermented milk product have shown to inhibit ACE both *in vitro* and *in vivo* in animal study. No changes were noticed in the plasma AcSDKP, ACE activity or the active renin concentrations after 7-day administration of the product, however, urine AcSDKP was increased to some extent. AcSDKP is a marker of the specific.

ACE activity of the N-terminal domain. It was determined that neither plasma nor endothelial ACE was inhibited and no specific effect was observed on N-terminal or C-terminal ACE-domains [38].

The structure–activity relationships have indicated that the most promising tripeptide structure possess hydrophobic amino acid in the N-terminal, aromatic amino acid at the C-terminal and positively charged at the middle position. As far as the ACE-I dipeptides are concerned, the presence of amino acid residue with large side chain as well as hydrophobic side chain is preferred. The presence of amino acids Asp, Gly and Pro at N-terminal as well as Pro-Ser-Thr at the C-terminal are responsible for the stability of peptide towards luminal enzymatic peptide hydrolysis. In the analysis of peptide stability and permeability it was observed that many dipeptides such as Ile-Pro-Pro exhibited high ACE-I activity *in vitro* and were verified to possess high intestinal stability [39–41].

8.3 Safety aspects of goat milk derived ACE-I peptide

The milk of cow which is an essential part of human nutrition holds a safe reputation. Peptide sequences of different length are generated when the ingested milk in the gastrointestinal tract is attacked by different enzymes which hydrolyze the milk protein. The human body is constantly exposed to the protein hydrolyzates without facing side effects. Moreover, Food Drug Authority have listed the hydrolyzates obtained from the protein as “generally recognized as safe” (GRAS). However, European countries have issued no health claim regarding the protein hydrolyzates and also not authorized the milk protein derived peptides as GRAS. Drugs acting as ACE-inhibitors, such as captopril and enalapril, hold some common adverse effects, which could theoretically concern also milk-derived antihypertensive peptides because of their ACE-I activity. ACE-inhibitors control RAAS and cough, hypotension and hyperkalemia are the most commonly reported adverse effects. However, dozens of clinical studies with different kinds of antihypertensive peptide products have been executed and no treatment-related safety concerns have appeared [46, 47].

Casein hydrolyzates as well as Val-Pro-Pro have showed no toxicity when toxicological studies were carried out on animals. There was no indication to support establishment of either the Lowest Observed Effect Level or Maximally Tolerated Dose; both being greater than 2 g/kg/day. Similarly, no adverse effects associated to casein-derived tripeptides were observed in a subchronic (90-day) repeated-dose toxicity study with rats or in a pre-natal growth study with rabbits [48].

The tripeptide generated by hydrolyzing the milk protein with enzyme preparation derived from *A. oryzae* and also the tripeptide Ile-Pro-Pro obtained by hydrolyzing milk have showed neither mutagenic nor clastogenic activity *in vitro* and did not showed any side effect in a 90 day repeated dose. Neither mutagenic nor clastogenic effect was observed in Wistar rats which were given 141 fold higher doses than the estimated intake as a functional food in an oral toxicity study [49].

8.4 Application prospects of goat milk derived ACE inhibitory peptides

The peptides possess multifunctional properties and are easily absorbed. Therefore, ACE-I peptides derived from food sources hold a great promise in the development of a novel physiological functional food peptides foe preventing high BP as well as for therapeutic purposes. Moreover, these peptides can serve as starting compounds for the development of antihypertensive drugs against ACE. In Japan, soup containing ACE-I peptides and as well as sour milk have been marketed to cure hypertension. In Japan, the thermolysin digest of dried bonito (called "Katsuobushi oligopeptide") has been officially approved as Foods for Specified Health Use by the Ministry of Health and Welfare in Japan [50, 51].

It should be noted, however, that the physiological activity of many bioactive milk components has been analyzed mostly in *in vitro* studies and experiments conducted on animals, but never on humans. The development of economically feasible industrial methods for the generation of biologically active milk components poses a new challenge for food scientists and food technology experts. Though, the significance of milk proteins and peptides for the formulation of functional food has been verified and described from long time but the mass production of these peptides is still not done. New research efforts are undertaken to optimize the activity of milk proteins and peptides in nutrition and their availability in the human body. The choice of foods containing biologically active peptides continues to be limited. Newly identified peptides will be introduced to the food processing industry with the advent of new technologies, such as membrane separation, nanofiltration and ultrafiltration. Macroencapsulation and nanoencapsulation methods may serve as a source for new solutions that could increase the stability of peptide in foods and during the process of digestion [52].

Therefore, this matter requires high interest and importance to reveal whether these ACE-I peptides also possess the effects that of commonly used synthetic drugs. In spite of the results obtained from these antihypertensive peptides from food proteins, it should also be considered that these results are obtained from *in vitro* and can vary from the effects obtained *in vivo*. Many peptides have showed results *in vitro* but the BP lowering activity of these peptides in *in vivo* is yet not confirmed. So, it requires efforts to examine whether these peptides are effective in lowering BP *in vivo* in all cases and to explain the mechanism of the antihypertensive activities shown by these peptides. Before considering the exploitation of these peptides in physiologically functional food, therapeutic purposes and prevention of hypertension, it is very necessary to evaluate the efficacy and long term effects as well as safety of these peptides by extended clinical trials on human volunteers [53].

The concentration of future research should be on the content, biologically availability of peptides, and milk derivatives in protein. Future studies to understand and investigate the physiological mechanism responsible for the bioactivity of these peptides could be possible only with the applications of proteomic, metabolomics method and peptidomic. The process of enriching foods with peptides can also give rise to legal concerns when health claims are made on the resulting end products [52].

9. Bioavailability

Generally, after oral dosing the peptides are rapidly metabolized to the constituent amino acids by the peptidases present at the brush border membrane and the bioavailability and absorption remains very low. However, it is reported that at least dipeptide and tripeptides are absorbed intact, which later on enter in the circulation and produce systemic effects. The absorption of bioactive peptides is carried out via carrier-mediated transport or paracellular diffusion. Apparently, short tripeptides are actively transported *via* a specific transporter (PepT1) and oligopeptides via the paracellular route. The tripeptide Ile-Pro-Pro and Val-Pro-Pro are absorbed by using three different absorption models and are transported in small amounts intact across the barrier of the intestinal epithelium [42].

Half-lives of absorption and elimination of ACE-I peptides are only few minutes. The resistance against many human proteolytic enzymes have been observed with ACE-I peptides possessing Pro or Pro-Pro residues at the C-terminal position [34, 43, 44]. Therefore, there is a strong likelihood that these peptides reach the circulation and target sites intact and exert also systemic effects. As concern the casein-derived radiolabelled tripeptide Ile-Pro-Pro, it was observed that it absorbed partly intact from the intestinal tract after a single dose to rats. Substantial amount of radioactively labeled peptides were detected from several tissues including liver, kidney and aorta. The process of excretion of the tripeptide was very slow, even after the 48 h the radiolabelled peptide was not completely excreted. Ile-Pro-Pro did not bind to albumin or other plasma proteins *in vitro*. In view of this and the long-lasting retention of the radioactivity in the tissues, increase of Ile-Pro-Pro may occur in ample concentrations to cause BP lowering effects e.g., by ACE-inhibition in the vascular wall [45].

10. Conclusion

Hypertension is observed as distinct disease and can be regarded as major risk factor to the CVD; it contributes directly to the renal failure, peripheral arterial disease, stroke, artery disease and congestive heart failure. If successful BP reduction is achieved then the risk of CVD and incidence of coronary mortality particularly with the elderly having multiple risk factors, can be dramatically reduced. Bioactive peptides which have a positive impact on body functions can be obtained from the caseins and whey proteins of the goat milk. The release of these inactive peptides present within the precursor protein sequence is done by the enzymatic hydrolysis or by fermenting with lactic acid bacteria, in vivo or in vitro. The research on antihypertensive bioactive peptides derived from natural the proteins of goat milk specially ACE-I peptides have shown significance over synthetic inhibitors for the treatment of hypertension. Therefore, the goat milk proteins have laid the foundation for an alternate natural source with lesser side effects and higher ACE-I activity. Thus, these bioactive peptides can be applied in the nutraceutical and pharmaceutical industries.

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Chapter 17

Role of Goat Milk in Infant Health and Nutrition

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Abstract

Goat husbandry is widespread due to high adaptability of goat to different and extreme environments. Goat milk is valuable from a nutritional point of view in terms of both protein and lipid fraction. The complex polymorphism of its casein fractions as well as the peculiar fatty acid profile makes goat milk interesting for its high potential in exploitation for human health. Genetic polymorphisms of milk proteins play an important role both in eliciting different allergic reaction and for derived peptides with functional properties. The purpose of the present chapter is to report information on the possible impact of goat milk protein and lipid fractions on cow's milk protein allergy, and on some infant diseases as generalized epilepsy and metabolic disorders.

Keywords: caprine casein polymorphism, caprine fatty acid profile, cow milk allergy, infant epilepsy, infant obesity

1. Introduction

The most represented animal species in terms of milk productions are cow (81.05%), buffalo (15.14%), goat (2.25%), sheep (1.20%), and camel (0.35%) that contribute differently to milk world production [1].

Milk represents the first food for each newborn, able to satisfy the nutritional needs differently based on yield and composition. Although the proximate composition of goat milk is quite similar to cow milk, the former has received increasing attention due to its peculiar protein, fat and mineral composition and bioactive components.

Greater digestibility has been attributed to goat milk due to its casein curd, which is softer and smaller and makes it more easily attached by human digestive system than that derived from other milks. Moreover, size of the fat globules and high proportion of short and medium chain fatty acids also affect the digestibility since it provides a better dispersion and a more homogenous mixture of fat.

Although the content of lactose in goat milk is comparable to that of other milking species, goat milk is rich in lactose-derived oligosaccharides (OS), especially fucosylated and sialylated OS, which are not degraded by human digestive enzymes and exert prebiotic and antimicrobial functions in the gastrointestinal tract.

An appropriate nutritional intake in childhood is required for not only growth and development but also to support health and immune functions, with short and long-term implications for human well-being. Goat milk has always enjoyed particular attention for its beneficial effects in human nutrition, in particular for fragile categories such as infants and the elderly, even if the potential benefits attributed to such milk were based more on anecdotes than on scientific data.

To date, scientific evidence collected in more than 70 years of scientific research and corroborated by recent advances in milk biochemistry and *in vivo* and *in vitro* studies aimed at evaluating the effects of milk components on human physiology, bring great attention to goat's milk for its nutritional and medical value.

2. Methods

The present chapter reports recent advances on the role of goat milk in several aspects of infant health. In particular, the peculiar composition of goat milk protein and lipid fractions has been deepened with the aim to exploit the use of such milk in infant nutrition.

The complex genetic polymorphism of casein fraction of goat milk may offer a strategy in the treatment of cow milk allergy, due to the low amount of casein fractions in milk proteome. The study of the inflammatory response to goat milk in terms of cytokines production by peripheral blood mononuclear cells (PBMCs) stimulated with milk protein fractions represents a novel approach aiming at verifying the effective role of goat milk in the treatment of infants with cow milk allergy. PBMCs are easily isolated from blood and are used to investigate the effect of food bioactive molecules on various immune cells.

The impact of milk protein mixture, casein and β-lactoglobulin fraction on cytokine production by PBMCs from infants with cow's milk protein allergy is discussed in the present chapter. Ten patients with cow's milk protein allergy and ten non-allergic control infants were included in the study [2].

The composition of protein fraction has been investigated for its role in infant epilepsy by means of *in vitro* system using PBMCs collected from 10 children with generalized epilepsy and 10 control children [3]. The level of cytokines, produced in response to purified casein and whey protein fractions, obtained from goat milk and milk from human and other milking species, represents a tool to evaluate the pro or anti-inflammatory role of food in triggering the epileptic seizures.

Cytokines secreted by PBMCs are soluble polypeptides and glycoproteins that bind to specific receptors and are extremely potent at low concentrations. Their potency is partly due to the regulation of leukocyte function during inflammation.

The effect of protein fractions from milk on the production of cytokines and reactive oxygen species (ROS) of PMBCs from infants with generalized epilepsy was studied.

Levels of TNF-α, Interleukin-10 (IL-10), IL-6 and IL-1β in culture supernatants were determined using Luminex Multiplex Assays, while the level of ROS was measured in the culture supernatants using an OxiSelect in vitro ROS/RNS assay kit.

The effect of the four casein fractions and the mixture of the two main whey milk proteins from different ruminant species (cow, sheep and goat) on cytokines and oxidative phenomena in PBMCs from children with generalized epilepsy are discussed in the present chapter [4]. Separation of milk protein fractions was obtained using reversed-phase (RP)-HPLC.

PBMCs were obtained by density gradient from blood of 10 children with generalized epilepsy and 10 controls. Children with epilepsy were grouped according to cytokine levels as follows: one group having levels of cytokines comparable to those of the control group; a group with cytokine levels at least 5-fold higher than the control group; and a last group having cytokine levels at least 10-fold higher than those of the control subjects. The production of TNF-α, IL-10, IL-6 and IL-1β was studied in PBMC cultures, incubated with the four different casein fractions and a mixture of α-Lactalbumin and β-Lactoglobulin from dairy cows, sheeps and goats. In the cultured supernatant were also measured the levels of reactive oxygen species (ROS).

Finally, the present chapter gathers information on the peculiar fatty acid profile of goat milk lipid fraction and on the factors influencing the increase of fatty acids with beneficial role in human health. With this regard, the acidic profile of milk and digested milk has been studied with the aim to sustain infant nutrition in the prevention of metabolic disorders as childhood obesity.

The effect of *in vitro* digested milk on mature adipocytes 3 T3-L1 was studied comparing milk from different species including human [5]. Cellular viability, apoptosis, oxidative response and gene expression levels of NF-κB p65 and HMGB1, involved in the regulation of inflammatory response, were evaluated.

In order to mimic milk digestion, simulated salivary fluid at pH 7, gastric fluid at pH 3, and intestinal fluid at pH 7 were prepared. Adipocytes *in vitro* model has shown the potential to study the role of goat milk in relation to preadipocyte differentiation, mediated immune response and oxidative status.

3. Protein fraction in caprine milk

In-depth studies have revealed that goat milk is characterized by the presence of numerous polymorphisms in the loci of casein. The different alleles, depending on whether they are strong, weak or null, are associated with different levels of casein synthesis in milk and with different phosphorylation and glycosylation rates of the peptide chain.

According to the technological properties of milk, goat's milk from subjects with strong alleles was associated with a greater activity of milk coagulation enzymes, resulting in a greater inclusion of nutrients in the curd, higher yields in cheese and more compact curds with respect to the milk of animals carrying weak alleles. In fact, it has been shown that homozygous goats for strong alleles (in particular CSN1S1 AA goats) are able to more effectively use food proteins and high-energy diets, resulting in the production of milk that is richer in proteins and fats [6]. The milk of animals with strong genotype also has larger fat globules and a better creaming ability than the milk of goats with null genotype [7]. Furthermore, the CSN1S1 genotype influences the concentration of some fatty acids (FA): goat's milk homozygous for strong alleles have a higher content in short and medium chain FA (SCFA and MCFA), mainly synthesized *de novo* in the mammary gland, less branched chain (BCFA) mainly derived from rumen bacteria and less odd chain FA (OCFA) partly derived from rumen bacteria and partly from *de novo* mammary synthesis from C3 precursors. Indeed, CSN1S1 defective alleles induce negative feedback on *de novo* fatty acid synthesis in goat mammary epithelial cells.

3.1 Role of caprine milk in treatment of cow milk allergy

Goat milk offers advantages in treating people afflicted with cow milk allergies (CMA) and gastro-intestinal disorders [8]. Cow's milk allergy is the most commonly reported childhood food allergy; recently a pan-European birth cohort study using the gold standard diagnostic procedure for food allergies confirmed challenge-proven CMA in <1% of children up to age 2 [9]. It has been reported that children affected by gastrointestinal allergy and chronic enteropathy against cow milk could be beneficially treated through goat milk therapy; although some caprine milk proteins could exert immunological cross reactivity with cow milk proteins [10]. Children with CMA present a high risk of reaching out to side reactions to other mammalian milks, so goat's or ewe's milk-based formulas or products may be used only after individual testing. High casein polymorphism and check for the absence of cross-reactivity could lead in future to a therapeutic approach based on personalized nutrition.

In pediatric patients with CMA, IgE-binding epitopes on as1-casein, as2-casein, β-casein, κ -casein, β-lactoglobulin, BSA, IgG heavy chain, lactoferrin were recognized [11].

A novel approach has been conducted to study the inflammatory response to goat milk in infant with CMA by evaluating cytokines production by peripheral blood mononuclear cells (PBMCs) stimulated with whole milk, casein and β-lactoglobulin [2]. Goat milk proteins lowered the production of pro-inflammatory cytokines and enhanced the release of anti-inflammatory ones from PBMC compared to cow milk. In particular, secretion of the regulatory cytokine IL-10 after PBMC stimulation suggests that goat milk might prevent aberrant reactions towards antigens. Indeed Tiemessen [12] studied the role of IL-10 in T-cells reactivity of children affected by CMA highlighting the possibility that activated allergen-specific T-cells might concur to the formation of an active form of immune suppression *in vivo* through the production of IL-10. At the same time, TNF-α displayed lower level after stimulation with casein fractions isolated from goat than from cow milk in children with CMA. However, it is important to test the immune reactivity against each protein fraction before considering goat's milk as a safe substitute for feeding infant with CMA.

The level of synthesis of each protein fraction in milk due to genetic polymorphisms plays an important role in eliciting different degrees of allergic reaction. High frequency of the weak allele F, the presence of null allele for CSN1S1, and the high frequency of A0 genotype at CSN1S2 locus in goat breeds as Garganica goat makes this milk useful for testing on allergic subjects. Low levels of αs1-CN in goat milk means that its casein profile is closer to human milk than that of cow milk as human milk does not contain the αs1 -fraction and αs2 -fraction [13], while the major constituent is β-casein [14]. The phosphorylated serine residues of αS1 -casein, β-casein, and αS2 -casein appear to be an important allergenic epitope able to bind IgE even after a denaturing process. The αS1 -casein is characterized by linear epitopes released after protein digestion that can pass through the gastrointestinal system in immunologically active forms. The epitopes are mostly based in the primary sequence rather than in conformation. This is the reason why although extensively hydrolyzed formulas are considered the first choice for CMA treatment, these formulas have can also provoke an allergic reaction in some more allergic individuals, due to their residual allergenic epitopes [15].

Genetic polymorphism of goat milk proteins involved in human health and nutrition, associated with a different composition of milk proteins, may be responsible for the generation of a broad spectrum of casein-derived peptides [16]. Therefore, the study of the potential bioactivity of the peptide sequences released after hydrolysis plays a role of considerable relevance.

The study of goat casein loci can lead to a differentiation of the goat population, based on the final use of milk. Animals characterized by weak or null casein alleles could be used in breeding programs aimed at producing milk with hypoallergenic properties, while animals with strong alleles could be destined to improve the quality and properties of milk and related products [3].

In ruminant species, proteolytic activity in fresh raw milk can be attributed to indigenous enzymes, which originated from the animal, and to microbial (i.e. endogenous) enzymes. The major proteolytic system in milk is ascribed to the plasmin system, an alkaline serum proteinase system, and to cathepsins and elastase. Santillo et al. [17] investigated the effects of indigenous proteolytic enzymes on the release of bioactive peptides from goat milk. The authors have identified serine proteinases, and in particular plasmin, as protagonists in the release of numerous peptides deriving from β-CN and αs2-CN which could be considered bioactive molecules. The majority of the peptides showed similarity in the structure with bioactive peptides elsewhere described in goat and bovine milk and in dairy products. Some of the peptides have been shown to perform ACE inhibitory activity or have shown similarity in the structure with antihypertensive or antioxidant peptides.

3.2 Role of caprine milk in infant epilepsy

Epilepsy includes a group of neurological disorders characterized by periodic episodes of spontaneous seizures; the World Health Organization estimates this disorder affects 0.8% of the world population [18].

Several reports hypothesize the existence of a correlation between seizures and certain foods. The role of food products of animal origin on the diet has been widely recognized, especially with regard to the effects of protein fractions. In fact, milk proteins play an important role in stimulating the innate immune response, through the activation of pro and anti-inflammatory cytokines [2]. From this perspective, the effect of goat's milk protein fractions on the production of pro and anti-inflammatory cytokines was tested in newborn patients with epilepsy.

Cytokines are generally synthesized and secreted in response to immunological stimuli; they are soluble glycoproteins involved in growth regulation mechanisms, in the activation of immune cells and in inflammatory and immune responses, able to reach distant cells in other organs, through the peripheral circulation [19].

Stimulation with milk protein fractions from different milking species influenced pro and anti-inflammatory cytokines, produced ex vivo by PBMCs isolated from children with generalized epilepsy. Tumor necrosis factor-α produced by PBMCs cultured with caprine milk induced higher levels of this cytokine in 80% of infants. However, the levels of TNF-α detected in PBMC stimulated with goat's milk reached lower levels with respect to bovine and ovine milk. Regarding the TNF-α production, casein fraction induced lower levels in a higher percentage of patients, while the whey protein fraction induced higher levels of TNF-α in 10% of children, regardless of species. Furthermore, TNF-α produced by PBMC cultured with bovine and ovine whey protein was found to be lower in 70% of patients, while TNF-α produced by PBMC cultured with goat whey protein fraction showed intermediate levels in 80% of cases.

Bovine, caprine and ovine milk resulted in low IL-10 production by cultured PBMCs in at least 50% of cases, both for casein and whey protein fractions for all milk species studied. In general, the total amount of IL-10 detected was lower than that of other cytokines involved in this study. Interleukin-10 exerts extensive anti-inflammatory properties thanks to its inhibition of antigen-presenting cellular function and suppression of proinflammatory cytokines production [20]. Albenzio et al. [2] found higher levels of IL-10 in PBMCs cultured against cow and goat milk fractions in both healthy infants and infants affected by CMA.

Goat milk and casein fraction induced the highest levels of the same cytokine IL-1β in 80% of cases and whey protein induced an intermediate level in 80% of cases. Interleukin-1β is involved in promoting arousal toxicity and possibly in seizure generation [21]. There is a striking example of a dual role of cytokines on neuronal survival in diseased tissue; in particular, neuroprotective actions of IL-1β have been reported, probably mediated by its ability to induce the synthesis of astrocyte growth factors, promoting cellular repair mechanisms. The chronic expression of IL-1β during epileptogenesis suggests its involvement in the modulation of spontaneous seizures [22].

Caprine milk showed the highest level of IL-6 in 80% of patients, while bovine milk intermediate levels in 50% of patients, and ovine milk the lowest level in 60% of patients. The bovine and caprine casein fractions stimulated higher levels of

IL-6 in 80% of cases, while sheep casein stimulated a lower level in 80% of cases. In addition to the animal species, the whey protein fraction stimulated a lower level of IL-6 in most of the patients studied. The complexity of the PBMC response against stimulation by milk protein fractions can find an answer in the bivalent nature of IL-6, which is necessary for normal nervous system development but has neurotoxic and proconvulsive effects when increased levels are detected in the brain [23].

Subsequently the effect of milk protein fractions (αS1-CN, αS2-CN, κ-CN, β-CN, and a mix of α-LA and β-LG) from different animal species (bovine, ovine, and caprine) was evaluated on pro- and anti-inflammatory cytokines on infant patients [4]. Evaluating the production of cytokines by PBMC after exposure with milk protein fraction is of great interest to identify potential antigens in milk. In this study the patients were grouped as: 1) children with epilepsy having low levels of cytokines not different from those of control children (LL-EC); 2) children with epilepsy having cytokine levels at least 5-fold higher (medium levels; ML-EC) than those of control children; 3) children with epilepsy having cytokine levels at least 10-fold higher (high levels; HL-EC) than those of control children.

Table 1 reports the mean levels of TNF-α, IL-10, IL-6, and IL-1β in PBMC from blood of children from HL-EC group, incubated with 100 μg/mL of κ-CN, αS1-CN, αS2-CN, β-CN, and a mix of α-LA and β-LG obtained from bovine, caprine, and ovine milks. The results of this work demonstrate how complex interleukin modulation is in response to the different protein fractions, whether casein or whey protein.

Lower concentration of TNF-α was associated to PBMC incubated with bovine milk than with ovine or caprine milk. The major contribution to the elevation of TNF-α level was attributed to the β-casein fraction.

IL-1β and IL-6 recorded lower level after incubation with caprine and ovine milk than bovine milk. The differences in cytokine responses may be associated with genetic polymorphisms of the milk proteins. Concentration was lower for caprine apart from the group of patients investigated; in particular, HL-EC groups demonstrated a lower secretion in the blood stream of the interleukin. Concentrations of IL-6 were higher in cultured PBMC incubated with αS2-CN from bovine and ovine milks than in that from caprine milk. In particular, the β-CN fraction induced the highest levels of TNF-α in ovine and caprine milk, whereas the αS2- CN fraction from bovine milk stimulated the highest level of IL-6 and played a major role in production of IL-1β from cultured PBMC. In epileptic children having high cytokine levels than those of control children, the protein fraction of milk able to modulate the secretion of inflammatory interleukins appears to be represented by alpha s2 casein. Results of these recent works highlight how much the understanding of the effects of complex food matrices such as milk is still far from being completely revealed.

Caption to **Table 1**. Children have been grouped according to the level of cytokines compared to the level found in blood from control patients, as follows: LL-EC group of children with epilepsy having levels of cytokines comparable to those of

Interleukin	Bovine milk	Caprine milk	Ovine milk
TNF-α, pg./mL	284.72 ± 9.33	329.78 ± 8.14	336.40 ± 8.42
IL-1β, pg./mL	58.01 ± 1.02	50.44 ± 0.92	53.44 ± 1.06
IL-6, pg./mL	1,347.86 ± 28.81	1,245.12 ± 26.89	1,266.38 ± 30.01

Adapted from Albenzio et al. [4].

Table 1.
Mean level of TNF-α, IL-10, IL-6, and IL-1β in PBMC from blood of children with generalized epilepsy, incubated with 100 μg/mL of κ-CN, αS1-CN, αS2-CN, β-CN, and a mix of α-LA and β-LG obtained from bovine, caprine, and ovine milks.

control group (low level); ML-EC group of children with epilepsy with cytokine levels at least 5-fold higher (medium levels) than those of the control group; HL-EC group of children with epilepsy having cytokine levels at least 10-fold higher (high levels) than those of control group.

In studies regarding childhood epilepsy, it is noteworthy to investigate the onset of oxidative stress following milk feeding, as it contributes to acute injury-induced neuronal damage [24].

The evaluation of stimulation of cultured PMBC with milk and protein fractions from different species on ROS/RNS levels, evidenced that caprine milk was able to mitigate the effect on oxidative stress than bovine and ovine milks. Furthermore, within caprine milk protein fractions the ROS/RNS levels were found comparable. Lower levels of ROS/RNS detected in PBMC cultured with caprine milk fraction could be related to the lower levels of TNF-α in the corresponding fraction.

It has recently been reported that the neuronal damage generated by acute injuries, resulting in detrimental effects on areas of the brain associated with learning and memory function, may be partially due to oxidative damage, which occurs during epileptogenesis [24]. Those authors also suggested that a combination therapy, based on antioxidants and antiseizure drugs, might help to reduce the cognitive impairment as comorbidities occurring in epileptic patients.

4. Lipid fraction in caprine milk

Milk fat derived from small ruminants represents a valuable source of fatty acids, from a nutritional and health point of view [25].

Small ruminants' milk fat presents high content in medium-chain fatty acids (C6–C10; MCFA) and five fatty acids (C10:0, C14:0, C16:0, C18:0, and C18:1), accounting for >75% of total fatty acids in caprine and ovine milk. In fact, levels of the MCFA as caproic (C6:0) (2.4%, 1.6%), caprylic (C8:0) (2.7%, 1.3%), capric (C10:0) (10.0%, 3.0%), and lauric (C12:0) (5.0%, 3.1%) are significantly higher in goat than in cow milk, respectively [26].

During digestion, MCFA are more susceptible to the action of digestive enzymes, thanks to their low molecular weight and water solubility. Gastric lipase plays a particularly important role, as it promotes faster and more complete hydrolysis than in long-chain fatty acids. Hydrolysis of MCFA releases free fatty acids which can then be absorbed without being re-esterified in intestinal cells. MCFA have been used in the treatment of some metabolic diseases; Sanz Sampelayo et al. [25] reported that some patients suffering from malabsorption problems, pancreatic insufficiency, deficiency of bile salts or subject to intestinal resection have been treated with capric and caprylic acid. Derivatives of caprylic and capric acid were emphasized as medical and nutritional specialties: MCFA were suggested as tools in the control of obesity, in lowering serum cholesterol, in infant feeding and in the treatment of childhood epilepsy. Furthermore, some studies show antimicrobial and antiviral activity for C8: 0, C10: 0 and C12: 0 [27], in particular lauric acid has been studied for its antimicrobial activity against Helicobacter pylori [28].

The fat component of milk also contains essential nutrients, such as vitamins (A, D, E, K) or their precursors (carotenoids), essential polyunsaturated fatty acids and isomers of conjugated linoleic acid (CLA), which humans are not able to synthesize. CLA are a group of positional and geometric isomers of linoleic acid (cis9, cis12-C18:2, n-6). The isomer cis9, trans11-CLA, named rumenic acid, is the most prevalent—75–80% of the total CLA content in milk and meat [29]. CLA accounted for 2–4%, calculated as a percentage of total fatty acids esterified in phospholipids, in caprine and ovine milk, and less than 1% in bovine milk [30].

Dairy products naturally contain CLA and vaccenic acid (VA) as they are produced in the rumen. The CLA content in milk is influenced by numerous factors, both endogenous (animal breed, genetic type, lactation stage and pregnancy) and exogenous (diet and environmental conditions).

Diet represents the factor that most influences milk CLA content, which can be naturally enriched by fresh pasture feeding [31], or through the use of specific dietary formulations including oilseeds or fish oil [32]. The content of CLA, VA and α-linolenic acid (ALA) in milk, cheese and meat are profoundly influenced by the diet of animals, which is the major source of variation. The use of pasture, fresh forage and specific vegetable fat supplements in the sheep diet greatly influences the content of these compounds in sheep products [33].

In the Mediterranean area, grazing represents a fundamental dietary strategy in improving the health component of fatty acids present in sheep's milk and meat. In fact, the meat and milk of grass-fed ruminants are characterized by a higher content of CLA, omega-3 fatty acids, beta-carotene and vitamins A and E than the meat and milk of animals fed indoors. Green herbs are particularly rich in polyunsaturated fatty acids, especially ALA, which have a positive effect on the content of C18: 3n-3, VA and CLA in milk and meat. ALA in the rumen undergoes a partial biohydrogenation at VA, in animal tissues is then partially converted into cis-9, trans-11 CLA, thanks to the intervention of Δ9-desaturase. Fish oil was used in the diet of goats resulting in a significant increase in the rate of transfer of dietary EPA and DHA into milk [34]. Recently, CLA and VA have acquired substantial importance as a consequence of the encouraging results in human studies [35].

Biochemical studies showed beneficial effects of the cis-9, cis-11 CLA on neoplastic and atherosclerotic processes [36, 37] as well as a cholesterol-lowering effect [35]. Epidemiological studies showed that C18:3n3 is associated with a reduced risk of cardiovascular diseases [38], whereas EPA and DHA have beneficial effects on proper brain and visual development in the fetus, and maintenance of neural and visual tissues throughout life [39].

In different studies it has been shown that CLA, being an efficient ligand of PPAR alpha, is able to activate the peroxisomal beta oxidation [40] required for the synthesis of DHA starting from ALA. In addition, the peroxisomal beta oxidation is also the catabolic pathway of oxygenated eicosanoids [41], thus carrying out an anti-inflammatory activity. It follows that the diet should be rich in CLA and VA in order to increase the biosynthesis of DHA and the presence of fatty acids of the omega-3 series among highly unsaturated fatty acids (HUFA). Furthermore, CLA is metabolized in a similar way to linoleic and is able to decrease the formation and incorporation of arachidonic acid, contributing to the increase of the n-3 HUFA score.

4.1 Role of caprine milk in infant metabolic disorders

According to data provided by the World Health Organization (WHO), the number of obese people in the world has tripled since 1975. Obesity and overweight are now recognized as real public health problems in every part of the world [42].

The first cause of obesity and overweight is an energy imbalance between calories consumed and calories expended, which is mainly due to an increased intake of energy-dense foods rich in fat and to physical inactivity due to the sedentary nature of many forms of work and to the enhancement of urbanization. Overweight and obesity are strictly related to the insurgence of many other diseases affecting human health, represented by cardiovascular diseases, diabetes, musculoskeletal disorders, and some types of cancers.

In recent decades, pediatric research has focused on finding a relationship between childhood obesity and infant nutrition in the first six months of life [43]. In fact, in the period between the final stages of fetal growth and the first months of the newborn life, preadipocyte cells develop in mature adipose tissue, driven by hormonal and nutritional stimuli. Childhood obesity appears to be associated with an increased risk of obesity, premature death, and disability in adulthood. Furthermore, obese children exhibit breathing difficulties, increased risk of fractures, hypertension, early markers of cardiovascular disease, insulin resistance, and psychological distress.

Until recently, adipose tissue was considered only an energy reserve organ, but, following the increasing diffusion of obesity, researchers have focused attention in this field over the past twenty years [44], coming to the consideration that adipose tissue does not represent only an energy reserve, but is an important endocrine organ that has numerous targets, including some areas of the brain such as the hypothalamus. Adipose tissue is also involved in the regulation of many processes, such as homeostasis of fat mass and nutrients, regulation of the immune response, control of blood pressure, thyroid and reproductive system functions [45].

Obesity is a metabolic disorder that manifests itself in two phenomena, namely the increase in the number of adipocytes, due to hypertrophic phenomena, and an abnormal lipid filling of already existing adipocytes, caused by hyperplastic phenomena [46]. Hyperplasia occurs mainly in the developmental age, while hypertrophy in adulthood. Obesity starts with an excessive energetic intake, due to the ingestion of fats and carbohydrates, which induces mature adipocytes to store the excess of energy as triglycerides that accumulated within the adipocytes cells, thus activating the adipogenesis with consequent growth of the cells in size and number. This cellular transformation causes a change in the adipokines secretion, the activation of pro-inflammatory processes and the increase of oxidative stress phenomena [47].

Infant diet is able to influence the development of adipose tissue in adults, because the transformation of preadipocyte cells into mature adipocytes takes place during the last stages of fetus growth and the first months of newborn life. Being milk the only food taken by the newborn in these phases, many researchers are interested to study the effects of milk fat component, particularly fatty acids, on the adipose tissue.

Flachs et al. [48] observed that some n-3 series LC-PUFAs (polyunsaturated fatty acids), as EPA (eicosapentaenoic acid) and DHA (docosahexaenoic), can exert a metabolic action on adipose tissue to prevent obesity. Some authors have tested the effect of MUFAs (monounsaturated fatty acids) and CLAs (conjugated linoleic acid) as herbal extracts for obesity [49]. Guo et al. [50] have shown that caprylic acid and MCFA (medium chain fatty acids) have the ability to inhibit the synthesis of triglycerides by adipocytes. Other authors have also observed a relationship between fatty acid composition of diet and childhood obesity, evidencing synergistic effects among different fatty acids; in particular the association of n-6 series PUFAs with high concentrations of LA (linoleic acid) and of ALA (alpha-linolenic acid) seems to support growth of adipose tissue under nutritional *stimuli* [51]. However, both the quantity and quality of fatty acids that reach the adipose tissues are influenced by the biochemical processes during digestion [52].

It is therefore interesting to understand the effect of the digestive process on milk fatty acids bioavailability, and whether this process may influence adipose tissue. Caprine milk was compared to human and formula milk to evaluate evaluated the effect of *in vitro* digestion on mature adipocytes, paying particular attention to the role of milk fatty acid composition [5]. Digested caprine milk source exhibited a reduced cellular 3 T3-L1 viability due to activation of apoptotic phenomena. Apoptosis is an important biological process by which the body removes aged cells during physiological or pathological conditions [53], avoiding eliciting inflammation. Moreover, digested human and formula milk induced lower oxidative stress in mature adipocytes evidenced by lower levels of ROS than caprine milk digested sample probably due to the peculiar free fatty acids profile of different milk sources.

The role of ROS in adipose tissue is complex. In preadipocytes the accumulation of mitochondrial ROS could inhibit cell proliferation [54], whereas in mature adipocytes from obese rats high level of ROS were observed and protection of adipocytes from oxidative stress is recognized as a potential clinical strategy in obesity treatment [55].

Caprilic acid has been shown to induce ROS generation and might also modulate PPARγ activity indirectly via the ROS signaling pathways [50]. Accordingly, digested milk from caprine showed a mean content of free caprilic acid higher than FM and HM (5.17 μg/ml for caprine, vs. 4.85, 3.5 μg/ml of extract for formula and human milk respectively), and this could partly explain the lower ROS content in digested human and formula. On the other hand, many natural lipid compounds with anti-inflammatory and antioxidant effects have been used to treat obesity such as n-3 PUFA, EPA and DHA, MUFA and CLA [49]. Santillo et al. [5] observed a higher content of free oleic and linoleic acid in digested human milk and infant formula; oleic acid content 1.5 and 6-folds higher and linoleic acid content 2 and 5.5-folds higher than what observed in ruminant milk, respectively. Since ROS are key signaling molecules that play an important role in the progression of inflammatory disorders [56], NF-κB p65 and HMGB1 were evaluated. HMGB1 promotes inflammation and its receptors interact with NF-κB p65 forming a positive feedback loop to sustain inflammatory conditions [57]. Among treatments, the lowest gene expression was found in HM and CM, the highest in FM.

5. Conclusions

Goat milk has received increasing attention due to its composition, in particular for feeding of fragile categories such as infants and the elderly.

Goat milk protein fraction revealed the presence of a high number of alleles at the four casein loci, associated with different levels of casein synthesis into milk. Recent research evidenced the important role of goat milk protein fraction in eliciting hypoallergenic reaction and in triggering cytokine response in cow milk allergy and infant epilepsy, respectively.

Moreover the exploitation of caprine milk in infant nutrition, in particular cases of pediatric metabolic disorders, should further investigate the role of the acidic profile of such milk on the mechanisms of both adipocyte differentiation and pro-inflammatory *stimulus*.

The role of goat's milk as a nutritional intervention useful to support clinical therapies in some emerging pediatric diseases shows promising results thus deserves further research.

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Chapter 18

Goat's Milk (GM), a Booster to Human Immune System against Diseases

Rajendra Panta, Vinod Kumar Paswan, Pankaj Kumar Gupta and Dhruba Narayan Kohar

Abstract

Milk is clean lacteal secretion from mammalians shortly after parturition. GM is taken as a complete meal in human diet. GM is the only milk from milching species that possess possibility of substituting human milk. Availability of A2 casein in GM make it comparable to human milk in terms of protein. The most vulnerable ones are infants, aged people and pregnant women as their immune system could answer at any time if extra supplement is not administered. In this case, GM is only option that is highly compatible and nutritious nourishing food naturally. It has been used in curing respiratory problems, diarrhoea, colic, gastrointestinal disturbances etc. Feeding GM enhances production of immunoglobulin, beneficial gut microbiota, phagocytosis activities. Presence of inherent antibodies suits GM for using it in curing Tuberculosis. It contains every needed nutrient in higher amount as compared to milk from other animals. Per servings it has 13% more Calcium, 47% more vitamin A than Cow's milk. It is filled with most of the trace minerals. Selenium, an immune system enhancer provides anti-oxidative and anti-inflammatory protection via inhibition of bacterial growth. Chlorine and Fluorine acts as natural germicides. GM contain good source of Potassium which is crucial for maintainance of blood pressure and functioning of heart, it protects against arteriosclerosis. GM not only reduces the level of total cholesterol due to presence of Medium Chain Triglycerides but also improve mineralisation of skeleton and haemoglobin level. GM consists huge source of biorganic sodium, the absence of which results in arthritis. People who are lactose intolerant even can consume GM as it has low lactose content and for those who finds its smell and taste unusual, there is option of fortification. Because of easily digestible and readily bioavailable nature its consumption has been increased.

Keywords: arteriosclerosis, bioavailable, capra milk, fortification, immunity, substitute

1. Introduction

Goats are small ruminants that were among first domesticated farm animals which are into herding from about 10,000 years ago [1]. The acclimatising capacity of goat is peculiar as they can be economically reared in areas ranging from tropics, deserts, temperate to harsh climate of mountains without fluctuation in productivity [2]. Goat is a major supplier of dairy and meat products for rural people and regarded as a "Poor man's cow" [3].

The world's goat population has increased by around 55% from 1991 to 2011 whereas cattle population grew only by 9% and sheep population decreased by about 7%. In between these years Goat's milk (GM) production increased by around 70% [4] which can however be greater because of unreported home consumption of GM in large amount in case of developed countries [5]. The production of GM in world showed an increase of 62% from 1993 to 2013 from 11 to 18 million tons [6]. Except in Antarctic, GM consumption by human is found in all over the world [6]. The contribution of developing countries in goat rearing is noteworthy. Out of total goat population more than 90% alone is maintained by countries in Asia and Africa [7]. Majority of goats including dairy ones in Asia are in the hands of small-scale farmers, among which many of them are poor and landless [8]. The production and consumption pattern of GM and its products has increased in recent decades. Growth in consumption of such milk products is due to their known beneficial effects on human health which are already recognised by the scientific community (**Table 1**).

Total annual milk supply of goat is about 3.4%, sheep milk is 1.4%, camel milk is 0.2%, cow milk is 85% while buffalo contribute 11% [9]. About 80% of total GM supply is only from Asia [3] of which main countries include India, China, Bangladesh, Iran, Pakistan and Turkey [10]. 36.7% of world dairy goats are reared in Indian subcontinent producing 40.7% of the world's goat milk, with India (60.6%, 129 L/doe), Bangladesh (16.9%, 37 L/doe) and Pakistan (13.3%, 100 L/doe) [11]. Out of 500 breeds of goat only half dozen is raised for milking purpose and about 600–700 million dairy goats are present in the world (**Figure 1**) [12].

The major species of milching dairy goat includes Sannen, Anglo-nubian, Toggenburg, British alpine. They produce good quantity of milk. For an instance Toggenburg can produce 7.57 litres of milk per day [13]. Factors like breed, season of kidding, stage of lactation, species, age, parity, colostrums, feed, environmental conditions, length of dry period, disease, body weight etc. can cause change in GM composition [14].

	Total[2] [million head (%)]		**Dairy [million head (%)]**		**Milk [Mt (%)]**		**Yield[3] [L/head]**	
Continent	**Sheep**	**Goats**	**Sheep**	**Goats**	**Sheep**	**Goats**	**Sheep**	**Goats**
Asia	512 (43.6)	556 (55.4)	135 (54.0)	106 (52.1)	4.73 (45.6)	8.04 (52.7)	35.1	76.2
Africa	352 (30.0)	388 (38.7)	79 (31.7)	80 (39.6)	2.54 (24.5)	3.93 (25.7)	32.2	48.9
Europe	131 (11.2)	17 (1.7)	33 (13.3)	9 (4.3)	3.01 (29.0)	2.54 (16.6)	90.8	290.1
America	84 (7.1)	38 (3.8)	3 (1.1)	8 (4.0)	0.09 (0.9)	0.75 (4.9)	33.0	93.4
Oceania	95 (8.1)	4 (0.4)	<0.1 (0)	<0.1 (0)	<0.01 (0)	<0.01 (0)	—	—
Total	1,173 (100)	1,003 (100)	250 (100)	203 (100)	10.37 (100)	15.26 (100)	41.5	75.3

Source: Ref. [7].

Table 1.
World panorama of dairy sheep and goats.

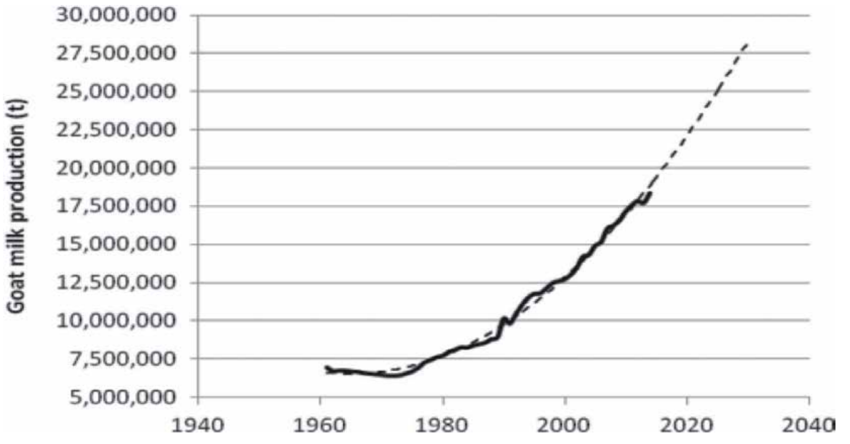

Figure 1.
World goat milk production trends from 1916 to 2016 (solid line) and forecast to 2030 by using time series model (dashed line). Source: Ref. [7].

Milk is clean lacteal secretion from mammalians shortly after parturition. GM being highly compatible and nourishing complete natural food, can serve as a substitute for a meal. Its acceptability has increased in recent years which is mainly due to its low fat and capacity to neutralize acids and toxins present in body and also due to higher gross composition than that of cow's milk. GM has potential that enable tolerating different technological treatments to obtain a product which have ability to satisfy the demand of consumer in terms of health, nutrition, safety and pleasure. Beside qualitative criteria (colour and odour), other aspects should also be given equal importance (milk protein, fat, bacteriology, freezing point, lipolysis, somatic cell count, immunoglobulins, inhibitors etc) for improving the quality of milk [15]. Human milk consumption as defined by the International Congress of Food "milk is the product of the total, full and uninterrupted milking of dairy female in good health, also nourished and not overworked". It must be collected properly with no colostrum [16].

GM can be consumed as an alternative to cow milk as it is less allergenic [17] and highly digestible [18]. It has been reported by Park (1994) that between 40 and 100% of patients allergic to cow milk proteins can tolerate GM. It is also recommended to pregnant women and infant to fulfil their nutritional requirement at growing stage [19] and also to old and convalescent people [20]. It is immune to

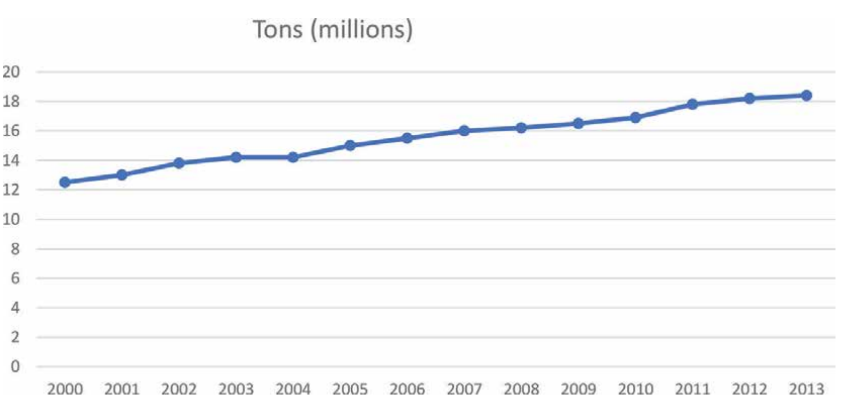

Figure 2.
Goat milk production in the world from 2000 to 2013 (million tons). Source: Ref. [21].

several diseases and boost the immunity system of human. It differs from cow and human milk as it shows distinct alkalinity, higher buffering capacity and certain therapeutic values in medicine and human nutrition. The nutritional and health benefits of GM are related to a number of medical problems, the most important being food allergies and a pure substitute for those who are allergic to cow milk (**Figure 2**) [22].

2. Methodology

This review chapter is a compilation of numerous research and review paper. In the course of writing this chapter we have reviewed number of articles, proceedings, magazines, newspaper, bulletin, editorial etc, Solids so that a broad range of information could be collected and presented. So, this is a thorough and detailed information regarding goat milk and its nutritive as well as medicinal values, accordingly which its conclusion has been drawn.

3. Composition of GM

GM because of its specific composition is being considered as a high-quality raw material for manufacturing food of infants along with population with particular needs [23]. Fresh goat milk appears as a white, opaque liquid with a little sweet in taste having no odour in practical life [24]. The Solid content in goat milk ranges from 12 to 18% while protein content in solid lies between 3 and 4.5% in goat milk [25]. Compositional and nutritive value of goat milk can be preserved, enhanced and improved by the aid of processing [26].

The composition and milk yield of goat varies with varying factors such as diet, breed, management, environment, age, stage of lactation, season, plane of nutrition etc. [27]. GM having all the composition in adequate amount is preferred as a high-quality milk and it should be free from pathogens and foreign substances such as antibiotics, antiseptics or residue of pesticides and should not differ from that of cow's milk in taste and odour. GM is proven to have a better and efficient digestibility, buffering capacity, alkalinity and therapeutic values as compared to human and cow's milk in human nutrition and medicine [28].

3.1 Fat

The physical properties like surface tension, viscosity and specific gravity of GM are higher in comparison with cow milk [17]. The fat globules of GM are smaller than bovine milk. The smaller sized fat globules allow dispersion and more homogeneous mixing of fat in milk. The average diameter of globules in GM ranges from 1.5–2 μm while that of cow's milk ranges from 2.5–3.5 μm [24] which is the reason behind GM to be known as "self homogenised or naturally homogenised milk". Having smaller fat globules and greater surface area facilitate GM to be more digestible than cow milk as total surface area of globules gets effectively connected with the lipids [29]. Also, lipases in the gut tentatively attack the lipids ester linkages in the short chain fatty acids more readily and rapidly helping in faster digestion of GM [30]. GM is enriched with higher proportion of short and medium chain fatty acids, mostly butyric, palmitic, caproic, capric, caprylic, linolenic, alpha- linolenic, lauric, myristic acid while lower in longer chain fatty acids like oleic and stearic [23]. Among these 3 (Capric, Capryllic and Caproic) have been named after goat because of their predominance in GM [31].

3.2 Protein

Milk is composed of casein and whey protein where casein (alpha s1, alpha s2, beta and K-caseins) represent 80% of proteins while rest part is filled by major whey proteins (alpha-lactoglubulin and alpha-lactalbumin) [32]. The major protein in cow milk is alpha s1 casein while in GM it is beta casein. One of the most representative free amino acid in GM is Taurine [33] which is higher in GM as compared to cow milk [34]. Out of 10 essential amino acids 6 (threonine, isoleucine, lysine, cystine, tyrosine, valine) are found in high amount in GM than in cow milk [35]. Main reason behind the low amount of folic acid in GM is that it contains high concentration of folate binding protein making it unavailable for human to digest and absorb. The heavy fat content and mucus-producing components of cow milk are absent in GM and it is complete source of proteins containing all essential amino acids [36, 37]. Fragments of GM caseins have been found to possess antimicrobial peptides that shows strong activity against gram negative bacteria [38].

3.3 Vitamin

The content of Vitamin A in GM is higher than in cow milk as goat convert all beta carotene from foods to Vitamin A (retinol) in milk which is the reason for whiter GM and milk fat [17]. Also, higher casein content is GM promotes the same [39]. It contains 25% more Vitamin B6, 47% more Vitamin A than cow's milk and it mainly possesses Vitamin A2 [40]. Content of Vitamin D of both GM and cow milk is similar that is mostly needed during infancy (**Table 2**) [41].

3.4 Lactose

Major carbohydrate in GM is Lactose whose content is slightly lower in GM than in cow's milk [42]. Lactose, a valuable nutrient favours intestinal absorption of calcium, phosphorus and also in proper utilisation of vitamin D [31]. It is crucial for milk synthesis and during secretion of milk in the duct system of udder [5]. As compared to cow milk, GM contains surplus amount of lactose derived oligosaccharides. Other carbohydrates that are present in small amount includes oligosaccharides,

Vitamin	Goat milk	Cow milk
Vitamin A (IU)	185	126
Vitamin D (IU)	2.2	2.0
Thiamine (mg)	0.068	0.045
Riboflavin (mg)	0.21	0.16
Niacin (mg)	0.27	0.08
Pantothenic acid (mg)	0.31	0.32
Vitamin B6 (mg)	0.046	0.042
Folic acid (ug)	1.0	5.0
Biotin (ug)	1.5	2.0
Vitamin B12 (ug)	0.065	0.357
Vitamin C (mg)	1.29	0.94

Source: Ref. [17].

Table 2.
Composition of vitamin (per 100 g) of goat and cow milk.

glycopeptides, glycoproteins and nucleotides [42]. GM oligosaccharides are thought to be exhibiting the anti-inflammatory effects in induced colitis [43]. GM oligosaccharides are especially beneficial for infants due to their prebiotic and anti-infective properties (**Table 3**) [45].

3.5 Minerals

GM contains major and trace minerals that includes Ca, Na, Mg, P, K, Zn, Mn, Se, Cu, Co, Fe which have great health benefits. Percentage of Zn in GM is higher than in cow's milk that is responsible for maintaining healthy skin, healing of wound, act as antioxidant and eliminate reactive oxygen species via its role as a cofactor for antioxidant enzyme superoxide dismutase (SOD). Mineral content in GM is higher than that of human and cow milk ranging from 0.7 to 0.85% [46]. GM contains 13% more calcium than cow's milk per serving and 134% more potassium [47]. Selenium content in goat and human milk is higher than that found in cow milk [48]. The Selenium in GM plays a key role in acting as a cofactor for the functioning of glutathione peroxidase (GPX), an antioxidant enzyme which scavenges harmful free radical in body and helps in macrophage activation (**Table 4**) [49].

Component	Cow milk	Goat milk	Human milk
Protein	3.58	3.52	1.63
Fat	4.14	4.25	3.75
Total solids	13.19	13.00	12.57
Solids not fat	9.25	7.75	8.82
Lactose	4.96	4.27	6.98
Ash	0.71	0.86	0.21

Source: Ref. [44].

Table 3.
Average composition of cow, goat and human milk (%).

Mineral (mg)	Goat milk	Cow milk
Ca	134	122
P	121	119
Mg	16	12
K	181	152
Na	41	58
Cl	150	100
S	28	32
Fe	0.07	0.08
Cu	0.05	0.06
Mn	0.032	0.02
Zn	0.56	0.53
Se	1.33	0.96

Source: Ref. [17].

Table 4.
Mineral contents (per 100 g) of goat and cow.

4. Nutritional value in GM

Because of the highest nutritional value, GM is preferred over cow and buffalo milk [50]. The nutritional and health benefits of GM are directly related to the medical problems that are faced by people of which main being allergies towards milk proteins obtained from cow's milk [51]. It provides 70 calories per 100 ml. The superior digestibility of GM, its proper fatty acid composition and content of bioactive compounds seem to give those properties to it that help in treating or preventing certain medical conditions. Bioactive peptides derived from milk plays vital role in human health and nutrition. The most vulnerable ones are infants, aged people and pregnant women as their immune system could answer at any time if extra supplement is not administered.

The amount of calcium and phosphate supplied from GM is of much importance to human nutrition. It contains 1.2 g calcium and 1 g phosphate per litre which is higher than that contained in human milk. So, GM offer excess of calcium and phosphorus to human infant that is easily absorbed by them [30]. GM supply adequate amount of Vitamin A and niacin to human infant. Though it supplies excess of thiamine, riboflavin and pantothenic acid [5, 30] it is deficient in terms of Vitamin C, D, B_{12}, pyridoxine and folate [52]. So, these nutrients should be supplied at the time of infant feeding by applying appropriate fortification. American Academy of Paediatrics forbade the use of GM products for infants under one year mainly because they can cause intestinal irritation and anaemia. Infants of such age who are allergic to cow's milk-based formulas are only fed on goat's milk formula after properly consulting baby's doctor or paediatric nutritionist [53].

One of the reasons that consumers are accepting GM and its products in an appreciable manner is due to its nutritive value. It is beneficial in maintaining health, physiological functions, in the nutrition of child and elderly ones [54]. It is reported that it contains off flavour. This is due to the fact that membranes around fat globules in GM are more fragile which may relate to their greater susceptibility in developing off flavour than in cow milk. However, fresh milk obtained under sanitary conditions from properly fed and hygienically managed goats is found to be free from such objectionable flavour and odour [55].

Cow's milk is reported to be mucus forming for many people but goat milk is not only non-mucus forming but also help in neutralising the mucus. GM has been a viable alternative for those children who are having difficulties in digesting cow's milk as it is second best option, first being mother's milk. The composition of goat and human milk is almost similar. Children who drink goat milk tend to remain more satisfied between meals and sleep through the night [56]. 2.5% of infants during first 3 years of their life suffer from cow milk allergy [57] while this percentage rise from 12 to 30% for infants who are less than 3 months old [58]. Not just for infants but also for adults and nursing mother, GM has been good alternative because of its unique properties. GM is rich in vitamins, minerals, trace minerals, enzymes, protein, fatty acids and amino acids (especially tryptophan) that are easily utilised by human body. The greatest advantage of consuming GM by many people lies in the fact that those who cannot digest cow's milk find it easy in digesting GM without any complications. The reason for this is yet to be known but it is thought that this action in GM is due to lower lactose content (7% less than that of cow milk). There is one fact which says that our body takes 20 minutes to digest GM while it takes 2–3 hours in digesting cow's milk [56].

Conjugated Linoleic Acid (CLA), an important bioactive component is naturally found in GM which helps in immune response stimulation. Mediators of immunity such as cytokines, prostaglandins, immunoglobulins etc, are modified by the action of CLA. The CLA possess ability to reduce the allergy related immunoglobulin IgE in humans that suggest anti-allergic potential of lipid [38]. The richness of GM in Medium Chain Triglycerides (MCT) helps in improving nutrients absorption and energy production in the body. MCT along with other amino acids exhibits antimicrobial activity [59].

Taurine (free amino acid) performs different roles in human body such as growth and brain development, formation of bile salts, calcium flux modulation, stabilisation of membranes as an osmoregulation by attenuating toxic substances. Its deficiency in human tissues may be the result of cardiomyopathy, epilepsy, lack of growth etc. [60]. In case of animal studies, Taurine is suggested as an important amino acid in alleviating muscle fatigue and can build up exercise capacity during workouts [46].

Amount of Vitamin A contained in GM is similar to human milk which is crucial for innate and adaptive immune responses that also includes cell-mediated immunity and antibody responses as well. Deficiency of this vitamin leads to decreased innate immunity that will affect NK cell function and phagocytic activity. Vitamin D plays an important role in the immune system and help preventing infections, autoimmune diseases, cancer and diabetes. Vitamin C which is present in greater amount in GM than in cow's milk has shown to affect many aspects of the immune system including regulation of immunity via antiviral and antioxidant properties [49].

As compared to cow's milk GM has higher content of Ca, P, K, Se, chloride, Zn, Cu [61, 62]. Potassium is crucial in acid/base balance and also in the proper functioning of muscles, nerves and kidneys. Chloride maintains fluid balance, blood pH and osmotic pressure. Calcium and phosphorus strengthen the structure of bones, muscles and help in blood coagulation. Selenium is vital in protecting cell against free radicals and also it acts as a major component in preventing dengue fever. Copper helps in metabolism of iron and oxygen and also defence the cell against free radicals [49].

5. GM medicinal value

Multivitamins, proteins, minerals (including trace one), fatty acids as well as Lactic acid bacteria in GM help in fighting human against diseases including diarrhoea, vomiting, constipation, gastric discomfort, respiratory disorders and many other [20].

5.1 Prevention of dengue fever

Dengue fever which is transmitted by the bite of *Aedes aegypti* mosquito is of great problem in tropical countries. Each serotypes of dengue virus (DEN 1, 2, 3 and 4) are equally responsible to cause severe dengue and haemorrhagic syndrome [63]. Ferropenic anaemia and bone demineralization were better recovered with GM. Dengue is endemic in 112 countries of the world [64]. Regular consumption of GM is suggested by doctors in case of dengue fever because it is necessary to maintain body fluid balance and also transfusion of platelets is not possible in all cases. If platelet level drops (below 20,000) and there is significant bleeding then platelet transfusion should be provided. Selenium (Se) which is present in GM act in preventing dengue. GM have more than 2.5 times the Se powdered infant formula (19.98 mg/L vs. 7.47 mg/L) as compared to cow milk and nearly 35% greater than pasteurised cow milk (19.98 mg/L vs. 14.85 mg/L) [65]. As compared to cow milk GM possesses 27% more Se [33]. Se if become deficient can cause an irreversible cardiomyopathy [66]. Se helps in controlling the human immune system in case of autoimmune disease by upgrading it when necessary and degrading it when it is overactive. Se has anticlotting effect while thrombotic and pro-clotting effects are due to its deficiency. The replication of dengue virus is prevented by Se. T cell and interleukin both are vital component of immune system and Se help by modulating the production of interleukin or by increasing the T cell function [67]. In treatment of dengue fever GM and its products are very helpful as they directly modulate human immune system. Immune response and antioxidant protection of host can be significantly improved by the incorporation of Se as selenocysteine in GPx [68]. Deficiency of Se can be prevented by having pills and animal products that contain Se [69].

5.2 Antimicrobial properties

Proteins derived from milk are proved to be precursors of antimicrobial peptides. GM have been reported to have antimicrobial activity of several pathogenic bacteria that are contained in food materials. GM caseins fragments are good source of antimicrobial peptides that are effective against gram negative bacteria [38]. Alpha-S2 Casein (CSN1S2) in GM is studied for its antimicrobial property. The result indicated that this caprine protein has inhibition activity that opposes the pathogenic bacteria by optimal concentration of 5 mg/ml in all bacteria especially Gram positive (*Listeria monocytogenes, Staphylococcus aureus and Bacillus cereus*) and negative (*Escherichia coli, Salmonella typhi and Shigella flexneri*) [70]. This property of CSN1S2 casein is detected when it goes through degradation by gastrointestinal enzyme pepsin [38]. The distinct antimicrobial impact of GM and its specific chemical composition can result in increased antimicrobial compounds production [71]. Another study shows that during the fermentation of GM with individual microorganisms of kefir grains, bioactive substances were released that have antimicrobial properties against deadly strains of bacteria present in food [72]. Short chain fatty acids (SCFA), Medium Chain Triglycerides (MCT), capric, caproic and caprylic acids found in GM have been proved to possesses antimicrobial activity [59]. GM proteins can be in-vitro hydrolysed by enzymes or can be fermented by lactic acid bacteria which give potent antioxidant peptides [73].

5.3 Treatment of cardiovascular disease (CVD)

CVD includes diseases that involves heart and blood vessels, veins, coronary heart diseases, high blood pressure, arrhythmias, atherosclerosis etc. Inorder to maintain normal blood pressure and proper heart functioning a good amount of potassium rich food is needed and GM serves for the same. GM supply 498.7 mg of K and 121.5 mg of Na that is sufficient in preventing high blood pressure and protecting against atherosclerosis. Atherosclerosis is likely to occur if people are adopting unhygienic inactive lifestyle (smoking, diet and exercise) and after incidence of dyslipidemia, diabetes, high blood pressure etc. [74]. The Angiotensin converting enzyme (ACE) inhibitory peptides obtained after hydrolysis of GM caseins have shown beneficial effects on blood pressure regulation [75]. Fat in GM reduces total cholesterol levels thereby making it as a food of choice for the prevention of cardiac disorders. GM have selenium and its absence is thought to cause irreversible cardiomyopathy [66]. When excess amount of fat is deposited in the arterial wall and blood vessels then cardiac arrest is common. In case of goat, fat present in its milk and meat is considered as user friendly [76]. The Low-density lipoprotein (LDL) is known as "bad cholesterol" as it transports cholesterol from liver to blood vessels while High-density lipoprotein is "good cholesterol" as it transports cholesterol from vessels to oxidative modification of LDL which suppresses atherosclerosis [74].

The composition of GM exceeds cow's milk in monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA) and MCT which have beneficial health effects especially in cardiovascular conditions [23]. Due to anti-inflammatory effects of CLA GM decreases the atherosclerosis incidence [38]. The MCT present in GM includes capric, caproic and caprylic acids which comprises 15% of total milk fat. The higher constituent of MCT in GM helps in lowering cholesterol deposits in the arteries, dissolve and prevent cholesterol deposits in the gallstones. Also, the presence of MCT decrease the synthesis of endogenous cholesterol thus helping to boost the immune system [77]. Capric, caprylic acids and MCT are used in treatment of many diseases including cystic fibrosis, coronary by-pass etc, because of their unique ability to provide energy directly without being deposited in adipose tissues [78]. GM is naturally homogenised while cow's milk requires homogeniser. When fat globules are forcibly broken down by mechanical homogeniser, an enzyme associated with milk fat i.e., xanthine oxidase become free and can penetrate intestinal wall. When it reaches blood stream via intestinal wall, it can cause tissue scar on the heart and arteries which leads to mechanism causing arteriosclerosis while it is prevented in case of GM [77].

5.4 Treatment of gastrointestinal diseases

Infants who are suffering from problems like gastrointestinal disturbances, vomiting, colic, constipation and diarrhoea can be treated when they are fed GM. Pasteurised GM is easily tolerated by infants who are suffering from such diseases. GM easily assimilates in human body as chemical composition of GM is almost similar to human one which therefore enhances the bioavailability of nutrients in it. It is reported that GM consumption increases the uptake of Iron and Copper in digestive tract [79]. The readily bioavailable nature of GM has increased its consumption in recent years. The availability of beneficial gut microbes increases when GM is taken. Soft curd formed in fermented milk of goat is easily digested and absorbed [22]. People who are lactose intolerance can also easily digest it because of its small sized fat globules in which the total surface area of globules are effectively connected with lipids and also the fat globules of GM do not clump together as in cow's milk [29].

GM is the vital source of biorganic sodium, the absence of which causes arthritis. Human stomach stores more sodium than any other organ. The absence of sodium causes digestive discomforts and inhibits stomach from producing needed enzymes leading to bloating and even ulcers. Soft curd in GM can be advantageous for adult humans who are suffering from gastrointestinal disturbances and ulcers [5]. Also, the property of high buffering capacity of GM appears to be fruitful in treating gastric ulcers [52]. The intestinal inflammation and clinical symptoms (diarrhoea and bloody stools) in colitis can be decreased by consuming GM. The presence of oligosaccharides in its milk exhibits anti-inflammatory effect in the management of Inflammatory bowel disease (IBD) [43]. It has been reported in one study of rats infected with colitis when fed GM oligosaccharides reduces and promotes recovery of damaged colonic mucosa due to less severe lesions in colon and production of more favourable gut microbiota [38].

5.5 Treatment of cancer, allergy and others

Alpha lactalbumin present in GM is anti-carcinogenic by nature. CLA in GM is full of anti-carcinogenic properties. It is also studied that tumour cells in patients with skin and bladder cancers were killed by alpha lactalbumin. The passive transfer of serum albumin in GM to the blood has an inhibitory effect against growth and development of breast cancerous cells [75].

Proteins are most common antigens that are important for proper body functioning. On the basis of nature, allergies can be acute or chronic that have symptoms ranging from non-life threatening to life threatening. It is recommended as an substitute for patients with cow milk allergy [54]. Eczema, Rhinitis and digestive problems are simple symptoms while bronchospasm, anaphylaxis and urcaria are severe one. GM is less allergenic than cow's milk. GM is thought to resolves 30–40% of problematic cases of childhood cow milk allergy. Some researches shows that alpha S1 casein in cow's milk is the reason of cow milk intolerance. It has been found that level of alpha S1 casein in GM is 89% lower than that of cow milk. Therefore, GM is less allergic and improves digestive disorder, colic diseases etc. in people with cow milk sensitivities [80]. Lactose intolerance in many child and adults is caused by the deficiency of lactase enzyme that functions in easing the digestion of lactose. Generally, in case of lactose intolerant individuals, unhydrolyzed lactose passes into the large intestine whereby it is fermented by the aid of microbes which results in the production of hydrogen, methane, carbon-dioxide, SCFA leading to flatulence, diarrhoea as well as abdominal pain [81]. When ulcers worsen it takes a new form i.e., cancer and it is well known that the high buffering capacity of GM prevents gastric ulcers [52].

GM is used as a good alternative to treat mammary, colorectal and colon cancer [82] in case of animal models, as well as in vitro models of human melanoma [83] colorectal and breast cancer [84] because of the known anticarcinogenic properties of CLA [85] which is in surplus amount in it. Lactic Acid Bacteria (LAB) present in goat milk exhibit potential role in combating against cancer [86]. The risk of occurrence of cancer, carcinogenic toxicity and tumour suppression are prevented by LAB present in GM [87]. The bacteria in GM after isolation and microencapsulation can be used as a probiotics to cure cancer [88]. The study of different strains of LAB in GM can strengthen the research of cancer prevention [89].

5.6 Immunological properties

Se is vital as it plays role in proper functioning of the immune system and thyroid activity as well as participates in spermiogenesis thereby affecting fertility [90]. It is an integral part of the antioxidant capacity of the organism [91]. GM and its products act as immunity booster and prevents from several illness in infants [87]. There is involvement of many cells like T lymphocytes (T-cells), Natural Killer (NK) cells and B-lymphocytes (B-cells) in the innate and adaptive immune response. Even though the structure of Immunoglobulin's (Ig) are similar, minor differences exist in the main immunological classes (IgG, IgM, IgA, IgD and IgE). The major properties of serum immunoglobulin accounts for IgG and IgA. Several researches have shown immunomodulatory effects of GM in case of both in-vitro and human studies. The release of nitric oxide (NO) from human blood cells exhibits cardio protective effects in the milk consumer and also possesses antibacterial activity which prevents them from infections. Content of sialic acid is higher in GM which acts as an important biological component in playing crucial role in brain development and in boosting infant immunity [92, 93].

6. Conclusion

Since GM is rich surplus to calcium, proteins, bioactive compounds it can be taken as a "functional and nutraceutical health drink". The role played by GM in eliminating major health complications including digestive, respiratory, immunological, viral, cardiac, cancer, allergy, osteoporosis, malabsorption, anaemia etc. favours longevity to human life. The contribution of small developing nations in the production of GM should not be neglected rather new technological innovation's assistance to those nations will uplift the production and contribute to mankind as the consumption of GM has increased in developed nations. The compositional attributes of GM can be raised if goats are provided with ample browsing, adequate temperature and stress-free environment. It should be supplemented with folic acid and can be fortified if consumers find its odour unpleasant.

Goat rearing has several economic returns after its milk, meat, hair etc. are marketed. Goat business can help uplifting the life standard of people in rural areas. The unique properties of GM and its products carve for its more marketing potential. Its nutritional value in treating diseases has broaden its future prospects. If grading up is followed to improve the performance of local breeds of different nations then eventually more milk can be produced that benefits human. That is why more thorough and detailed descriptive research in this field is needed to fight against life taking diseases.

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Section 11

Goat Meat as a Protein Source

Chapter 19

Goat Meat: No Less Source of Protein in Comparison to Other Meat for Human Consumption

Melody Lalhriatpuii and Amit Kumar Singh

Abstract

For normal body metabolism and maintenance of life, nutrients at appropriate quantities have to be ingested by animals as well as human beings. Proteins are one of the vital nutrients required by the individual body. Vegetable proteins are as good as animal proteins; however, a single plant does not serve every essential nutrient needed by the living body. Therefore, a variety of plants and vegetables has to be ingested to meet the requirements. Goat meat is a good source of animal protein, and it is widely consumed by people in developing countries ever since it has no religious taboo. However, goat meat consumption is a lot less in the western sides and most of the developed countries. The nutrients content in goat meat is undervalued, which needs to be emphasized to encourage its consumption. Spreading awareness in different parts of the world, that are less accustomed to goat meat, for health benefits along with improved trade policies for rationalized goat meat cost would substantially enhance the availability and preference of cosumers for goat meat. Furthermore, goat meat has the ability to capture growing organic meat industry. In current chapter, valuable properties of goat meat along with different factors affecting the demand of goat meat have been discussed.

Keywords: animal protein, goat meat, developed countries, cosumers, quality nutrition

1. Introduction

This chapter describes the desirable quality of goat meat (also known as chevon) over the other products, i.e., chicken, beef, and pork. Meat is considered as complete food having a different variety of nutrients required by the individual. Protein is one of the macronutrients necessary in a large amount that serves as a building block of the body, components of blood biochemical and enzymes taking part in the metabolic reactions. A single animal protein found in meat can be more satisfactory than a single protein present in plants; therefore, a person may require to ingest a variety of plants to meet the body requirements. Most people in the West are not exposed to the goat meat industry and are not aware of the same health benefits. Meanwhile, the reasons for less consumption of goat meat could be the availability of other meat types like poultry, fish, beef, and pork [1, 2]. A study conducted by [3] showed that the rising prices of sheep and goat meat lead to a decline in its demand. Another reason for less consumption of goat meat could be unfamiliarity and the intense flavor [4]. Despite that, people from developing countries have more likeness towards goat meat.

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Investigations of [5] suggested that migrants from such developing nations towards West, prefer goat meat which may be one of the reasons of increased goat meat demand in concerned areas. It is a noticeable point that Boer, Kiko and Black Bengal goat breeds are known for their high quality meat production among other breeds [6].

Unanimously buyers have become more well-being cognizant and are currently mindful and more prepared with relevant data regarding the food's impact, including meat they burn-through. The expanded purchaser mindfulness has brought about the rise of a consumer class that requests restorative nourishments. Chevon has more or less the same concentration of protein; however, contrasted with other red meats like beef and sheep, it has lower fat (especially the saturated fat) and cholesterol content [7, 8] yet, a higher polyunsaturated unsaturated fat (PUFA) [9, 10]. The composition, regarding the fat substance and unsaturated fat profile, makes chevon more restorative meat than other red meats. Subsequently, chevon can fill in a unique market specialty. As an immediate outcome of its leanness and a desirable unsaturated fat profile, chevon's recognition of the worldwide meat market is expanding as well-being cognizant buyers favor less fatty and more interested in the lean meat product [6, 7]. Humans' global population is likely to develop to nine billion by 2050 [11, 12]. The need for expanded population necessity is a requirement for supportable and efficient meat and its related products. This prediction of populace intervened increment in animal inferred protein's interest for human utilization makes a massive opening for goat meat to enter a supply chain of meat and other protein items [13].

The producer has to look for the consumer's demand and awareness of the health risk of consuming different kinds of meat. Numerous customers need information and introduction to goat meat items and their health benefits. This unawareness of the goat meat has led to lower consumption, which is further an obstacle faced by the business [14]. Studies propose that customer interest in purchasing the products builds up when they know the product's nutritional supply and health benefits [15, 16]. Research done by [3] in the United States reported that the family spends a 1.6 CHF (Confoederatio Helvetica Franc) more on sheep and goat meat when the head of the family has a university degree, which indicated that education has a positive impact on goat meat consumptions. Educational achievement is a principle determinant in food utilization decisions and is connected emphatically with substantial nutritional intake [17].

Sheep and goat raised under general conditions on regular fields produced healthy meat over other red meat [18, 19]. Since goats are mostly reared on a natural niche, they can cope with the harsh conditions; therefore, they receive less medication and are not usually fed with feed additives and other chemicals as promoters. The meat we get could be considered organic in comparison to other meat items. Furthermore, farmers are seen to make use of mixed lots of sheep and goats for better utilization of available environmental resources [5]. Goats may well proliferate under low concentrate supply which lessens competition for food grains to other farm animals [20]. As instruction emphatically corresponds with the consciousness of these perspectives related to food utilization [21, 22], family units with a well-educated family head will, in general, have more appeal and demand for sheep and goat meat.

2. Materials and methods: research methodology

Most of the literature findings for this chapter was done by referring reputed and reliable sources. A thorough search was made to find suitable articles from various search engines. Furthermore, it is essential to know the general and a specific protocol followed by scientific work. Due to the differences in the protocol and the concentration of chemicals involved in the analysis, the readingobtainedfrom one method could be different from the reading attained with another technique. Knowing the procedure monitored would help the readers understand the work better and help make a scientific comparison. A protocol developed by the Association of Official Analytical Chemists [23] is generally followed to estimate the major nutrients present in the sample. However, it is vital to know the appropriateprocedure depending on the nature of the sample. When meat samples are concerned, the animal body's water content may range from 50 to 95%. Therefore, it is crucial to know the moisture level in the meat sample ever since the moisture concentration is inversely proportional to the sample's dry matter concentration. The crude protein level in the sample is assessed indirectly by determining the nitrogen content, which is then multiplied by the factor 6.25, considering that protein contains about 16% nitrogen.

The fat content of the animal body is variable, and fat increases with age. The fat concentration in the sample can be estimated by solvent extraction method [24]. The extracted total fats can be further esterified and saponified following the technique of AOCS [25]. The chloroform-methanol method can also extract the total lipid concentration in the sample [26]. The meat sample's fatty acid concentrations can be measured using gas chromatography directly by synthesizing fatty acid methyl ester. Nevertheless, there are few more techniques available for the estimation of fatty acid in the sample. The total ash is estimated following the AOAC method, where a sample is ignited at 600°C in a muffle furnace for about 4 hours. Major minerals like calcium and phosphorous concentration in the sample are estimated following the titrimetric method by AOAC and Talapatra *et al*. [27]. The minor and trace minerals are analyzed using Atomic absorption spectrophotometer [23]. Proteins are made of amino acids. The individual amino acid content in the meat samples is determined using ion-exchange chromatography of the acid-hydrolyzed protein [23] and Chromatographic determination of amino acids by using automatic recording equipment [28]. When it comes to statistical analysis of the data, Analysis of Variance of compare means and General linear model is the most common practice. For data comparison, a probability of $p < 0.05$ was considered statistically significant in most of the cases, and $p < 0.01$ could be labelled as a trend.

3. Nutritional value of goat meat

The moisture content of goat meat ranges from 62.13 to 78.3%; protein, 15.31–24.83%; fat, 0.80–21.24% (**Table 1**). The protein content could vary from the portion of sampling from the carcass and the age of animals at slaughter. The ash content is in the range of 0.43 and 3.51%. Overall, the compositions of chevon (goat meat) and mutton (sheep meat) are comparable concerning moisture, protein, and ash contents [45].

Breed	Meat slice	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	References
Desert goat	*Semimembranosus* muscle	75.04	20.8	2.8	1.23	[29]
Saanen × Angora	Loin	71.43 M 70.32 F	20.71 M 20.68F	6.79 M 8.0F	0.98 M 0.96F	[30]
Saanen × Angora	Leg	74.24 M 73.93F	20.77 M 20.76F	4.02 M 4.33F	1.03 M 1.02F	[30]
Saanen × Angora	Remainder	72.67 M 71.90F	20.32 M 20.16F	6.07 M 6.97F	0.95 M 0.95F	[30]
Nubian × Florida native	Loin	75.4	21.5	2.1		[31]
Spanish × Florida native	Loin	75.2	21.8	2.2		[31]

Breed	Meat slice	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	References
Florida native.	Loin	74.1	21.8	3.1		[31]
Castrated Boer	*Semimembranosus* muscle	76.21	19.74	1.51	0.93	[32]
Boer bucks	*Semimembranosus* muscle	77.54	19.31	0.80	0.94	[32]
Castrated feral bucks	*Semimembranosus* muscle	74.90	20.13	1.36	0.99	[32]
Feral bucks	*Semimembranosus* muscle	75.98	19.07	1.33	1.07	[32]
Non-descriptive	neck, forequarter, hind quarter, back, and flunk	74.37	21.52	3.29	1.23	[33]
White Improved breed	m. adductor	76.47	20.21	2.28	1.13	[34]
Pure Boer	*Longissimusdorsi*	72.35	24.53	3.06	0.98	[35]
¾ Boer + ¼ SPRD	*Longissimusdorsi*	72.01	25.22	2.76	0.98	[35]
½ Boer + ½ SPRD	*Longissimusdorsi*	72.48	24.40	2.73	0.97	[35]
½ Anglo + ½ SPRD	*Longissimusdorsi*	72.79	24.18	2.44	0.99	[35]
Black Bengal	Mixed muscle	72.79	21.90	3.72	1.15	[36]
Crossbred	Mixed muscle	73.46	20.85	4.51	1.08	[37]
Non descriptive (<7 m, age)	Mixed muscle	78.3	15.31	1.77	1.2	[37]
Non descriptive (8–10 m, age)	Mixed muscle	75.7	18.43	2.71	1.31	[37]
Non descriptive (>11 m, age)	Mixed muscle	73.8	20.3	3.07	1.63	[37]
Egyptian Baladi goat kids.	*Longissimusdorsi*	75.32	19.97	3.28	1.13	[38]
Black Bengal	*Longissimusdorsi*	75.1	20.9	2.54	1.09	[39]
Black Bengal	*Longissimusdorsi*	74.5	21.2	2.95	1.07	[40]
Non-descriptive	Mixed muscle	75.55	20.32	1.66	0.43	[41]
Black Bengal	Meat and fat minced	76.66	24.54	4.14	0.95	[42]
Crossbred	Longissimuslum borum muscle	75.2	19.7	1.57	3.51	[43]
Black Bengal	*Biceps femoris*	73.70	19.25	2.82	1.04	[44]
Black Bengal	*Deltoid*	71.22	21.82	3.08	1.10	[44]
Black Bengal	*Longissimusdorsi*	70.76	23.20	3.54	1.08	[44]
Black Bengal	*Trapezius*	73.25	18.95	2.32	1.05	[44]

Table 1.
Proximate composition of goat meat.

Minerals	Boer goat with low energy diet (LE, 9·9 MJ/kg DM) for 56d	Boer goat with high energy diet (HE, 12·1 MJ/kg DM) for 56d	(mg/100 g) of LD muscle of Egypt Baladi goat kids	*Biceps femoris* Black Bengal goats	*Deltoid* Black Bengal goats	*Longissimusdorsi* Black Bengal goats	*Trapezius* Black Bengal goats
Ca	880·84	946·55	12.35				
I	41·68	43·38					
K	141·57	130·88	240.22				
Mg	32·51	35·36	21.41	0.51 ± .025a	0.62 ± .009	0.73 ± .010	0.42 ± .010
Na	56·73	49·83	69.17				
P	631·97	653·69					
Cu	0·20	0·14		8.37 ± .064a	7.57 ± .022	6.95 ± .017	5.15 ± .028
Fe	1·19	1·78	2.97				
Pb	0·013	0·016					
Zn				90.9 ± .881a	83.1 ± .369	80.8 ± .860	67.6 ± .294
Mn				8.6 ± .147a	7.3 ± .129	7.2 ± .108	5.5 ± .108
References	[46]	[46]	[38]	[44]	[44]	[44]	[44]

Table 2.
Minerals concentration in chevon.

Cooked meat (85 g each)	Calories	Fat (g)	Saturated fat (g)	Cholesterol (mg)	Protein (g)	Iron (mg)
Chevon	122	2.8	0.79	63.8	23	3.2
Chicken	162	6.3	1.7	76.0	25	1.5
Beef	179	7.9	3.0	73.1	25	2.9
Pork	180	8.2	2.9	73.2	25	2.7
Lamb	175	8.1	2.9	78.2	24	1.4

Table 3.
Nutritional value of meat from different species [29].

The major minerals Ca and P, and other minor minerals concentration in chevon are given in **Table 2** and are inconstant. Chevon is a good source of calcium (Ca), phosphorous (P), potassium (K) and has a fair amount of iron (Fe), iodine (I), sodium (Na), zinc (Zn), magnesium. Chevon has a low calorie, low fat and low cholesterol item than chicken, pork, beef, and mutton (**Table 3**).

The fatty acids and their fraction in meat can vary, and it can be altered by the inclusion of good quality fats as a supplement in the animal ration. High animal fat consumption, especially from red meat, could raise overall blood cholesterol, especially LDL cholesterol levels. Nutritional profession and therapists often encouraged lower consumption of red meat than lean meats to control blood cholesterol levels and, consequently, diminished the danger of illness. Considering its high dietary benefit and its more prominent unsaturated to saturated fat proportion, chevon can conceivably improve the well-being of human populaces against unhealthiness with a much-decreased danger of causing stoutness and its related metabolic illnesses, for example, insulin resistance, type II diabetes mellitus, cardiovascular diseases and metabolic disorder [46, 47]. Therefore, the chevon business can exploit the developing interest in accepted food [48]. This interest in natural nutrition is mostly roused by the purchasers' well-being concerns [49]. Natural food can be characterized as ordinary food things liberated from engineered synthetic compounds, such as anti-microbials, fertilizers, herbicides, pesticides, and genetically adjusted living organisms [50]. Moreover, goat meat and meat products can give food security to the expanding total populace while limiting adverse effects on the climate and well-being since the advancement of natural food creation is generally determined by the possibility of supportability and ecological concerns [30].

4. Goat meat: a good supplier of nutrients, especially protein

Plant-based proteins are frequently low in SFA, and therefore, they are endorsed as an option for animal-origin proteins. Be that as it may, the caloric expenditure of around one day's protein consumption from a plant-origin is multiple times higher than if derived from lean meat. Studies intended to advance and keep up weight reduction in overweight grown-ups demonstrate that proteins from lean red meat, poultry, or fish all help substantial bodyweight. Momentum research further proposes that protein-based diets are all the more satisfying contrasted with carbohydrate-based food sources. This demonstrates that taking macronutrient blend to support a higher level of calories from protein is related to higher satiation and lean mass. Higher protein intake for overweight people has likewise been appeared to support weight reduction more successfully than carbohydrate-rich eating regimens [29].

Amino acids fractions	**Boer goat with high energy diet for 56d**	**g/100 g of M. longissimuslumborum muscle of South African indigeneous kids**	**g/100 g of M. longissimuslumborum muscle of South African indigeneous castrates**	**(g/16gN) of LD muscle of Egyptian Baladi goat kids**
Aspartic acid	2·03	7.65	8.01	5.58
Threonine	0·9	4.64	4.67	4.65
Serine	0·58	3.76	3.89	4.15
Glutamic acid	3·16	13.43	13.80	16.89
Proline	0·74	3.15	3.32	4.11
Glycine	1·68	3.76	3.93	5.28
Alanine	1·28	4.83	5.03	6.53
Valine	1·19	3.97	4.06	4.58
Methionine	0·49	2.22	2.29	3.04
Isoleucine	0·49	3.93	3.86	4.36
Leucine	1·75	7.03	7.10	8.52
Tyrosine	0·63	3.07	3.24	2.42
Phenylalanine	0·91	3.63	3.43	4.29
Histidine	0·63	2.26	2.48	2.68
Lysine	1·76	8.36	7.52	8.94
Arginine	1·44	5.53	5.67	5.80
Cystine	0·30	0.92	0.92	1.07
Tryptophan	0·22	0.99	0.79	Not determined
References	[46]	[47]	[47]	[38]

Table 4.
Amino acids composition of chevon.

The protein composition, i.e., amino acids make up of chevon, is given in **Table 4**. Goat meat is a good source of arginine, leucine, isoleucine, methionine, lysine, and threonine. It also has a fair amount of aspartic acids and glutamic acids among others amino acids.

5. Way forward for boosting Goat meat

Despite of remarkable role of goats in livelihood of developing country's households, channels of marketing for goat are mostly informal unlike in other livestock species [51]. Other meat animals production and marketing channels have been improved with progress of time much more than goat production and marketing [52]. Most of the goat meat produced and consumed locally in developing nations and major production never meets global trade [6]. Thus, lack of organized production, marketing and consumption pattern may be considered as the major reasons for poor goat meat familiarity in Western world. Nevertheless, high nutritional value of chevon makes it stand out from the list of other red meats. Goat meat has the value to capture the increasing organic food market [48]. An improved marketing strategy of highlighting the value of goat meat, its role to build the households

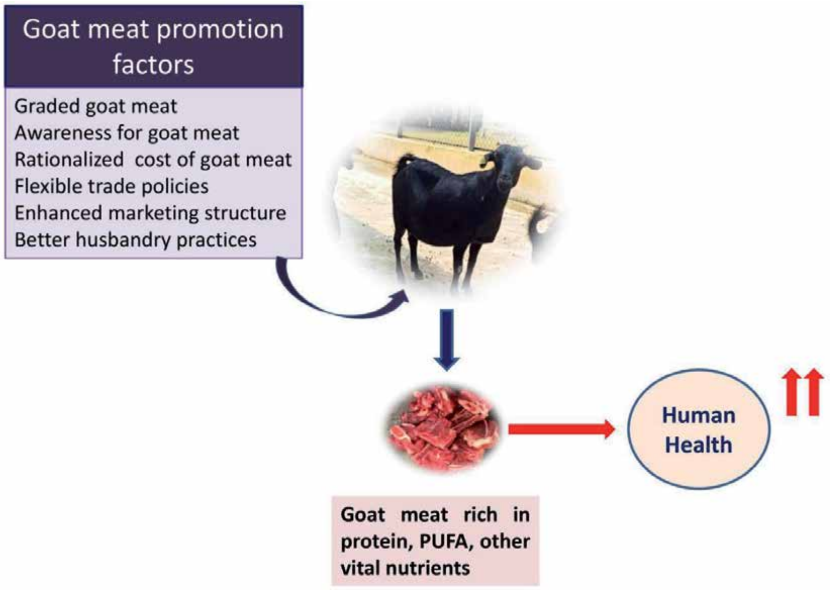

Figure 1.
Goat meat promotion factors. Source: Photo by authors.

of developing nations along with better utilization of "green resources" might help in upgrading trade of goat meat in Western world. In addition to that, standardizing the farming procedures, quality assurance, and quality products supply in channelized markets are expected to boost goat meat industry (**Figure 1**) in folds in upcoming era of more health concerned consumers.

6. Conclusions

Animal protein demand has risen due to the increased human population. Adequate protein is useful in developing a lean body as it is more satisfying than carbohydrate origin food. Animal protein also controls food craving as it is bulky and satiating for the body. Goat meat can be one of the critical sources of animal protein. It has protein as good as other animal meat and meat products. Additionally, it has good amount of health promoting PUFA and other vital nutrients for humans.

Spreading awareness about constructive and beneficial effects of goat meat in direct or indirect ways may be considered as the first stepping stone towards enhancing quality meat supply to the Western world. Nevertheless, consumer preference has gradually shifted towards quality products than merely opting quantity as they became aware of ill effects of consuming more calories per gram of protein as in the case of vegetable origin proteins.

Better husbandry practices, trade policies, rationalized cost of chevon through enhanced distribution channels, graded goat meats, and friendly marketing policies will bring substantial changes in goat meat availability and preference in different parts of the world, especially in Western world.

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Section 12

Economy of Goat Production

Chapter 20

Milk Quality, Somatic Cell Count, and Economics of Dairy Goats Farm in the Czech Republic

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Abstract

Mammary gland anatomy in small ruminants is very similar to that of cows; however, milk synthesis throughout lactation exhibits many functional particularities in small ruminants compared with that of cows. Goat's milk is beneficial for human nutrition owing to the fatty acid composition, fat globule size, and conjugated linoleic acid content. As a raw material for dairy products, goat's milk must be safe for human consumption. The number of mesophilic microorganisms, somatic cells, and selected mastitis pathogens should be limited. A prerequisite for the production of milk of high hygienic quality is the health of the mammary gland. Goat's milk processing into cheese and other products is in the Czech Republic mostly performed on farms, partly for direct sales to consumers and partly for supplying selected stores. Revenues from dairy commodities represent the most important source of income for dairy goat farms. Mammary gland health has an important effect on the economics of dairy goat farms. Profitability can fall by up to 1/3 owing to indirect effects of udder health problems.

Keywords: goat, milk quality, somatic cell account, economics, farm profitability

1. Introduction

1.1 Goat breeding in the Czech Republic

According to FAOSTAT database, approximately 1 billion goats were bred worldwide in 2018; the largest number of goats were bred in Asia (approximately 52%). The European Commission (EC) has reported a total of 74.6 million sheep and goats in 27 countries of the European Union in 2019, which represents a decrease of 15% compared to the number reported in 2000. Almost a quarter were bred in Greece (33%) and a high percentage in other countries, such as Spain (24%), Romania (14.5%), France (11%), and Italy (10%). According to the EC, approximately 0.4% of sheep and goat stocks are bred in the Czech Republic.

Goat breeding has a long tradition in the Czech Republic. Since 1941, based on the law 'Act No. 361/1941 Coll. 'About the Breeding of Farm Animals', performance control has been introduced in Bohemia. According to statistical data obtained from performance control, 10 breeds of goats were bred in the Czech Republic in 2019. The most common breeds were White Shorthair and Brown Shorthair goat (both are Czech national goat breeds). The number of goats in the Czech Republic has fluctuated significantly. Since 2018, there has been a slight decrease in the number of goats reared. In 2020, 28,919 goats (the Czech Statistical Office, CZSO) were bred in the Czech Republic. According to the preliminary results of the general agricultural account for 2019 published by the CZSO at current prices, small ruminant breeding in the Czech Republic amounted to approximately EUR 8,601 thousand, which in 2019 accounted for 0.4% of animal production and 0.2% of the total output of the agricultural sector. The CZSO data show that small enterprises predominate in the Czech Republic, most breeding 1–10 goats (88.2% of enterprises) - 41.8% of the total number of farmed animals. However, with the growing demand for goat's milk products, companies that keep more than 400 goats have been emerging in the Czech Republic in recent years. A total of 6.2% of goats were bred on such farms. In the Czech Republic, goat breeding is focused mainly on milk production and, subsequently, on manufacturing of cheese and dairy products, such as kefir and yoghurt. In 2019, goat cheese production reached 266 tonnes at a price of approximately 11.5 EUR/kg.

In the Czech Republic, goat's milk is processed directly on farms and distributed as milk products. Although goat breeding is not one of the main areas of animal production, it is essential for the agricultural sector. In recent years, the Ministry of Agriculture of the Czech Republic has intensively supported research and development in sheep and goat breeding. Sponsored projects: P1 -'Influence of genetic polymorphism of lipogenic enzymes on milk fat composition and fatty acid (FA) content in milk of small ruminants' and P2 - 'Research of factors influencing profitability, quality, and safety of milk and dairy products in small ruminant farms in the Czech Republic'—have closely monitored milk production, hygienic quality of raw milk, and composition, including by-products. Based on the results, measures were proposed to improve both microbiological and nutritional quality of milk while achieving maximum economic profit.

2. Material and methodology

As part of the projects (P1 and P2) mentioned above, milk production was monitored on a farm with shorthair goat breeding. An integral part was the monitoring of daily milk yield and the content of individual milk components. The contents of fat, protein, lactose, and non-fat solids were determined. Sampling was always performed during morning milking and took place at regular monthly intervals from April to August (during the years 2013–2017). The obtained average values of milk yield indicators and milk components content during the monitored

	2013	2014	2015	2016	2017
Daily milk yield [kg]	0,990 ± 0,050	1,540 ± 0,044	1,806 ± 0,055	1,207 ± 0,070	1,100 ± 0,047
Fat [%]	3,941 ± 0,145	2,955 ± 0,089	3,178 ± 0,080	3,019 ± 0,068	3,051 ± 0,086
Protein [%]	3,174 ± 0,046	2,913 ± 0,021	2,879 ± 0,022	2,980 ± 0,019	3,026 ± 0,038
Lactose	4,251 ± 0,027	4,381 ± 0,025	4,412 ± 0,021	4,390 ± 0,017	4,382 ± 0,038
Non-fat solid	8,332 ± 0,051	10,716 ± 0,115	11,259 ± 0,097	11,237 ± 0,070	11,165 ± 0,127

Table 1.
Average values of milk and milk components in goat's milk (own measurement).

Acid	2013		2014		2015		2016		2017	
	Mean (%)	SE	Mean (%)	SE	Mean (%)	SE	Mean (%)	SE	Mean (%)	SE
Butyric C4:0	1,58	0,045	2,4	0,082	2,42	0,079	2,5	0,064	2,3	0,029
Caproic C6:0	1,73	0,036	2,49	0,07	2,56	0,048	2,62	0,021	2,51	0,02
Caprylic C8:0	1,94	0,048	2,54	0,096	2,63	0,092	2,81	0,054	2,73	0,017
Capric C10:0	6,94	0,251	8,39	0,355	8,75	0,289	9,27	0,248	9,3	0,08
Lauric C12:0	2,99	0,123	3,19	0,148	3,42	0,108	3,79	0,146	4	0,06
Myristic C14:0	8,92	0,151	9,57	0,206	9,98	0,24	9,97	0,236	10,56	0,12
Myristoleic C14:1	0,12	0,012	0,11	0,007	0,1	0,007	0,14	0,013	0,12	0,009
Pentadecanoic C15:0	1,13	0,03	1,08	0,015	1,05	0,023	0,92	0,036	1,07	0,03
Palmitic C16:0	27,98	0,656	27,45	0,627	26,7	0,911	27,35	0,302	27,57	0,343
Palmitoleic C16:1	1,07	0,033	0,49	0,025	0,51	0,015	0,63	0,017	0,58	0,026
Stearic C18:0	11,82	0,731	10,99	0,564	11,23	0,798	8,83	0,345	9,56	0,443
SUMA t-C18:1	2,14	0,095	2,35	0,066	1,77	0,164	1,87	0,111	1,84	0,212
C18:1n9c	22,82	0,572	19,87	0,859	19,07	0,657	19,76	0,503	18,6	0,406

Acid	2013		2014		2015		2016		2017	
	Mean (%)	SE	Mean (%)	SE	Mean (%)	SE	Mean (%)	SE	Mean (%)	SE
Linoleic C18:2n6c	2,26	0,081	1,9	0,062	2,42	0,042	2,67	0,097	2,43	0,144
Arachidic C20:0	0,31	0,012	0,28	0,014	0,26	0,009	0,2	0,006	0,24	0,013
α-Linolenic C18:3n3	1,01	0,063	1,03	0,066	1,06	0,05	1,13	0,024	1,13	0,121
CLA			0,69	0,031	0,59	0,044	0,55	0,047	0,46	0,039
omega-6	2,41	0,085	2,92	0,062	2,62	0,043	2,89	0,101	2,65	0,144
omega-3	1,14	0,07	1,2	0,003	1,27	0,047	1,31	0,026	1,31	0,123
SUFA	67,52	0,618	70,38	0,976	70,89	0,619	70,05	0,425	71,7	0,147
MUFA	28,02	0,655	24,67	0,943	34,2	1,347	24,38	0,427	23,03	0,256
PUFA	4,25	0,149	3,84	0,084	4,3	0,127	5,56	0,04	5,28	0,253
Omega6/omega3	2,11		2,43		2,06		2,21		2,02	
AI	2,07		2,42		1,82		2,37		2,61	

[a]The overview does not include minority FAs with a content below 0.05%.
t-C18:1 = trans isomers C18:1 including e.g. vaccenic acid (t11-C18:1); CLA = conjugated linoleic acid (mixture of isomers c9,t11-C18:2 and t9,c11-C18:2; SFA = saturated fatty acid; MUFA = monounsaturated fatty acid; PUFA = polyunsaturated fatty acid.

Table 2.
Profile of the most important FA[a] in individual samples of goat's milk (own measurement).

period are presented in **Table 1**. Part of this monitoring (project P1) was also the screening of the composition of fat acids (FAs) in goat's milk (**Table 2**).

The composition of FAs in the milk of White Shorthair goats was analyzed. The animals were monitored from 2013 to 2017 (P1) on the largest goat farm in the Czech Republic—an organic farm that maintained the same feeding strategy in all monitored years. The winter feed ration that was fed at the beginning of the study, consisted of haylage of approximately 2 kg/piece/day, hay ad libitum, and a grain mix, which was dosed during milking in the milking parlor in a total amount of 300 g/piece/day. The summer feed consisted of meadow vegetation of approximately 2 kg/piece/day (loaded into the stable), hay ad libitum, and grain mix, which was also dosed during milking in the milking parlor in a total amount of 300 g/piece/day. In 2013, only the goats in first lactation were included; in 2014, the animals in second lactation were selected; in the following years (2015–2017), only the animals in third lactation were included. The methodology for determining the FA content has been described by Borková et al. [1]. Based on the obtained results, the atherogenic index (**AI**) [AI = (C12:0 + 4 × C14:0 + C16:0) / (monounsaturated fatty acid + polyunsaturated fatty acid)] was calculated.

Three individual sets of milk samples (P2) were collected from 2 farms in the Czech Republic (White Shorthair goat farms) during lactation (April, June, and August; at least 30% of the animals were always taken from the farm) to monitor the occurrence of bacteria in goat's milk. Concurrently, microbiological analysis of the pooled milk samples was performed in an accredited laboratory.

The bio-economic model EWSH1 of the ECOWEIGHT software package [2] was used to quantify the effect of udder health on the economics of goat farms. The model makes it possible to comprehensively consider the above-mentioned changes on farms. The impact on the production and the flock structure (culling rate and fertility) and the costs and sales were considered. The universal design of this software allows for widespread evaluation of production and economic farm data [3], despite the fact that it is primarily used to calculate the economic importance of traits for breeding of small ruminants [4].

3. Results and discussion

3.1 The benefits and composition of goat's milk

The goat's milk is very beneficial as part of the human diet, but consumption of cow's milk significantly exceeds that of goat's milk. Milk and dairy products are the dominant source of income (50–80%) for small ruminant farms. Therefore, the quantity and quality of milk are important for sustaining sales and breeding costs. As the demand for goat's milk increases, so do milk quality requirements, especially those of milk components essential for higher-quality cheese production. The amount and composition of proteins and lipids are among the most important indicators of the nutritional quality of goat's milk. Therefore, it is important to monitor the proportion of individual proteins in goat's milk and the composition of FAs in milk fat. Goat's milk and its products are a valuable source of nutrients for humans. A significant advantage of goat's milk compared to cow's milk is the composition of milk fat. Goat's milk fat is rich in lower saturated FAs, such as caproic acid (C6:0), caprylic acid (C8:0), and capric acid (C10:0). These FAs are beneficial for treating intestinal diseases, malabsorption syndromes, cystic fibrosis, and heart disease [5, 6]. In contrast, lauric acid (C12:0), myristic acid (C14:0), and palmitic acid (C 16:0) are considered hypercholesterolemic FAs, which increase the proportion of low-density lipoprotein (**LDL**) cholesterol in plasma and increase the risk of cardiovascular disease.

Table 2 shows that the goats in first lactation had a lower saturated FA milk content (up to 14 carbons). Similar conclusions were reached for cattle by Kelsey et al. [7]. Our result is also consistent with that of Akerlinda et al. [8], who reported a reduced production of saturated FAs in first calves due to incomplete development of the mammary gland, which may reduce the production of saturated FAs. In contrast, the first lactation animals showed the highest milk content of saturated FAs with a larger number of carbon atoms. The effect of lactation order was not significant for monounsaturated FAs, except oleic acid. From 2013 to 2017, the average PUFA content was 3.84% to 5.56% of the total FAs. The average ratio of omega-6 to omega-3 FAs was favorable in all monitored years, ranging from 2.02 to 2.43. The optimal ratio of omega-6 to omega-3 PUFA levels in human nutrition is in the range of 2:1–6:1 [9]. There was no trend in PUFA content between animals in first and subsequent lactations. However, some differences were observed from 2014 to 2017 for animals in third lactation, probably due to the animal's individuality or environmental factors, such as hay and haylage quality.

The atherogenic index (AI) is an indicator of the nutritional value of goat's milk; a higher value is associated with a higher risk of atherosclerosis. Stergiadis et al. [10] reported the amount of the atherogenic index in cow's milk in the range of 2.56 to 2.69 (depending on the breed). Thus, goat's milk shows a more favorable ratio of saturated to unsaturated FAs than cow's milk. The best average atherogenic index (AI) value in goat's milk fat was found in 2015. In contrast, in 2017, there was a rapid increase in the AI value comparable to that of cow's milk.

3.2 Hygienic quality of goat's milk

Goat's milk must meet the hygienic standards of food safety as a raw material for incorporation into dairy products. The limiting factor should be the total number of microorganisms, the number of somatic cells, and the content of selected mastitis pathogens. Monitoring the hygienic quality of raw goat's milk products, intended for human consumption, should be one of the basic husbandry obligations. Goat's milk used for milk products in the Czech Republic must meet the following legislative requirements:

- Raw goat's milk used to manufacture products without heat treatment must not contain more than 500,000 CFU/mL for the total plate count (**TPC**) and 500 CFU/mL for *Staphylococcus aureus*;

- Raw goat's milk used to manufacture heat-treated (pasteurized) milk products must not contain more than 1,500,000 CFU/mL for the TPC.

Bacteria in milk intended for consumers should be effectively eliminated by pasteurization (except for spore-forming bacteria, such as *Bacillus*). Bacteria in raw milk can be a source of thermostable enzymes with proteolytic and lipolytic effects that survive pasteurization, reducing the quality of milk as a raw material for further processing. Such bacteria can negatively affect the composition and processing of goat's milk, resulting in a reduced yield of dairy products, which can cause economic losses to the producers. Therefore, it is necessary to monitor mastitis bacteria in raw goat's milk to evaluate the health status of the herd. It is also important to monitor somatic cells count (**SCC**) in milk, which may indicate the health status of the mammary gland and the overall health of the animal.

Somatic cells count (SCC) in goat's milk has been the subject of many recent studies. It is known that SCC in the milk of small ruminants shows significantly higher values and variability compared to that of cows, even in the case of a healthy mammary gland [11]. High SCC levels in goat's milk do not always indicate bacteriological contamination or inflammation of the mammary gland, but they may also indicate the animal's overall condition. In addition, the SCC of goat's milk is affected by factors other than infection, and it can fluctuate depending on the stage of lactation, lactation order, etc. Therefore, it is necessary to assess the condition of the animals more comprehensively by measuring SCC in pool milk samples and to monitor the relationship between the SCC values of goat's milk and the occurrence of mastitis pathogens, and chemical composition and technological properties of milk. The obtained information can be used to improve the quality of goat's milk on farms, especially its technological properties, which can be economically beneficial to farmers.

The occurrence of bacteria in raw goat's milk (pool and individual samples) was monitored on selected goat farms (P2) in the Czech Republic.

From **Table 3**, it is evident that the values of the total number of microorganisms in raw goat's milk on both farms (P2) throughout the monitored period met the legislative limit of the Czech Republic for the requirement for the production of heat-treated pasteurized milk products, including the requirement for the production of raw milk products. The numbers of *Staphylococcus aureus* for the production of raw milk products were exceeded only in Farm B in August, in the case of *Staphylococcus aureus*, effectively eliminated.

Table 3 shows that the values of the TPC in raw goat's milk from both farms met the legislative limit for the Czech Republic. The milk was suitable for the production of heat-treated pasteurized milk products and raw milk products. The numbers of *S. aureus* in raw milk products were exceeded only by those in milk samples collected from Farm B in August. Coliform bacteria and *S. aureus* were effectively eliminated by pasteurization.

The pathogens detected in individual milk samples taken during lactation from the 2 farms (P2) are shown in **Table 4**. The most frequently observed are the so-called environmental pathogens, of which coagulase-negative staphylococci are predominant (in 27.9% of all monitored samples). Other commonly observed pathogens are *Staphylococcus* PK-(delta haemolysin negative) (23.4% of samples), *Staphylococcus* PK-(delta haemolysin positive), *Enterococcus* sp., and *Streptococcus uberis*. *Staphylococcus intermedicus* and *Trueperella pyogenes* were detected in only 1 case. However, there was minimal detection of contagious pathogens. *S. aureus* was detected in both farms (5.4% of samples), and *Mannheimia* sp. was detected in 0.5% of cases.

Month	TPC	CB	PB	TB	*S. aureus*	Yeasts	Fungy	SCC
Farm A	CFU/ml	CFU/ml	CFU/ml	CFU/ml	CFU/ml	CFU/ml	CFU/ml	10^3/ml
April	$2{,}3.10^4$	<10	<10	<10	$8{,}0.10^1$	$8{,}0.10^2$	<10	946
June	$6{,}8.10^4$	<10	<10	<10	$1{,}5.10^2$	$1{,}2.10^2$	<10	949
August	$2{,}0.10^5$	$1{,}5.10^4$	<10	<10	$2{,}0.10^2$	$3{,}6.10^3$	<10	948
September[a]	$2{,}0.10^2$	<10	<10	<10	<10	<10	<10	—
Farm B								
April	$8{,}9.10^4$	<10	<10	<10	$2{,}8.10^2$	<10	<10	1149
June	$1{,}2.10^4$	<10	<10	<10	$1{,}0.10^2$	<10	<10	825
August	$1{,}1.10^3$	<10	<10	<10	$7{,}5.10^2$	<10	<10	1267
September[a]	<10	<10	<10	<10	<10	<10	<10	—

[a]*Pasteurized milk, Total plate count (TPC), Coliform bacteria (CB), Psychrotrophic bacteria (PB), Thermoresist. Bacteria (TB),* Staphylococcus aureus *(S.aureus), Somatic cell count (SCC).*

Table 3.
The microbiological quality of the pooled of the raw goat milk.

Mikroorganisms	**Farm A (107 ks)**	**Farm B (115 ks)**	**Total**	**Total (222 ks)**
	(%)	**(%)**	**(%)**	**Number[a]**
Enterococcus sp.	3	2	2,3	5
Mannheimia sp.[b]	1	—	0,5	1
Staphylococcus aureus[b]	9	2	5,4	12
Staphylococcus PK- (delta hemolyzin +)	4	5	4,5	10
Staphylococcus PK- (delta hemolyzin -)	28	19	23,4	52
Staphylococcus intermedicus	—	1	0,5	1
Streptococcus uberis	1	3	1,8	4
Trueperella pyogenes	1	—	0,5	1

[a]*The number of individual milks with the occurrence of bacteria in the milk (77 pcs) is lower than the number of total detected cases of bacteria (total of 86 cases), which is caused by the occurrence of 9 milk samples with the detected presence of two different bacteria.*
[b]*Contagious pathogens.*

Table 4.
Summary of the occurrence of bacteria in individual samples of goat milk.

Individual goat's milk samples were divided into milk samples with and without bacteria (**Table 5**). Pathogenic bacteria were found in 37.4% of the samples. The mean somatic cell count value for the samples containing bacteria was found to be 1.960 × 10^3/mL (statistically significantly higher compared to the mean SCC value for the group without bacteria). However, goat's milk samples that were free of mastitis pathogens also had a high value of somatic cell score. The average SCC value of goat's milk without mastitis was 1.422 × 10^3/mL, which may be affected by several factors, such as the animal's health and stress factors. Somatic cells have their own enzymes that can negatively affect the properties (mostly technological) of milk. Therefore, it is appropriate to monitor pathogenic bacteria, SCC values, and the total number of microorganisms in raw goat's milk.

As part of the project's solution mentioned in the introduction, several other indicators of the quality of the produced and processed goat's milk were monitored. Great attention has been paid to the refinement and expansion of knowledge about the relationships between the quality parameters of milk of small ruminants, especially the microbiological quality and content of somatic cells and its technological properties. For example, a negative effect of high SCC on rennetability and thermostability was observed. For milk samples with SCC > 1,000 thousand cells/mL, a longer renneting time and lower thermostability values were found. The effect of SCC on milk components was also observed. Individual milk

	Samples without bacteria detection	**Samples with bacteria detection**
No of samples (n)[a]	114	68
Proportion of cases (%)	62,6	37,4
Average number of SCC (10^3/ml)	1422	1960

[a]*Simultaneously with the bacteriological analysis of individual milk samples, the number of somatic cells in these samples was determined. For technical reasons, perform the PSB determination only on 182 samples out of a total of 222.*

Table 5.
Sample frequency and SCC values in groups with or without bacteria.

samples with SCC > 1,000 thousand cells/mL showed a decrease in lactose content. Furthermore, the impact of SCC on the composition of individual protein fractions and the content of chlorides, sodium, and potassium in milk was studied. The results have been published on an ongoing basis or are currently being prepared for publication [12–20].

The implementation of the obtained results was then mediated by economic evaluation of the impact of the mammary gland health on production economics. The production and economic data were analyzed using the ECOWEIGHT program. Because of the direct processing of milk on farms and the sale of milk in the form of dairy commodities, it was possible to evaluate the indirect effect of the mammary gland health on the economy of breeding. The calculation was modeled on goats of the White Shorthair breed.

3.3 Economic aspects of udder health

Udder health, reflected by the incidence of clinical and subclinical mastitis, is an important factor that influences the quantity and quality of milk as well as animal welfare. As mentioned above, the somatic cells count (SCC) in milk, also expressed as a somatic cell score (SCS), is an indirect indicator of udder health. With an increase in SCC, the quality of goat's milk decreases and its technological properties deteriorate, thereby causing a decline in the overall efficiency of milk and dairy commodity production [21]. Economic evaluation of the SCC (or SCS) effect can be carried out directly using basic milk price correction [22]. When milk is processed and sold as final products (e.g. cheese, yoghurt, kefir, and cottage cheese), the effect of the mammary gland health status can only be determined indirectly.

Evaluation of the udder health effect on production economy was based on the qualitative data described above and on own investigation of production and economic data provided by dairy goat farmers (P2) over the period 2015 and 2018. Production system is mostly intensive, purebred and closed, just purchasing the young bugs. Young goats needed for flock replacement are reared at farm. Goats are mated at autumn followed by kidding on February. Milking of goats starts early after kidding and a half of produced milk is used for kids' nutrition until full weaning of kids at 47 days of age. In the basic production system presented in **Table 6** the average production and economic data of White Shorthair goat farms have been taken into account. Based on the similarity between the production and economic parameters and breeding systems, it can be assumed that our findings would also

Farm parameter (unit)	Variant abbreviation	Value	
		Base	Changed[a]
Milk yield per 280d of milking period (kg/goat)	MY	749	674
Fat content (%)	F%	3,09	2,78
Protein content (%)	P%	2,94	2,65
Conception rate of goats (%)	CON	95,8	86,2
Litter size (kids/litter)	LS	1,89	1,70
Labour costs (EUR/goat/year)	—	89,98	98,97
Veterinary costs (EUR/goat/year)	—	17,70	19,50

[a]*The cumulative change in production and economic data at once was taken into account in the variant "All".*

Table 6.
Selected production and economic data of dairy goat farms (own calculation).

be valid for local farms of Brown Shorthair goats. In terms of indirect udder health indicators, an average SCC of 710,000 cells/mL milk was recorded on evaluated farms [23]. Considering that the SCC of 1,000 thousand cells/mL milk is generally stated as a limiting value, the presented production and economic data correspond to the parameters of a healthy farm.

Variation in the parameters, listed in **Table 6**, reflects the described relationship between the SCC and the farm's basic production level. The average value of production parameters (milk yield per milking period, fat content, protein content, goat conception rate, and litter size) applied in the base setting was changed by −10% and then all parameters were adjusted in one calculation (variant All). To take into account the additional costs of the treatment of animals with health problems, the value of labour and veterinary costs was also increased by 10% in all variants. The bio-economic model EWSH1 of the ECOWEIGHT software package [2] was used to quantify the effect of udder health on the economics of goat farms.

Revenue from dairy commodities represents the most important source of income for dairy goat farms in the Czech Republic (92% on average). A smaller fraction comes from the sale of animals and subsidies (see **Table 7**). Similarly, for New Zealand farmers, Solis-Ramirez et al. [24] reported that sales of milk and dairy products accounted for up to 99% of revenue, and only 1% came from other sources (subsidies were not accounted for, and sales of farm animals were recorded only for 1 of the evaluated farms).

The most significant costs of goat farms in the Czech Republic (**Table 7**) are milking and processing cheese (42%), feeding (25%) and labour (17%) (other costs account for 16%). The cost of veterinary care does not exceed 3% of the total cost. For comparison, dairy goat flocks in New Zealand [24] have a comparable cost structure with high feed (21% for concentrates and minerals), milk processing (20%), and labour costs (15%). If the indirect effect of udder health on the

Parameter (unit/goat/year)	Base	MY	F%	P%	CON	LS	All
Cheese yield (kg)[a]	65.2	58,7	58,5	59,1	63,7	64.2	49.1
Culling of goats due to reproduction (%)[b]	12	12	12	12	28	12	28
Total revenues (EUR)	983.98	893.62	953.48	956.80	967.78	963.76	825.23
Where: cheese a by-products	903.48	813.15	872.97	876.30	892.16	892.01	758.07
Other[c]	80.47	80.47	80.47	80.47	75.61	71.75	67.16
Subsidies (EUR)[d]	38.19	38.19	38.19	38.19	38.04	37.73	37.58
Total costs (EUR)[e]	642.85	626.19	652.29	652.06	645.87	645.87	622.52
Total profit (EUR)	379.28	305.62	339.33	342.89	359.94	355.62	240.33
Farm profitability (%)[f]	59%	49%	52%	53%	56%	55%	39%

[a]*Based on the milk yield intended for cheese processing (0.107 kg cheese/kg milk).*
[b]*Percentage of total loss (culled and death).*
[c]*Revenues from other categories (bugs and reared animals) and culled goats.*
[d]*Include support for performance testing, rearing and breeding of animals and conservation of genetic animal resources.*
[e]*The labour and veterinary costs were of 89.98 EUR and 17.70 EUR in the base system and increased by 10% in the studied variants (described in details in* ***Table 6****). Other costs include: fixed costs (96.25 EUR/goat/year) and costs for other categories (goats and rearing of young animals) expressed per goat.*
[f]*The ratio of profit (revenues - costs) and total breeding costs expressed in percent.*

Table 7.
Production and economic data of farms according to the basic setting and studied variants (own calculation).

economy of Czech goat farms (variant All) is considered, the share of other costs increases from 17–24%, reflecting the overall change in the level of production and the basic flock structure. The reduction in milk yield available for further processing (−58 kg) and the number of weaned kids (−0.21 kids per goat) resulted in a higher culling rate of goats, higher need for rearing goats for flock replacement (by 4 young goats/100 goats of the basic flock), and an overall reduction in the production lifetime of goats (by 0.5 years). Thus, there are not only additional costs (for the veterinary treatment and rearing of young goats) but also losses in sales. Consequently, farm profitability can fall by up to 1/3 owing to indirect effect of udder health problems. The profit remains positive, most likely due to the high intensity of production. However, farms with lower production levels may experience a drop in profit below the zero cost-effectiveness limit. Similarly, in the case of goat farming in New Zealand and Brazil [24, 25], high variability in farm profitability was found (from 10–179%), and the different production intensity of local farms was reported as one of the main reasons.

4. Conclusion

Goat's milk and goat's products are growing in popularity. At the same time, the requirements for its quantity, quality, and safety are growing. On small ruminant farms in the Czech Republic, milk usually does not go as a delivery to a dairy as in cow's milk production, but it is processed locally into products where detailed research into the properties of goat's milk is needed. The application with the quality limitation for internal use on farms in the quality system can contribute to the formal support of the quality system for official quality verification purposes, but above all practically to animal health, product quality, consumer food safety, and farm operational security. Our results show that mammary gland health indirectly affects economics of dairy goat farms. As in the case of dairy cattle, the additional costs associated with the treatment of sick animals (cost of medicines, veterinary treatment, and work of herdsman) and the actual decrease in milk production owing to disease incidence will be the most important factors that define economic consequences. Nevertheless, higher prevalence of subclinical infections, occurring commonly in dairy flocks of small ruminants, should be considered.

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Conflict of interest

"The authors declare no conflict of interest."

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Chapter 21

Economics and Profitability of Goat Breeding in the Maghreb Region

Chniter Mohamed, Amel Dhaoui and Jamel Ben-Nasr

Abstract

This chapter presents a review of the North-African goats, with particular focus on their current state, constraints and research prospects and development. In recent years, goat milk and meat have become acceptable and recognized as the source of healthy nutrient in the Maghreb countries. However, goat populations are generally confronted with severe nutritional deficits during feed scarcity period which exacerbate disease and health troubles and consequently low performances. They are mainly elevated in small herds and their productions are commercialized throughout an informal sector. Thus, if the informal sector is to be convinced to market goats commercially through formal ways, then knowledge of the economics of goat farming should be provided in the Maghreb countries. Under the economics of farming goat, we will investigate the trend in the demand and supply of goat milk or meat, trend in the number of goats slaughtered, and the cost of raising goats in the Maghreb region. We are going to evaluate the economics and profitability of goats as farm animal and their marketing strategies in the Maghreb region.

Keywords: goats, breeding, productivity, marketing, North Africa

1. Introduction

Goat represents an important genetic resource reared worldwide for milk, meat and fibers. Goat herds are maintained under a variety of conditions, mainly in small scale farming systems [1]. Goat breeding farming is mostly described as low-input systems across the world, whether extensive or semi-intensive [2, 3]. In limited resource areas, dairy goats provide sustainable livelihoods and enable smallholders to accumulate assets, besides to their wholesome and nutritious milk-based products. Global dairy goat population was estimated to reach 218 million in 2017 [4]. Asia owns the biggest part of the world population (52%), and then Africa with 39%, Europe with 5%, Americas with 4%, and Oceania with less than 1%. Noting that the world dairy goat population increased by almost 22% from 2007 to 2017, Africa experienced the most rapid increase (+32%), followed by Asia (+19%), and Oceania (+3%), with a slight decline occurred in Europe (−0.9%) and Americas (−0.7%). Goat farming is concentrated in Asia with 58.2% of the world goat population, followed by Africa with 36.1% and finally in the regions of America and Europe, with respectively 3.4% and 1.5% [5].

Goat milk and its products are preferred for their health and nutritional benefits, including greater digestibility and lipid metabolism, in addition to their taste, compared to cow milk [6]. Following to the growth of its population, global goat milk production increased (+62%) from 1993 to 2013. From 2007 to 2017, goat milk production increased by 16% [4] and reached 18.7 million tons in 2017. The largest increase in goat milk production (22%) is marked in Asia, followed by Africa (13%), Oceania (9%), Americas (5%), and finally Europe (4%) [4]. It was important to remember that Europe contributes with 15% of the total goat milk with only 5% of the population, considering its greater specialization and commercialization [7].

Farming represents the main activity of the North African people where meat was the major food product consumed together with wheat in an indigenous way. The domestic livestock of the North African is mostly beef, sheep, goat, camel, and poultry [8]. Goat is placed among the main popular domestic livestock in North African countries considering its ability to adapt to harsh environments and thrive with minimal food and water input [9]. In North African countries, the genetic diversity and origin of goats have not been properly and fully analyzed, where studies have been limited and little is known about the reared native goat populations [10]. Until now, goat sector is missing references on factors linked with the economics and profitability of its breeding and marketing strategies in the North African North African. In line with the current interest in domestic animals and their farming profitability, the present investigation was carried out to evaluate the economics and profitability of goats as farm animal and their marketing strategies in the Maghreb region.

2. Methodology

An appropriately literature analysis was conducted to assess economics and profitability of goat breeding in the Maghreb region. Papers reporting "Goats Breeding, Productivity, Marketing and North Africa" were mainly considered in our study. Journals in electronic data bases (Elsevier, Pubmed, CABI and Web of science) were consulted for an appropriate bibliography. A Total of 53 suitable references were considered for this chapter and only published ones up to the publication year 1984 were considered.

3. Current state of the North-African goats

Typical Mediterranean climate is the main characteristic of the Maghreb region [11], with a long summer period of intense drought and excessive heat (May to September), followed by irregular rainfall from autumn to spring (October to April). Since the early 1950s, Maghreb countries have experienced a rapid demographic growth following the significant rhythm of urbanization contributing to a marked increase in the demand of dairy products [12]. Maghrebian countries represent a rich potential of goat genetic resource, from which the main African breeds have been derived [13]. In these countries, goat milk is reared mainly for family consumption (liquid milk or white fresh cheese, the Jben) where there is no strong dairy tradition [14]. In marginal areas, the role of goats as mainstream protein sources remains unparalleled owing to their adaptability to harsh conditions and continuous climatic changes, then contributing to both the food and financial security of households, particularly the resource poor [15, 16]. Traditional meat products represent one of the earliest cultural heritages of the Tunisia, Algeria, Libya, Morocco and Egypt [17]. Maghrebian communities are particularly dependent on goat production [18] where the consumption of goat meat fluctuates with the religious affiliations of the ethnic groups and demand increases during the Muslim holidays. Thus, an important cultural event named "Aïd El-Kebir or Aïd Al-Adha" affects timing and structure of goat movements, and due to the arid and semi-arid climatic conditions, the season can also influence these movement patterns [17, 19]. Maghrebian communities consider meat products as nutrient-rich that promise health and wellness, and serving meat to guests is a sign of respect and a way to honor them [17]. The regional cultural habits vary greatly within the Maghrebian communities, giving rise to different styles of food across Tunisia, Algeria, Libya, Morocco and Egypt. Due to the climate, the meat products prepared are usually dried or cooked and are rarely smoked [17].

4. Algerian goat population

In 2016, Algerian goat population accounts for 4.9 million heads [4]. It is mainly reared under low-input farming systems [20] in the arid and semi-arid regions extending more than 80% of the territory [21]. Algerian goat population is located in difficult areas characterized by an economic activity, mainly mountainous in the north and steppe and sub-desert regions in the south [22]. It is maintained in an extensive mode [23] and includes four native breeds (Arabia occupied the Laghouat region, Mekatia located in the highlands and in some districts of the North, M'Zabia breed located in the northern region of the Sahara, and Dwarf/Naine of Kabylia occupying the mountains of Kabylie: **Figure 1**(**1**, **2**, **3** and **4**).

These adapted goat breeds are focused on mixed breeding choice for meat and milk [24, 25]. Goat native breeds play a major role in valorizing resources available under extensive production systems and marginal area, contributing for environmental and socio-economic stability [25].

Algerian goat population includes also the exotic breeds (Saanen, Alpine, Murcia and Chami) and their crossbreds representing a source of income for about 800.000 small farmers of semi-arid regions. They are keys in livelihoods of less-endowed households, being a source of cash income, milk and meat [5]. The choice of crossbred is due to changing consumer habits, economic expectations of farmers and desire to work with highly productive animals that can respond to the demands of the growing population [26].

Figure 1.
The four Algerian native goats.

The most important of Algerian local goats is Arbia breed reared mainly in steppe zone, semi-steppe areas and in highlands and especially appreciated for its meat production [27]. This is due the capacity of Arbia breed to survive under low input systems and its disease resistance, and its ability to adapt to nutritional fluctuations and environmental conditions [28]. The recent evolution of the price and the nutritional importance of kids' meat cause major change in goat farming [29] contributing to the regression of extensive system. While the demand for goat milk foresees the intensification of breeding system, the diversification of conduct mode and orientation of kids production [20].

5. Moroccan goat population

According to FAO [4], Moroccan goat population currently numbers for 5.23 million head and is composed of resilient local breeds well adapted to local climatic conditions, and is mainly concentrated in difficult and mountainous areas [30]. In Morocco, goat farming represents an input sector of agriculture and its flexible function, regardless its socio-economic importance and dynamic role in the development of economic activity in rural areas. In the north Morocco, goat herd is estimated to be 788,000 [31]. This sector plays an important socio-economic role for the local population providing food and contributing with more than 70% of income in rural mountain communities [32]. Exogenous and heterogeneous goat populations represent the main livestock from the north of Morocco and prove some phonotypical similarity when they were compared to Spanish breeds such as the Murciana-Granadina, the Malagueña or others Andalusian breed [33].

Draa goat (**Figure 2**(**5**)), breed derives its name from an oasis located in the southeast of the country the Draa Valley, is among the indigenous breeds with a satisfactory milk yield of 142 kg in 5 months of lactation, which is its most important feature [34]. Further, the demand for meat from kids is increasing because of its nutritional quality [35].

Figure 2.
The four Moroccan local goats.

The Barcha and Noire de l'Atlas breeds (**Figure 2**(**6** and **7**)) are very well adapted to the climatic and edaphic in the Atlas Mountains and conditions of that region. Compared to the Noire de l'Atlas, the Barcha goat is specified by white hairs on its dorsal line, the ears, and the snout. Milk produced by both breeds is exclusively used to suckle kids. The average milk production of these breed is low with an average of 68 kg/head/year and milk contains 16.2% of dry matter, 6.8% of protein and 6.3% of fat concentrations. Laaroussia goat (**Figure 2**(**8**)) is native breed to the north of Morocco that inhabits the western Rif Mountains and reared exclusively to valorize lands of forests. The average milk production of Laaroussia goats averages 53.2 kg during their 120 days of lactation.

The creation of co-operative cheese units and projects of dairy goat development were encouraged in the northern regions by the Moroccan public authorities [14, 36]. Although the success of such projects with the certification of the PGI (Protection Groupe Industriel; "Fromage de Chefchaouen"), some cooperative cheese units have difficulties to increase their productions and develop marketing. Several small units have been created around the Moroccan cities but the specificity of goat milk is not enhanced and cheeses are often made with mixed milks. These initiatives are based on goat milk which seems to have more potentialities than sheep milk. Better control of the technical management of farms, better monitoring of health problems and a good selection of successful broodstocks are necessary to have better productivity of goat farming in the province of Agadir [37].

6. Tunisian goat population

In Tunisia, the goat population has increased by 18.7% from 1997 to 2007, reaching more than 1.5 million heads. The growth of population has been followed by the increase of goat production, where the annual (2007) goat milk production was 12,200 tones and goat meat production 9500 tones (+9.8% and + 12.6%, respectively, in comparison with data of 1997) [4]. Almost (60%) of the Tunisian Arbi goats are located in the Centre and in the South and mainly reared in small herds in extensive mixed systems with sheep. Although these agricultural systems are changing, owing to socio-economic development, maintenance of this farming design is guaranteed by national projects for development of the small ruminant sector [1]. The native goat breed from Tunisia named Arbi, which means local, is well adapted to its natural environment (**Figure 3**).

Figure 3.
The Arbi native goat associated to Barbarine sheep.

The Arbi goat is mainly reared for meat production but also milk is produced only for home consumption. Under semi-arid conditions of the South, milk production measured in the first 6 weeks of lactation for goats suckling single ranged between 1.14 and 0.69 kg/head/day, while goats with twins produced 0.86–1.64 kg/goat/day [38]. In the North, milk production ranged from 1.2 to 0.75 kg/goat/day [39]. The Arbi goat is small-sized, long and haired with a pure black prevailing color. Both sexes are horned and adult body weight varies from 50 to 60 kg for males and from 35 to 40 kg for females [40]. The Arbi goat is long haired and the prevailing color is pure black and is horned; it is small-sized, adult body weight ranges from 35 to 40 kg for females and from 50 to 60 kg for bucks [40].

The breeding season of local goats occurred between September and March [38], where 80% of females exhibited oestrus at least once and 53% of cycles were associated with ovulations. The ovulation rate increased progressively to reach 100% from September to December, and then decreased during March to make a minimum of 14%. This season precedes a period of anoestrus (March–August) [41]. The sexual behavior for the local Tunisian goat is similar compared to that exhibited in the Algerian Bedouin goat characterized by a seasonal anoestrus occurred during spring and summer [42].

In Tunisia, genetic improvement was undertaken through crossbreeding indigenous goat with imported breeds and the results of on station evaluations have shown the superiority of the Alpine and the Damascus breeds in improving indigenous goat milk and meat production, respectively. Nowadays, in some regions (Gabès), the OEP (Office de l'Elevage & des Pâturages, Ministry of Agriculture) makes accessible Alpine and Damascus bucks to farmers in the oasis. Artificial insemination technique is used to disseminate improved germplasm [38].

7. Goat marketing and profitability

The young Maghrebian villagers, often from poor small farms, tend to emigrate in the big cities or in Europe and send money to their parents, than stay breeders when they cannot become artisan or find a rare public opportunity [43]. Consequently, less than 15% of small ruminants feed is from pastoral origin with the abandonment of pastoral practices in Maghreb area [44]. Goats and sheep farming can play a dynamic role in the development of economic activity in these rural areas considering its socio-economic importance for agriculture and its versatile function [45]. Goat contributes significantly to both food and financial security of the resource poor, particularly in marginal environments such as those within the Maghrebian countries.

Goat farming is preferably suited to poor economies as it needs a low capital investment in housing and equipment. Many of goat-farming projects tested were beneficial and provided employment opportunities. Farmers were unable to rear larger ruminants as they involved only held small amounts of land. Goats produce more meat and milk per unit of weight or feed input than sheep, camels or cows and they generate an economically viable option for poor farmers with no resources and for laborers without land [46].

Three criteria were used to categorize the operators in the industrial processors dairy sector in the Maghreb countries; the industrial capacity (quantity of milk processed yearly), the status (personal, private, co-operative) and the type of products they flow (drink milk and/or dairy derivatives). The organic label is also a good way to identify the agro-ecological characteristics of the product. But these characteristics require a very strict records and monitoring. Other proposals could be associated with the tourism in the area with creation of guest ranches or farm house inns, local supermarkets, exhibitions, regional labels [47].

Numerous artisanal dairy units were identified in the Maghreb countries. The aim of these initiatives is not only to characterize the products but also to attract the consumers by their roots in the territory. It means also that these promotions have not to be only a show but to be associated with larger operations and requiring the support of local organizations [48]. For example, GIPLAIT is an old state group managing some 14 units distributed throughout the country considering as the leading public company in Algeria [49]. GIPLAIT mainly operates with imported milk powder and milk fat and is undergoing restructuring with the aim to privatize some of its plants. GIPLAIT supplies the market with almost 70% of the total amounts of subsidized drink milk and 30% of the dairy derivatives, mainly yogurts and cheeses [12].

In Laghouat area of Algeria for example (**Table 1**), goats are mainly elevated for kids selling (90.57%), but some others objectives of production were justified as milk and/or meat for self-consumption, money profits from selling of goats and kids and practice tradition [50].

In Tunisia, a cheese unit nucleus (SOTULAIFROM Company) has been developed around the region of Béja in Tunisia which considered an example among the few cases of sheep milk industry in Northern Africa. After the 90s, the herd of dairy Sicilo-Sarde ewes decreased dramatically, then several projects try to reactivate this action with the creation of a new small scale unit "From art Béja" [47].

In northern Morocco, smallholders initiate to intensify goat production through commercialization of its dairy products, under the encouragement of Moroccan public authorities [51]. However, although dairy production provides an additional rather than alternative income for commercial dairy herds, the requirement to supply supplementary feed resulted in greater costs [51].

In the regions where the forage stock is still high, the lack of collective association and the loss of traditional collective management practices leads to overgrazing stressed by the higher frequency of drought periods due to climate changing [52]. Availability of additional feed restrains reproductive achievement and milk yield which, in turn, limit gross margin and restrict the financial viability of commercial dairy farming in northern Morocco [51]. Otherwise, goat is the only species able to take advantage of the agro-pastoral resources of the argan tree in South-West Morocco [53]. Considering the predicted effects of climate change on pasture areas, the adequate sustainable production way seems an evolution to semi-intensive mixed meat and dairy systems which valorize local alternative feeding resources in northern Morocco. This needs the development of co-operatives highly beneficial with the active support of participatory approach involving stakeholders from all steps in the value chain and. With such ways, low-cost and local alternative feeding can be generated to reduce grazing pressure and increase the goat production performance, generating both food and financial security of the region [51].

Variables	Modalities	Frequencies & citations (%)
Reasons for goat keeping	Milk and/or meat home consumption	58.5
	Cash income	57.5
	Tradition	45.3
	Passion	15.1
	Nursing lambs	4.7
Production objective	Kids	90.6
	Milk	9.4

Table 1.
Purpose and production objective of goat farming.

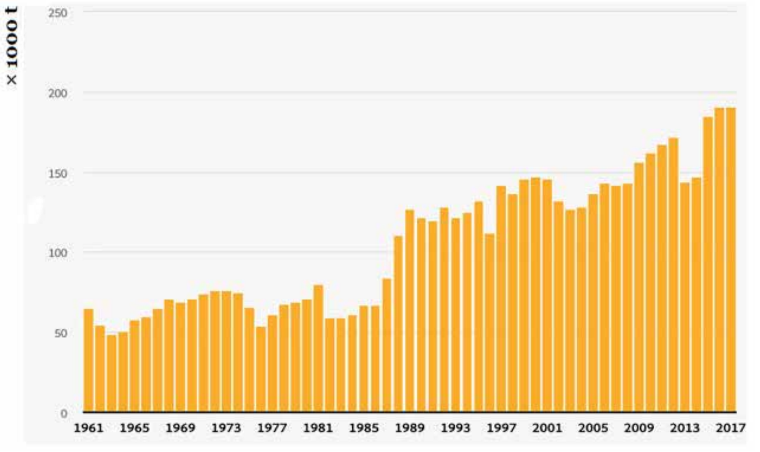

Figure 4.
Sheep and goat meat production in Morocco.

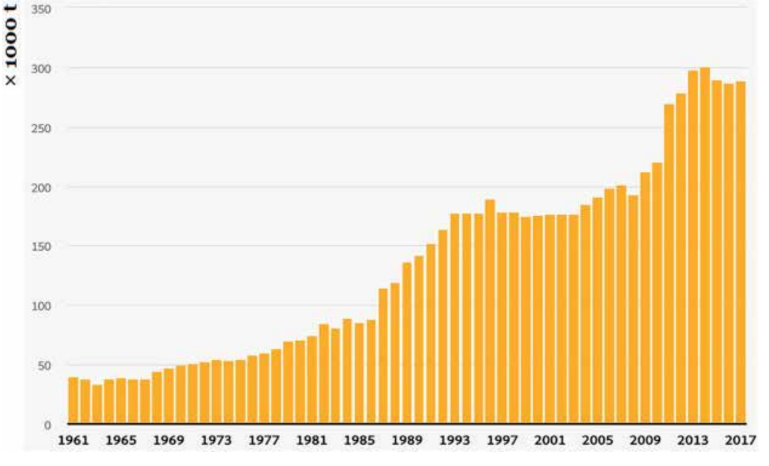

Figure 5.
Sheep and goat meat production in Algeria.

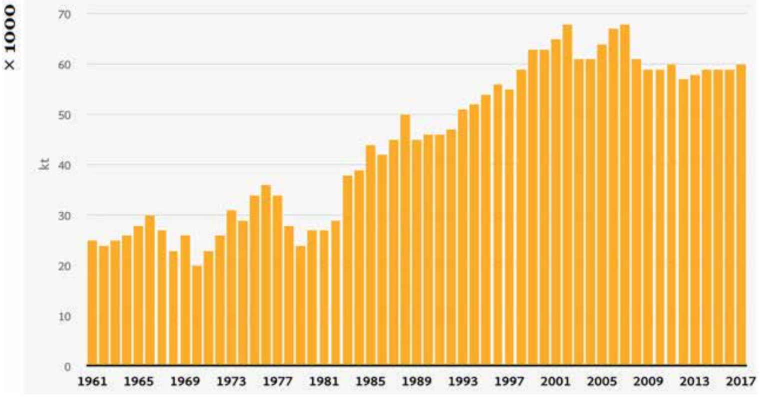

Figure 6.
Sheep and goat meat production in Tunisia.

The assessment of goat performance products is mainly associated with sheep productions. In 2017, indigenous sheep and goat meat productions reached 191, 289 and 60.0 kt respectively, in Morocco, Algeria and Tunisia [54]. Historically, indigenous sheep and goat meat productions reached an all-time high of 191 kt in 2016, 301 kt in 2014 and 68.0 kt in 2002, respectively in Morocco, Algeria and Tunisa. However, these productions reached an all-time low of 49.0 and 34.0 kt in 1963, and 20.0 kt in 1970, respectively in Morocco, Algeria and Tunisa (**Figures 4–6**).

In the Maghreb area, a large number of small agents competing for buying animals from breeders mainly on traditional markets ("souks") characterize the conventional marketing channels and often with low margins (85% of the price paid by the consumer goes to the farmer [44]. This allows the absence of variety of channels and a direct contact between the breeder and the consumer [55].

8. Conclusions

This global overview of goats in the Maghreb region has revealed that their attitudes are nowadays very opened according to each circumstance. For few of them, particularly the intensified systems, to be more sustainable and beneficial on the world market for milk or meat can be an intention. But in most situations, the potential of the goats is related to the perspectives of the neighborhood where they are elevated. In spite of their real resilience, it is likely that situations of rupture in these regions would lead to the decrease of goat population. The agro-ecological and eco-systemic challenges are both opportunities and menaces and their futures will be linked to the prospective capacity of the local actors to join forces and to organize together the transition towards new value chains.

Conflict of interest

None of the authors (M. Chniter, A. Dhaoui and J. Ben-Nasr) have a financial or personal relationship with other parts that could inappropriately influence or bias the chapter entitled "Economics and Profitability of Goat breeding in the Maghreb region".

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Chapter 22

Factors Affecting Household Goat Farmers' Market Participation and the Extent of Commercialization

Zamokwakhe Maureen Ntshangase, Tafa Sanelise, Bethwell Moyo, Sikwela Misery and Johan Van Niekerk

Abstract

This paper assessed the factors influencing farmers' choice to participate in selling goats and the extent of goat commercialization in Zululand district of Kwa-Zulu Natal Province in South Africa. Data were collected through questionnaires administered to 175 selected goat farmers in five local municipalities within Zululand district. A Probit model was used to estimate the factors affecting farmers' choice to commercialize while Tobit regression model was used to analyze the factors affecting the extent of commercialization. The Probit results show that the factors that positively and significantly affect farmers' choice to commercialize are gender, education level, quantity of goats, and type of marketing channel. The Tobit results revealed that factors that have a positive significant effect on commercialization are gender, level of education, experience in goat farming, and time of the year. The paper recommends that government support programs should be promoted to achieve high goat production and establishment of formal marketing goat sector to promote commercialization. Furthermore, information about goat nutritional attributes must be effectively shared with the society to change the negative stigma towards goats thus increasing the demand for goat and goat products, thus increasing farmers' market participation and promoting commercialization.

Keywords: goats, market participation, commercialization, sustainability

1. Introduction

Goat farming in South Africa (and other parts of Africa) has been the most extensive agricultural sector since the beginning of the 19th century. It is believed that goat population grows along with the human population. One of the reasons for a growing population of goat farming in Africa is that it is a farming sector that does not require intensive investment. For that reason, most South African farmers see goat farming as one of the strategies to curb food insecurity, for it is in high demand in the informal market.

However, the surprising thing is that goat farming is regarded as a poor man's trade. It is characterized by informality, lack of industry determination, value addition, and modern distribution channels. Very few farmers sell their goats through abattoirs, because most producers rely on consumers who are driven by cultural and traditional beliefs.

This chapter presents the factors affecting goat farmers' market participation and the extent of commercialization. The chapter is set out as follows; the next section defines the problem, followed by the methodology. After that, the discussion of results are presented, followed by the conclusion.

2. Definition of problem

There are very few large scale commercial goat farmers in Africa, and most of them are found in South Africa [1]. In South Africa, a large number of indigenous goats are owned by small-scale farmers found mainly in communal areas [2]. The white commercial farmers mainly rear Boer and Angora goats [3]. The goat resource in South Africa, which is mainly owned by non-commercial farmers and mostly of indigenous breeds is large enough to ensure a consistent supply of product to the market.

Goats significantly contribute to the country's goat population as it is approximately 63% [4]. Goat commercial farming is predominant in the Eastern Cape, followed by Limpopo then Kwa-Zulu Natal (KZN) Provinces of South Africa. Eastern Cape has more goats in South Africa accounting for 38% of the total flock followed by Limpopo with 18% and KwaZulu–Natal with 13% [5]. However, there is a potential to develop goat production in KZN as according to [6], more than 50% of cattle, 19% of sheep, and 74% of goats are on communal lands in the KZN province.

It is noteworthy that, goat marketing remains very low and informal in South Africa and this is exacerbated by low participation of goat farmers in formal markets [7]. One of the contributing factors to low market participation is that most goat farmers are mostly in rural areas where goats depend on the natural forage under extensive conditions throughout the year without nutritional supplements during the winter dry season. In general, smallholder farmers' productivity is low due to factors such as lack of information, lack of market access, and poor access to support services [8–10].

These factors are challenges in the improvement of smallholder production and thus smallholder producers are finding difficulties in commercializing their production. The major challenge to commercialization is how smallholders can penetrate and participate in markets [11]. Sharma et al. [12] also found out that participation in the commercialization process has been difficult for smallholder farmers because of inappropriate policies, insufficient access to technology, institutional obstacles, weak infrastructure, and unfortunate links to markets. In the past 18 years, the South African government implemented several policies and programmes and increased the agricultural sector's budget by supporting emerging farmers [13–15]. However, very little is known about smallholder goat farmers or goat production in general. The resistant nature of goats to disease and internal parasites, its adaptability to harsh conditions, less production cost, and easy increase of production because of the high possibility of twining makes goats more sustainable livestock to produce by smallholders thus demanding a commercial approach from farmers.

According to [16], smallholder commercialization is part of an agricultural transformation process in which individual farms shift from a highly smallholder-oriented production towards more specialized production targeting markets for their input procurement and output supply. According to [17] agricultural commercialization is the basis of economic development and integration of farm household into rural economy and society as an integral part of the process. Furthermore, [18] also assert that the transition from subsistence to commercial agriculture represents a key ingredient for low-income countries' economic development.

Therefore achieving goat commercialization will enhance the welfare as well as economic development for smallholder farmers. Notable, commercialization as an agricultural transformation will therefore have a substantial impact on agricultural production, food security, poverty alleviation, and economic contribution to the smallholder farmer at a household and a national level.

Goats are predominantly sold live for cultural and religious ceremonies and traditionally goats have served as a means of ready cash and a reserve against economic and agricultural production hardship [19]. However, the evolution in the meat industry and consumer health requirements are slowly creating an entrance for goats in the formal market since goat meat is now available in some retail stores in Eastern Cape, Gauteng, and in very few outlets in KZN [4]. Most goat products are exported to countries like Asia where they are mostly used and are in high demand than in local use [20, 21]. Despite the exporting marketing opportunities, smallholder farmers still have no access to these markets because of various production and marketing constraints they face. Producing for the formal market requires production resources such as land, water, on farm and off-farm infrastructure, labour force, capital, and good management skills [15, 22]. Poor access to these resources by household farmers affects how they may benefit from opportunities in agricultural markets hence lack of resources also hinders the commercial approach in goat production and marketing.

Globally, livestock production systems are undergoing rapid changes in response to population growth, urbanization, and increasing incomes [23]. The demand for livestock is largely influenced by socio-economic factors such as human health concerns, constantly changing socio-cultural values and rapidly increasing population. As such the increasing demand for the animal products is expected to improve the income and livelihood of smallholder farmers who account for the bulk of production in developing countries [23, 24]. However, most of the increasing livestock production is taking place outside the smallholder sector, which is the same trend with goat production. Goat meat matches consumer preferences for low-fat meat and consumer concerns on health [20, 21]. Therefore goats have the potential for being a diverse reservoir for future use if commercialization is achieved.

The problem investigated in this study relate to the farmers' choice to participate in goat selling and goat commercialization. Commercialization means a change from a subsistence type of production to a market-oriented to profit maximization [25]. Therefore, commercialization can transform smallholder goat farmers by shifting production practices from current consumption-oriented towards market-oriented thus achieving economic development through income growth. The question which can be asked is whether the household farmers do participate in marketing goats, the level of participation, and which market do they use to sell goats. Therefore, this chapter aim at identifying the factors affecting farmers' choice to participate in the marketing of goats and determine the extent of goat commercialization in the study area.

3. Methodology

3.1 Description of the study area

This study was conducted in Zululand district municipality, (ZDM) which is situated in the northeastern part of KZN. Zululand District Municipality is the biggest district in the province, making up 16% of its geographical area. The ZDM covers 14810km^2 and consisting of 803576 population size in total and 102982 people of the entire population are unemployed hence the level of poverty in the area is very high amounting to 33, 02% [26]. Approximately half of the area is under traditional authorities' jurisdiction while the remainder is divided between commercially owned farmers and conservation areas [26]. The ZDM district municipality comprises five local municipalities: Ulundi, Abaqulusi, Edumbe, Nongoma, and Pongola.

3.2 Sampling and data collection

The target population of the study was the household goat farmers in Zululand district in KZN province. Purposive sampling was performed in this study. One hundred and seventy-five goat farmers were randomly selected from the five local municipalities with 35 goat farmers from each municipality. Structured questionnaires were used to collect data through face-to-face interviews with goat farmers in the Zululand district. As household farmers did not have records, this study counted on farmer's recall for information.

3.3 Data analysis

Frequency and econometric analyses were done to analyze the data. Percentages were used to analyze the demographics of farmers. This study's socio-economic characteristics include gender, age, race, marital status, level of education, and employment status.

A Probit model was used to estimate the factors affecting the choice of commercialization. [27] asserted that when the Probit model is used to analyze the farmers' decision to participate in the output market, it has to be estimated as follows:

$$\begin{aligned} Y_i = \beta_0 + \beta_1 Age + \beta_2 Gender + \beta_3 Race + \beta_4 Marital\ status + \beta_5 Education \\ + \beta_6 N.Livestock + \beta_7 Market\ channel + \beta_8 Farm\ ass. + \beta_9 Det.price + e_i \end{aligned} \quad (1)$$

Where:

Yi is dependent variable, which is the choice to participate or not. It can take 1 if the farmer participate in commercialization and 2 if otherwise.

In order to analyze the factors affecting the extent of commercialization, Tobit regression model was used. This Tobit model was developed by Tobin in 1958. Tobit was chosen because it uses censored dependent variable as the information is available for certain respondents. Some studies have used the Heckman model to fulfil the same objective; however, Heckman is not efficient compared to the maximum likelihood of the Tobit Model. Tobit Model specification is as follows:

$$\begin{aligned} Y_i = \beta_0 + \beta_1 Age + \beta_2 Gender + \beta_3 Race + \beta_4 Marital\ status + \beta_5 Education \\ + \beta_6 N.Livestock + \beta_7 Market\ channel + \beta_8 Farm\ ass. + \beta_9 Det.price + u_i \end{aligned} \quad (2)$$

Where Yi presents the number of traded goats.

4. Results and discussion

4.1 Introduction

This section presents the results first and foremost. The objective was to assess the factors affecting household goat farmers' market participation and the extent of commercialization. The first sub-section presents the socio-economic profile of the goat farmers in the study area. The second section provides the empirical results, where tobit and marginal effect results are discussed.

4.2 Goat farmers' socio-economic profile

The significant of demographic information in academic research cannot be overemphasized. The socio-economic factors exert pressure on the decision making behaviour of a household. This study's socio-economic factors are gender, age, marital status, level of education, race, experience, and membership status in the farmers' association (see **Table 1**).

The Zululand population is predominantly black/African. For that reason, most respondents in the study area were Africans (98%), while the remaining 2% was made up of white respondents (see **Table 1**). Majority of African farmers were

Variable		Percentage
Gender	Male	75%
	Female	25%
Age group	16–20	2.4%
	21–25	6.5%
	26–30	5.9%
	31–35	7.6%
	36–40	7.1%
	41–50	18.8%
	51–60	28.8%
	61 and older	22.9%
Marital status	Single	38%
	Married	59%
	Widowed	3%
Level of education	Never been to school	19.4%
	Grade R to 8	33.5%
	Grade 9 to 11	22.4%
	Matriculated	18.2%
	Tertiary education	5.9%
Race	African	98%
	White	2%
Number of years farming	Less than five years	17.6%
	Five to ten years	25.3%
	10 to 20 years	24.1%
	More than 20 years	32.4%
Membership to an association	Yes	12%
	No	88%

Source: Author's computation (2021).

Table 1.
Socio-economic factors.

producing for subsistence purposes, while the white farmers were solely producing for commercial purposes.

It is important to note that in most African settings, male gender usually likes to keep livestock compared to females. Females predominantly look after crop production. Hence the results presented in **Table 1** reveal that Zululand farmers are made up of 75% male, and 25% females. The findings reveal that goat farming is dominated by males than females in the study area. Furthermore, the greater number of male respondents could also be attributed to the cultural ideology that males are the heads of the families and therefore own livestock and are often the ones answering questions in the survey despite the possibility of a wife being the owner of the goats in the household farm.

This study also reveals that older farmers are dominating goat farming when compared to the younger generation. 53% of respondents were between the ages 50 to 61, while the 31 to 40 age category comprised 33% and 13.5% were in the category of 18 to 25 years. Generally, young people are more likely to migrate in search of non-agricultural jobs whilst older people remain at home and do agricultural activities. Furthermore, the author assumes that youth with higher educational qualifications are always hesitant to engage in agriculture as a primary means of livelihood unless commercially available. In addition, climate change and the rapid increasing population demand for the transfer of food production activities and knowledge to young and literate society members. However, the limited participation of youth in goat farming is a concern for sustainable goat productivity and commercialization considering the level of chronic illnesses threatening the aging farmers and the high rate of youth unemployment.

Though education impacts farming, it is clear in this study that household farmers take it for granted, particularly with goat production as an average number of respondents without formal education participate in goat farming. Most (33,5%) of the respondents of goat farmers in the study area attended primary school, followed by secondary education with 22%, while 18% of the study population had matric and only 6% had tertiary education. 19% of the study population did not have formal education. These findings further confirm that most South African smallholder farmers have limited education and the lack of awareness among rural farmers can be attributed to the high level of illiteracy.

Regarding employment, less than 10% of the respondent were employed, the majority (64%) are getting state grants and not employed, followed by 26% who are unemployed. From these findings, it is clear that unemployment is one of the challenges facing rural goat farmers.

Marital status affects decision making in any household. In most cases, married farmers usually have children to take care of, which affects their decision because they have to invest in their families' future. This is why most goat farmers in Zulaland are 59% of the Zululand married farmers, while 38% single, followed by those who are widowed (3%). Membership in a farmers' organization is essential for every farmer's development. A farmers' organization is vital because it is where challenges facing farmers are mostly discussed. Results presented in **Table 1** show that most farmers in Zululand are not members of an organization.

4.3 Factors affecting the goat farmers' choice to commercialize

Table 2 shows the factors affecting goat farmers' choice to commercialize in the KZN area. These factors range from gender, age, marital status education level, market channels among others.

Gender plays a crucial role in the decision of whether to produce for commercial purposes or subsistence. This is because of the distribution of economic roles within

Variables	Coefficient	Standard error	Z	P > |z|
Gender	−.6785077	.298715	−2.27	0.023**
Age	−.0049891	.0075028	−0.66	0.506
a3_race	.2548782	.843632	0.30	0.763
Marital status	−.168734	.2115477	−0.80	0.425
Education level	.2442871	.1204557	−2.03	0.043**
b12b_livestock_goats_number	−.0026207	.0015519	−1.69	0.001 ***
c49_market_channels	.4065917	.405533	1.00	0.016 **
a10_farmers_association	−.0068096	.393273	−0.02	0.006***
c56_determine_price	−.0962389	.183803	−0.52	0.601
_cons	1.950179	1.976423	0.99	0.324
Number of observation: 150				
LR chi2(8) 14.84				
Prob > chi2 0.0953				
Pseudo R2 0.1050				
Wald chi2(6)				
Log likelihood −63.287164				

*Note: *** = 1% significance level, ** = 5‰ and * = 10‰ significance level.*
Source: Author's computation (2021).

Table 2.
Factors affecting the goat farmers' choice to commercialize.

a household. For example, roles that require physical strength are given to men while those that do not, are given to a females. The results revealed a significant relationship between gender and the decision to commercialize at $p < 0.05$ (see **Table 2**). African cultural norms that perpetuate the perception that livestock ownership is a responsibility of men also contribute to this finding. Therefore livestock gender ownership greatly influence goat commercialization.

Furthermore, the results revealed that education level significantly affects commercialization choice at 5%, positively. The influence of education in adopting new technologies by farmers is generally prominent [28]. On the same note, [29] argued that education is one of the most significant demographic characteristics for decision-making among farmers, for it directly improves knowledge capacity, the ability to understand and instantly make sense of information. The higher the level of education the more the chances of adopting new technology [30]. In this case, it is clear that the high literacy level can strengthen or enhance goat production because literate communities are more likely to take risks and thus more inclined to commercialize and quickly adopt new technologies.

This study's findings further reveal that the number of goats owned by the household was observed to be an important factor influencing the commercialization of goat for meat production with a statistical significance of $P < 0.001$. Households with large herds sold significantly more goats on average than those with medium and small herds. Such households presented a significant source of goats for the market and they could, therefore, be a target group for commercialization. These findings are in line with [31]'s arguments who noted that the insufficient number of goats amongst farmers with small herds restrict sale.

The results also revealed a significant relationship ($P < 0.05$) between the market channel type and commercialization choice. Thus, large numbers of goats are sold through informal market directly to the available consumer by the household farmer thus allowing the farmer to retain 100% of the selling price in the absence of a formal market. The large use of the informal market for goat sales in this study is not uncommon. There is nevertheless an enormous potential for the sale of goat meat as an additional source of income on farms. According to [24] despite the economic importance of goats, particularly in the sustenance of household food security in rural areas of developing countries, marketing of goats and chevon is not as formalized as that of other livestock.

4.4 Factors affecting the extent of goat commercialization

Tobit results are presented in **Table 3**, with marginal effect.

Tobit results presented in **Table 3** above indicate that gender was statistically significant at 10% with a positive influence on the extent of commercialization amongst the farmers. This positive relationship between gender and the extent of commercialization is inconclusive since any of the gender can commercialize. The marginal effect presents that gender affects the level of commercialization by about 9%. Age was also found to affect the level of commercialization at 10% positively. These results imply that an increase in age of a farmer has a high probability of increasing the extent of commercialization by 23.8% (presented by marginal effect). Many studies have concluded that age signifies the level of experience of a farmer. Moreover, farmers with more experience tend to participate in the market.

Levels of education significantly affect the extent of commercialization at 5%. The positive coefficient shows that the more educated a farmer becomes, the high possibility of commercializing their goat production. The results are in line with [24] who stated that educated farmers are more likely to participate in marketing of their products. This is because educated farmers are more likely to know the available marketing channels. Similarly, [32] attest that illiteracy affects one's ability to

Sell goats	Coef.	Std. Err.	T	P > |t|	dy/dx
Gender	.0928731*	.0506815	1.83	0.071	.0928731
Age	.0238155*	.0136858	1.74	0.086	.0238155
Education	.0428948**	.0215988	1.99	0.051	.0428948
If yes number	.0098008	.0225234	0.44	0.665	.0098008
Duration farming	−.0088377	.0192465	−0.46	0.647	−.0088377
Transport to market	−.0115561	.0224159	−0.52	0.608	−.0115561
Time of year	−.0321768*	.0190296	−1.69	0.095	−.0321768
Constant	.7903371	.1592653	4.96	0.000	
LR chi2(7) = 11.47					
Prob > chi2 = 0.1195					
Pseudo R2 = −0.3077					
Log likelihood = 24.364345					

*Note: *** = 1% significance level, ** = 5‰ and * = 10‰ significance level.*
Source: Author's computation (2021).

Table 3.
Tobit results and marginal effects.

access important agricultural market information (such as price updates) and fair marketing commitments. Illiteracy does not involve the inability to read and write only, but also inability to interpret agricultural market information. It is acknowledged that farmers with basic education are more likely to adopt new production technology and this impacts the number of goats produced and consequently market participation. Pienaar and Traub [33] indicate that most of the farmers in South Africa have 5 years of education (an equivalent of grade 5). The modern production technologies needed to increase agricultural production tend to be composite for the illiterate farmers, who are, therefore, less likely to adopt them. Therefore, the level of education has major implications for agriculture production since it is going through a series of innovations and development demanding a better-educated farmer. In addition, education influences the ability of farmers to adopt new marketing information and technology.

The time of the year presented in **Table 3** above signifies the season. It is significant at 10% but has a negative influence on the extent of commercialization of goat. The results are in agreement with the fact that goat meat is usually in high demand during traditional ceremonies. These traditional ceremonies usually take place during the holidays of April, June, and December. For that reason, most farmers do not sell their goats when they are not in demand. Domestic consumption of fresh goat meat for only traditional and religious ceremonies is the primary challenge for goat farmers as they are unable to sell throughout the year.

5. Conclusion and recommendation

Socio-economic factors have an impact on both farmers' choice and the extent of commercialization in the study. The study reveals that older farmers with experience are the ones likely to participate in the market. Educated farmers are also highly likely to participate in the market because they can access and be able to interpret marketing information. Age and level of education affect the number of goats owned and market participation. Level of education and experience enables the farmer to effectively manage goats thus achieving high productivity, as it is also easy for educated farmers to adopt new technologies that will improve production. Therefore there is a great positive relationship between productivity and market participation which consequently influences commercialization. It is noted in the study that the farmers use the informal market to sell their goats live and socio-economic issues largely influence the marketing as goats are sold in certain specific months which is the period where certain cultural, tradition or religious ceremonies are performed. There are no formal markets for goats and goats products, this is an issue as farmers depend on the available informal market which is not structured thus farmers in the study area have no choice to whom they sell their goats to.

The study reveals that a skilled and educated goat farmer participates in the market. Therefore, government programs that will train and skill goat farmers must be established to increase productivity and market participation. Market information is an important aspect of agricultural development as it enhances market performance and knowledge of market actors. Furthermore, training programs are important for adopting production and marketing technologies, thus enhancing rural goat farmers' productivity. Through the training programs, effective goat marketing strategies could be developed to inform consumers about attributes of goats to address the sociocultural stigma attached to goat and allow goat products to be accepted as an alternative protein source and this will allow goat sales to be throughout the year consequently achieving sustainable commercialization of goats. The goat product potential that is somehow overshadowed by cattle, sheep, and pig products will be illuminated by establishing formal markets. Training programs will also assist farmers in understanding the demand, price trend, and dynamics in consumer preferences. The study further reveals a positive relationship between market participation and productivity, therefore it appears that the quantity of goats is among the leading significant drivers thus efforts to increase production abilities are very important to promote commercialization of household farmers.

This study recommends that a pathway be created to support household goat farmers so that viable conditions to shift from subsistence farming to market-oriented farming are established. Government support for goat farmers will be imperative in this regard. The study also recommends establishing formal market structures where goat farmers can sell their goats and goat produce to promote market participation and, consequently, increase food security and poverty alleviation for rural farmers. Government support in establishing the formal market for goats will be of high importance as in return revenue could be collected from farmers thus contributing to the country's economy. The increasing evolution in consumer preferences and health consciousness is important for diffusion innovation and exploitation of new markets for goat products thus achieving commercialization. Climate change makes goat husbandry the main feasible economic and productive activity in mountain areas of South Africa, where the climatic and soil conditions hinder the sustainability of other livestock-rearing activities. Goats can effectively provide environmental and socio-economic services sustainable if well managed and also if there is a structured market for goats. It is noteworthy that the economic value of goats can be realized through commercial production and marketing of goat as well as through value-adding to goat products. There is therefore a need to explore vast marketing opportunities both local and international and at the same time improving goat production towards a commercial approach so as to ensure reliable supply and sustainability of these new markets.

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