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Goats (Capra)
From Ancient to Modern

Edited by Sándor Kukovics

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Meet the editor

Prof. Dr. Sándor Kukovics spent 40 years at the Research Institute for Animal Breeding and Nutrition (Herceghalom, Hungary) being responsible for the small ruminants sector. He also edited 30 books, published more than 1,000 articles and has licences for 4 products. Besides research work, he has been taking part in undergraduate and further education from various universities (in Debrecen, Mosonmagyaróvár, Gödöllő, Kaposvár). Since 1996 he has been the President of the Hungarian Sheep and Goat Dairying Public Utility Association. He has been the Executive Manager of Sheep and Goat Products' Board and Inter-professional Organisation since 2010. Between 2015 and 2019 he served as Vice President of the EU COPA-COGECA Working Party on Sheep and Goats and he has been a member of the Board of Directors of the International Goat Association since 2016. As an expert he has been taking part in the activities of several special groups in the EU working with small ruminants since 2004.

Contents

Preface

The current knowledge about goats is constantly expanding, so it is recommended to summarize it from time to time and make it available to interested readers. In this volume, readers can find interesting summary analyses of the goat varieties used in different countries, cashmere and pashmina wool, the differences in goat cheese varieties, and the active ingredients used in the treatment of goat diseases, and parasitism in goats.

Goats and breeds

The goat is one of our earliest domesticated animal species, parts of which were already found in objects from thousands of years ago. Not only was the goat endowed with certain qualities, but the buck was also included in the constellations, so other effects were attributed to it. In Egyptian and Greek culture, the goat had - and still has - a special place, which can also be found in cult objects and paintings.

In addition to its meat production, its milk production was also utilized at least 3,500 to 4,000 years before, and excavations in the former Mesopotamian area found, in addition to equipment suitable for milk processing, cheese that was many thousands of years old.

In the ***first chapter*** of this volume, the author summarizes information on the historical past of the goat, supporting his conclusions and findings with a number of figures.

Spain has the second largest goat population in Europe (and the EU) in breeding and production - according to the latest official figures, the size of the population is over 3 million. A large number of local varieties form the basis of the herd, and varieties specializing in both meat and dairy production can be found among them. Detailed descriptions of these can provide the reader with information not only about the past and present of the varieties, but also about their possible future.

In the ***second chapter*** of the volume, in addition to describing the Spanish varieties, the authors also describe the production systems used in the country.

Spain is also important for goat keeping/breeding because the animals from Spain have become the ancestors of the breeds that form the basis of the current goat population on the American continent. After, or in parallel with, the discovery of America, many goats reached different parts of the continent and became explorers, "pioneers," and helpers for poorer people over the past centuries.

There are already large numbers of goat breeds of different origins in the ***United States of America*** that have arrived there as a result of import ideas for different purposes. The foundations of the current goat herd have developed over the last 100 years. Meat and dairy herds as well as wool herds can be found in the country, and they even breed all kinds of crossbred offspring. From favourite animals with a few individuals to large-scale, huge farms, goat farms of all sizes can be found in the USA. Varieties have also developed that hardly occur anywhere else in the world. Of these, perhaps the most interesting is the Myotonic goat, whose meat-to-bone ratio (4:1) stands out even among the meat species. The fact that the world's best-known goat research institute operates in this country, and the goat population has increased dramatically in recent decades, reaching 2.7 million individuals in early 2020, is also an appreciation of the goat.

In the ***third chapter*** of the volume, the author presents a summary analysis of goat breeds bred and kept in production in the USA.

In the ***fourth chapter*** of this volume, the reader can get a summary of the goat breeds developed and bred in ***Nepal***. The varieties bred there are fundamentally different from those presented in the previous two chapters, although individuals from some of the world's milk and meat varieties have already arrived there.

Nearly 11 million goats are kept in production and breeding in Nepal, and most of them are among the hard Central Asian breeds. Significant genetic differences were also found between the goat breeds kept in each region, and even the authors showed clear differences between the individuals of each breed bred in different regions. In most goat-keeping countries, including Nepal, efforts are being made to improve the milk and meat production of domestic breeds using imported breeds, but breeds that are considered exotic here have also developed in the country. The results of the development based on the applied breeding and selection methods, as well as DNA tests and biotechnological methods are presented in this study.

Cashmere - Pashmina

Cashmere and pashmina (i.e., wool) have become expressions of coveted fashion, elegance, and luxury in recent years (their first traces can be found as early as 3,500 years ago) and the rise of these products has been huge in the last 20 years.

Although both products come from the same goat growing two layers of hair, the average fibre diameter of generic cashmere varies between 12 and 21 microns, while pashmina means a material made up of fibres with a fineness of 11 to 16 microns.

This excellent heat-retaining and light fibrous material is formed in the lower layer of goat hair. The amount is 200-300 grams per individual per year for cashmere goats and 80-180 grams for pashmina. The former is produced in both flat and mountainous areas, while the latter requires a special mountain with a special climate (above 5000 m). The finest and best quality pashmina is produced by goats kept around the Himalayas.

In the thousands of years of history of cashmere wool production, it has developed based on goats kept in India, Kashmir, Nepal, Inner Asia, Mongolia, and Northwest China, but this product is already produced in Australia, New Zealand, and in other countries. About 70% of world production is produced in China (about 15,000 tonnes per year), 20% in Mongolia, and 10% in the other countries concerned. There are huge quality differences between the qualities of cashmere produced in various countries.

However, the huge demand caused by the increasingly "permissible luxury" has cost the environment. This goat accounts for the vast majority of China's goat population of more than 122 million. Mongolia's originally seven million cashmere goat herds have grown from 7 to 27 million in the past two decades, with about 40% of the human population living on it. The huge increase in the goat population has caused significant environmental damage. About 70% of Mongolia's verdant lands have reached the brink of desertification due to overgrazing with goats - a population of 31 million sheep has caused almost negligible environmental damage compared to this. Government measures in China are trying to curb the phenomenon. There are also some government measures underway in Mongolia, but there is also an obstacle here: the country's third largest export is cashmere wool.

In the ***fifth chapter*** of this volume, a summary analysis of the production and use of ***cashmere*** wool can be read by those interested.

Readers can find an evaluation of the production of the finest ***pashmina*** and its economics in the ***sixth chapter*** of the volume.

Cheese quality

In order to prevent further natural damage in the territory of one of the successor states of Yugoslavia, now called Northern Macedonia, goat farming was banned in 1947, with catastrophic consequences for the number of goats and the number of people living on this species. Overgrazing was blamed on the goat and not the fault of the people who kept it. This fundamentally wrong approach was discarded from 1989, when goat farming was re-authorized in the country. Since then, in addition to the development of remaining local breeds, the populations of the most important dairy breeds in the world (Alpine and Saanen) have developed in the country, as well as crossbred herds of local Balkan goats and imported goats.

As in many regions of the world, the main reason for keeping goats in this country is milk production, and the utilization of the resulting reproduction for meat plays a smaller role in the income of individual goat farms. The properties and values of the three main types of goat cheese developed in the country are evaluated by the authors in this ***seventh chapter***.

Health

One of the most important topics in goat health is which ***drugs*** and which active ***ingredients*** can be used with sufficient effectiveness in the maintenance of health in goats. Many active ingredients are used in human medicine in addition to veterinary medicine, so the resistance of certain pathogens to certain active ingredients is and can be extremely important. This summary analysis includes almost everything you need to know about these active ingredients when treating goats. This subject is summarised in this ***eighth chapter***.

It should also be noted that many active ingredients appear and, when used, are also found in milk, as a result of which they inadvertently enter the human body and may even cause an undesirable effect there. Moreover, some active substances may be stored in certain organs temporarily or even for a period of time, which requires due attention in the case of meat consumption if, for some reason, the individual to be used has been treated with an antibiotic. Therefore, it is highly recommended to use these useful active ingredients carefully! Care should be taken to avoid bottom and top dosing and to comply with mandatory health waiting periods and to avoid their unjustified introduction into the human body.

It is of great importance to be able to vary the range of active ingredients available in order to avoid the development of resistance to certain pathogens and to keep our animals healthy and to prevent unwanted active substances from entering the human body.

In addition, some drugs may be toxic to goats that are debilitated by disease. Therefore, this study suggested the need for an effective system of management, diagnosis, and appropriate treatment that can reduce the risk of infection and increase the productivity of the animals.

The importance of internal ***parasites*** (goat helminthiasis) in the digestive system cannot be overemphasized. Many parasites can occur in the goat habitat and consequently in goats as well. The presence of parasites is a major deterrent to animal husbandry. They cause not only health problems but also economic damage, not to mention the cost and impact of drugs used against them.

A weakening or poor condition always raises the possibility of the presence of a parasite. It is worth considering that some research shows that the goat is up to four times more susceptible to individual internal parasites than the sheep.

However, it is recommended that the condition of the animals be monitored regularly, that the necessary systematic examinations be carried out if the presence of an internal parasite is suspected, and that appropriate treatments be applied if confirmed. This important subject is presented in this ***ninth chapter***.

Dr. Sándor Kukovics
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Section 1

Goats and Breeds

Chapter 1

Goats in the Ancient Near East and Their Relationship with the Mythology, Fairytale and Folklore of These Cultures

Merida Roets

Abstract

This study investigates the role of goats in the myths and folklore of various Ancient Near Eastern (ANE) cultures. Images in artefacts, and metaphors or direct reference to goats in texts (the primary sources in this study) from the geographic area of Mesopotamia, Sumer, Akkad, Anatolia and Ancient Iran (Elam) were studied. Secondary sources provided the context within which the sources occurred. Where images and references to goats occurred, their meaning and relationship to belief systems or their underlying 'motifs' within the ANE cultures are identified, categorised and discussed. This study shows that aside from the important utilitarian function of goats in the ANE, their use in rituals and symbolism has provided us with several motifs related to goats that are still in use today. These include the motifs of fertility, intelligence and craftiness.

Keywords: goat, Ancient Near East, mythology, cultures

1. Introduction

Man is essentially a myth-maker—using myths, folklore, fable and legend to contextualise the society in which he lives. Since goats have been a companion of man in the midst of his society since the dawn of civilisation, it is only logical that goats feature in oral tradition. Oral tradition that, over millennia, has been captured in the written myths, legends, epics, fable and fairy tales that we know today.

Many cultures have used goats in stories that portray various social constructs of their times. But here, it may be important to first digress and provide some analysis of the different types of folklore. Folktales, specifically, can be compared across cultures through recurring ideas or 'motifs' (dominant themes), which are defined by the political, economic and religious discourse of the time. Motifs may be situations, actions, events, characters or objects. Very often, the motifs are abstractions or models, the details being secondary and differing according to the variant: thus the typical situation (motif) of the hero outwitting the stupid giant or giants is the same whether the hero is a god, a prince, a young huntsman, a retired soldier or the Three Billy Goats Gruff. The purse of gold may be a jug of oil that never empties, the bird that lays the golden eggs, a plant that provides eternal life or the little goat that bleats causing a table laden with food to appear to the melancholic (but always attractive), ill-treated, stepsister [1]. It can be said that once we have identified the motif behind a folktale, we can then determine whether the goat has been used as a cursory object to creatively illustrate the story or whether the goat is the actual subject of the story.

Very often, in folktales, goats are used for creative illustration (sometimes the goat could just as well have been a pig, cow or chicken). But, other times, goats convey a specific meaning to the story and play a role in the motif that cannot be as accurately illustrated by another animal [2].

Folklore includes popular traditions, legendary ballads, local proverbial sayings, superstitions, old customs, folktales, legends, games, sports and nursery rhymes. Edward Clodd believed that the chief function of folklore was to explore the savage beliefs and practices underlying established religion. However, folktales also provide insight into human psychology through their underlying meaning [3].

Myth is generally distinguished from legends and fairy tales in that the former addresses cosmic themes such as the creation of the world, the beginning of life and the origins of civilisation. They may have arisen as embellished accounts of historical events, as a means to justify religious ritual or as metaphor or representation of natural phenomena [4]. Mythic stories are enacted on a supernatural scale: heroes of myth are gods and superhumans. Heroes of fairy tales and legends are ordinary men and women [2] although magic and fantastic animals, creatures or events may be involved.

Fables are a somewhat different genre. It is generally thought that fables were the creation of the slave Aesop who lived on the island of Samos in the sixth century BC. He won the favour of Croesus, king of Lydia, (and his freedom) by telling stories [5]. Aesop's fables have an industrious, efficient style, always ending with a moral. They are mainly for adult enjoyment and generally depict animals' instinctive behaviour in humanistic terms: the ant is industrious, the fox is crafty, and the tortoise is slow. Fable 'morals' or 'motifs' are centred on the notion that 'life is a constant struggle' and of 'survival of the fittest' [2].

Whereas fables are indifferent and realistic, the animals of European fairy tale are more compassionate and magical. Fairy tales are generally more optimistic and joyful than fables (although this is disputed by some and proven by some stories with unhappy endings [6]), are characterised by a lack of realism, are not believed by those who tell them and generally aim to teach [2]. Fables tend to depict animals as merciless and irresponsible, while fairy tales make them intelligent and benevolent. Fables tend to depict animals in terms of behaviourism, while the fairy tale reminds one of the analytical psychologies of Freud or Jung [2]. A distinction has been made that fairy tale and myth bring animals closer to men, while fables and satire, while seemingly doing the same thing, do the reverse; they are conflict-ridden and put animals in their place—as submissive to humans [2].

However, as we may all have experienced, the interaction with a live animal is a very fundamental and personal encounter, which largely negates the limitations often imposed by cultural perception. Thus, the goat, being an animal of unique intelligence, virility and behaviour, so close to man because of its usefulness and hardiness, has characteristics that have been described in the same way among different cultures. The goat is depicted as a symbol of fertility, abundance, aggression and good luck in many of these civilisations.

These cross-cultural similarities and differences are of interest but, also, the changes in how these animals are depicted over time warrant scrutiny. It is surely modifications in human and social conditions that create or cause these fluctuations in how goats are depicted because the character of goats is a genetic rather than an environmental manifestation.

This chapter investigates the role played by goats in the myths and folklore of various Ancient Near Eastern (ANE) cultures. To this effect, images in artefacts, and metaphors or direct reference to goats in texts (to be considered the primary sources in this study) from the area are studied. Secondary sources provided the context within which the sources occur. Where images and references to goats occur, their meaning and relationship to belief systems or their underlying 'motifs' within the ANE cultures are identified and discussed. Ultimately, this chapter aims to determine whether ANE cultures ascribed certain characteristics to goats that may still be applicable today.

2. Materials and methods

Although the array of domesticated animals is vast, this analysis investigates primarily goats (and similar species such as the ibex where relevant or where ambiguity occurs) in the myth, folklore and fairy tale (if these can be defined) of the Near Eastern cultures of Mesopotamia, Sumer, Akkad, Anatolia and Ancient Iran (Elam). The timespan that is covered by this chapter is approximately 3000 years. It is acknowledged that this is too vast an expanse to make specific inferences about the impact of the goat on the political, social or religious contexts within which goat symbolism may occur, nor can one surmise at the influence that this political, social or religious context makes on the way the goat is considered in society.

3. The domestication and use of goats (and other species)

It is believed that wild animals were herded into enclosures for killing to improve on the success of hunting—images depicting this practice have been found [7]. After a time, animals that exhibited certain characteristics that would make them predisposed to domestication became accustomed to this close contact. This close association between man and animal led to the domestication [8] of some species (but not others). These 'phases of domestication' can be categorised into 'wild', 'managed' and 'domesticated' [9] states.

Jared Diamond [10] has suggested several characteristics that would predispose certain species to domestication, and these include:

- High fertility and reproductive rate and a fast growth rate
- Animals that can be herded and handled without becoming aggressive
- Animals that are adaptable to a range of environments and feedstuffs that are not directly in competition with man's diet
- Animals with a docile nature that are not prone to flightiness or skittishness
- Animals that naturally move in herds, and submit to a pack leader

In all these characteristics, the goat excels.

According to Gilbert [11], wild sheep (Ovis) and goats (Capra) were the earliest livestock domesticated during the Palaeolithic to Neolithic transition (9000–7000 B.C.E.) in northern and eastern Mesopotamia. Pigs (Sus) and cattle (Bos) were predominantly domesticated in southern Mesopotamia. Later introductions included horses (Equus 2500 B.C.E.), donkeys (Equus 4000–3000 B.C.E.) and chickens (*Gallus gallus* 1500 B.C.E.).

Recent research [12] has placed the process of the domestication of goats in the region of south-western Asia, from the eastern Mediterranean to Turkey and from the southern Levant though south-eastern Turkey and northern Syria to the high Zagros mountain pastures and arid lowland plains of Iraq and Iran. The process of domestication spanned approximately 500 years—culminating around 8000 B.C.E. Zeder and Hesse [12] identified a distinct profile of young male goat slaughter and prolonged female survivorship (or delayed slaughter of females) in herds in the upland areas of northern Iraq and north-western Iran through the analysis of goat remains. Animal production involves the practice of keeping females for breeding and slaughtering males at a younger age for meat. This is in contrast to the remains of hunted populations, which clearly show a focus on fully adult males with females and young taken only occasionally.

The ancestors of the modern goat were potentially two species, *Capra falconeri*, and the Bezoar goat, *Capra aegagrus* [13], being the most cited candidate (*Capra hircus aegagrus* is still found in its wild form in the Zagros mountains of Iran and Iraq).

Most of the domesticated animals we know today originated in the Ancient Near East. These include cattle, goats, pigs, sheep, cats, dogs, ducks, chickens, geese, horses, donkeys and mules [8]. Their use for milk, meat, fat, leather, wool, hair, draught, transportation, manure [8], cheese [9], the storage of wealth [11], eggs [9], recreational (and possibly educational) zoos [9], drugs [9] and for religious use (sacrifice, extispicy and for maintenance of the religious complex) is documented.

Sheep and goats were kept in large flocks that belonged to the state, the temple or private owners and each was branded with its owner's mark (or that of the god for which it was intended). Clearly articulated contracts between owners and shepherds have been found. Shepherds often kept all the dairy products and some of the wool as compensation for their work. Their compensation could also include a share of the growth in the flock. **Figure 1** shows terracotta tablets inscribed with the records of goatherds and cowherds [14].

Wool (from sheep) and hair (from goats) were initially plucked (pulled or combed), but shearing was practised from the middle of the second millennium. Milk was obtained from cows, sheep and goats (camels and water buffalo were also used for this purpose). Yoghurt, cheese, butter and ghee were produced. Butter was made by churning the milk in a narrow-necked jar [7] and rolled with the foot or rocked [9]. Since fresh milk spoiled rapidly, it was often only used in medicines, which would be made fresh and used immediately. **Figure 2** shows a cylinder seal from Mari with a typical agricultural scene. Many such seals have been found, which may indicate the economic activity in which the owner of the seal may have distinguished him (or her)self.

Figure 1.
Terracotta tablets inscribed with the records of goatherds (left) and cowherds (right), unearthed at Lagash, Mesopotamia, and dated to 2250–2175 B.C.E. (housed in the collection at the Louvre, Paris: [17]).

Figure 2.
Cylinder seal from Mari (3000–2000 B.C.E.). Top register showing milking scene, bottom register with goats, hero figures and eagle with lion-head.

Figure 3.
Stone panel from the central palace of Tiglath-Pileser III. Neo-Assyrian, 730–727 B.C.E. Nimrud (ancient Kalhu), northern Iraq (housed in the British Museum).

Figure 4.
Goat skins used as flotation devices. Stone panel from the central palace of Tiglath-Pileser III. Neo-Assyrian, 730–727 B.C.E. Nimrud (ancient Kalhu), northern Iraq (housed in the British Museum).

Although horses were important in battle, goats were often taken as booty (**Figure 3**) and inflated goat skin bags were used in warfare as flotation devices (**Figure 4**).

4. Goats in the texts, art and imagery of the ANE

Primary sources available to the modern scholar of the ANE cultures include objects, architecture and written texts that have survived environmental extremes. This investigation seeks to determine whether, if goats appear in these material artefacts, there is some indication that they were considered more than merely useful as a livestock species with utilitarian value but also as an object in myth, legend or fairy tale.

4.1 Goats in ANE literature

Several texts excavated from ancient Mesopotamia refer to animals in general [15]. These can be categorised into the following types:

- Wordlists
- Omen collections (omina) (including guidelines involving extispicy and apotropaic rituals)
- Myths
- Short, functional fables, with no expressed moral
- Personified animals in longer narrative fables, debates or contests
- Mentioned in propagandistic literature as being subjugated, hunted, collected, etc. by the king.
- The consumption of animals (as well as recipes)
- In humorous and ironic anecdotes.

For several of these categories, examples were found in a collection of Sumerian inscriptions [16, 17]. If evident, this categorisation is shown and possible explanations for the texts are provided in parentheses.

- Page 99. 3.111—'Although it has never gone there, the goat knows the wasteland' (Category: ironic anecdote. Possible explanation: a goat has instinct to survive in the desert, or a goat is intelligent—this perhaps relates to the idea of someone having a 'gut feeling' about something)
- Page 101. 3.123—'May you hold a kid in your right arm and may you hold a bribe in your left arm' (Category: ironic anecdote. Possible explanation: the kid can be brought as an offering—to request a favour from the god—but if the offering does not work, you also can back it up with a bribe to the priest who can implore the god on your behalf. This is interesting, since it suggests that people were quite aware that priests could 'bend the rules' if requested/motivated to do so).
- Page 106. 3.153—'The goat spoke in the manner of a (wise) old woman, but acted in the manner of an unclean woman' (Category: ironic anecdote. Possible explanation: goats are considered intelligent, but they are bawdy and eat everything including unclean things, which make them unclean. Here, the sexual nature of the goat is identified).
- Page 128. 5.55—'A lion had caught a helpless she-goat' (and she said), 'Let me go and I will give you my fellow ewe in return.' 'If I let you go, tell me first your name!' The she-goat answered the lion, 'You don't know my name? "I am

cleverer than you" is my name.' After the lion had come to the sheepfold he roared, 'I released you!' She answered from the other side, 'You released me, you are clever,… the sheep are not here!' (Category: narrative contest. Possible explanation: again showing the intelligence of the goat. Alster [16, 17] suggests that this is the Sumerian fable that resembles closest to a true 'Aesopian' one. The Sumerian fables provide a definite answer to the much discussed question, whether or not the fable as a genre was invented by the Greeks. Although the genre is now proven to be considerably older than the Greeks, it does not necessarily mean, however, that it was first invented in Mesopotamia).

- Page 167. 8.Sec.B4.—'Wearing a long beard like a goat' (Category: humorous anecdote. Possible explanation: merely a physical description of a 'goatee' beard)

- Page 167. 8.Sec.B5.—'A goat is the gift of a large kid' (Category: ironic anecdote. Possible explanation: goats can reproduce at a very young age—as young as 4 months).

- Page 167. 8.Sec.B6.—"A goat speaks as follows to another goat: I also toss my head." (Category: ironic anecdote. Possible explanation: animals of the same species are likely to behave in the same way. Or, people of a certain character can identify with another person of the same character, that is, it takes one to know one).

- Page 169. 8.Sec.B8—'When the wolves were pursuing a goat, it turned around, and its feet stumbled over its own feet' (Category: humorous anecdote. Possible explanation: a goat is 'tripsy-footed'?)

- Page 171. 8.Sec.B28.—'A fox spoke to a goat, "Let me put my shoes in your house!" The goat answered, "When the dog comes, let me hang them on a nail!" The fox answered, "If the dog stays like that in your house, bring me my shoes. Let me not stay till midnight!"' (Category: narrative contest. Possible explanation: this dialogue again suggests the intelligence of the goat in being able to outwit another creature).

4.2 Goats in ANE artefacts and imagery

Goats are evident in the mythology of ANE as shown in various imagery. Two types of artefacts are available to the art historian [18]: objects in the round and two-dimensional objects. Objects carved in the round include figurines, theriomorphic vessels and weights. Figurines and animal-shaped vessels were often rendered in baked clay and rhyta (singular rhyton) in metal. Many of these objects were used in the temple complexes as votive objects (being brought as tribute to a god), as apotropaic figures (buried underneath the floors of buildings to ward off evil), were used during religious ceremonies or were used to weigh the produce brought to the temple by the citizens who formed part of the distributive temple economies. Two-dimensional objects included low-relief stelae, perforated panels in stone or ceramic, tablets and hollow carved stamps or cylinder seals. These objects had decorative use in temple architecture (stelae and panels). Tablets were used as administrative tools (to record numbers of livestock or produce), to train scribes, to capture true literature and royal inscriptions or to write letters. Stamps and cylinder seals were personal signatures used to identify objects or show ownership [19].

A general search for images of goats on ANE artefacts was undertaken. This was done through a search of archaeological research papers and books, which either provided references to relevant artefacts or showed photographs or tracings of artefacts. Where these items were considered important but the images were unclear, higher quality images were sought. Museum collections that have been made available for public viewing via the Internet were also examined.

This was followed by a classification and comparison of the images of the various artefacts.

To provide structure to the comparison, images that depict a similar theme or 'motif' were grouped. To this effect, a method was sought to provide some meaning to a classification. Whereas some scholars have argued that the depiction of animals in Mesopotamian art illustrates the start of religion, others have argued that animals provide merely a symbolic representation of the world as the artist saw it. However, it must be agreed that there must be multiple levels of meaning. To this end, the system provided by Root [20] to classify the use of animals in art is used here. An approximate seriation within each group was also undertaken (although it is conceded that the chronology provided by scholars commenting on these pieces is assumed correct, which may not necessarily be the case). The groupings made are discussed below.

4.2.1 Group A: goats as vehicles for experimentation with abstraction and decorative compositional dynamic

The goat lends itself to abstraction and decoration with its curved horns and upturned tail—this is especially the case in the use of the goat (or ibex) in the art of Ancient Anatolia. The depiction of goats in Mesopotamian art is often stereotypical, allowing one to assume that sketchbooks were used and artists trained in standard doctrines. In the artefacts of this group, the artists have attempted to depict goats in their most recognisable form (**Figures 5** and **6**). These include full profile; walking, or standing with their horned heads shown from the side; or lying down. Mostly, single animals are shown. Where goats are not shown entirely, they are suggested by parts of their body, such as horns in the goat-head rhyton (**Figure** 7).

Figure 5.
Elamite mountain goat from Susa, 3100–2900 B.C.E. (housed in the Louvre, Paris).

Figure 6.
A baked clay pot, sporting a goat, from Umma which is dated to the Amorite dynasty of the nineteenth–eighteenth century B.C.E. (housed at the Louvre, Paris: [17]).

Figure 7.
(a) Burnished pottery rhyton in the form of a goat's head from Iran (Elam) that is dated to 1000 B.C.E. (b and c) Earthenware goat rhyton dated to between 1000 and 2000 B.C.E. (All housed at the Sankokan University, Japan).

Although the objects and images shown here have been placed in the category of 'abstraction and decorative composition' because they are particularly striking, some inferences regarding their symbolism can be made. Firstly, these objects may have served as votive objects, as apotropaic figurines or as libation vessels (as part of a ritual in which characteristics of the animal depicted are expected to be imbibed by the drinker). Furthermore, it is interesting to note that in both objects of **Figures 5** and **6**, the goat is shown with its right leg foremost. As Green [21] suggests in a paper dealing with apotropaic figurines (that lead with the left foot), this may be the beginnings of the custom of entering a holy place with the right foot first.

4.2.2 Group B: goats as players in specific rituals of human society

Generally, ancient Mesopotamian gods were human in form. But both demonic and virtuous creatures were often depicted as animal-human hybrids. Specific animals were associated with certain gods and often became their symbols [9]. Thus, the dog was associated with Gula, the god of healing; the lion-snake-eagle with Marduk and the goat-fish with Ea (or Enki) [9]. Hatziminaglou and Boyazoglu [22], however, state that goats were sacred to Marduk and is often pictured accompanied by a goat (unfortunately, they do not reference this statement and are perhaps confusing images of Ea with Marduk).

Goats were an important element of divining the future [9, 23]: firstly, through unsolicited omens or observations (as from the omen list 'If a City is Situated on an Elevation' where both domesticated and wild animals were used) and secondly, through solicited omens through extispicy (reading of entrails) or merely a ritual involving an animal that did not necessarily involve its slaughter.

Where a god had an associated animal, as is the case, for example, with Ea or Enki, worshippers could bring tribute to a god either by the live goat itself or in the form of their animal statue (these votive objects could be clay, gold, bronze and/or sliver), or in the form of a figure bringing the goat tribute. Images and figurines depicting this practice (shown in **Figure 8**) are referred to by modern scholars as 'goat bearers' (British Museum). It is interesting to note the abundance of the 'goat bearer' imagery over several cultures (Sumerian, Anatolian, Assyrian and Elamite) and over a long expanse of time. Further examples can be found in the work of Marchesi and Marchetti [24], which shows more than five examples from several Early Dynastic Mesopotamian sites.

Comparison of these images reveals that all the goat bearers have goatees or beards and all but one (from Zincirli carrying the goat on his neck) bear the goats in his arms. This may be important since, as Breniquet [18] mentions, very often the animal used to represent the god in visual material or in association with him shares the facial features or appearance (physiognomy) and behaviour of the god. The placement of the animal with the god renders the reading unequivocal and is part of the essence of the god.

According to Heinsohn [25], tribute was not so much to the god but to the priests themselves who managed the temple complex, as thanks for the role played by the priest in the act of sacrifice (it could be dangerous), as well as for absorbing the guilt for the killing itself (an act created to calm an emotionally traumatised community—initially following a cataclysmic event). It seems that ritual sacrifice was abandoned when further cataclysmic events no longer occurred and thus sacrifice (used to placate an anxious community) was no longer necessary. At this point, votive objects may have replaced tributes of live animals.

Although modern scholars refer to these images as 'goat bearers' (British Museum; [16]), it is not clear from, nor mentioned in, the literature whether these statues represent worshippers, priests or the god Ea (Enki) himself. Where the goat bearers form part of a scene where other tribute is being brought, it seems clear that the goat bearer is indeed a worshipper or tribute-payer; however, where the images are solitary, the identity of the bearer is ambiguous.

Figure 8.
(a) Plaque from Nippur, temple of In'anak (early dynastic I (3000–2330 B.C.E.)) [27]. (b) A worshipper carrying kids from Susa, middle Elamite, thirteenth century B.C.E. (housed in the Louvre, Paris: [17]) (c) from the citadel gate of Zincirli 900–800 B.C.E. ([26]: Plate XV) (d) apotropaic protective spirit guarding entrance to private chambers, from Nimrud (ancient Kalhu), northern Iraq, neo-Assyrian, 883–859 BC. His curled moustache, long hair and beard are typical of figures of this date. Carrying goat and ear of corn (housed in the British Museum).

Whole herds of animals were kept for their gods by their temples and branded with their marks [9, 23]. One can assume that when live animals were replaced by votive objects as tributes, then, these same herds would not have been used as sacrificial animals, but as a means to support the attendants of the temple complex and to redistribute to the community.

Animals were also used as the recipients of evil transferred from a human host, what we know today as the 'scapegoat' ritual [23]. This 'transferral' of the evil (whether bad luck or an illness) could be achieved through the patient handling the animal, by the performance of a ritual and then letting the animal go (into a wasteland or a river), by the performance of a ritual and then slaughtering the animal and burying it (or discarding its remains in a river or wasteland, or by splitting the animal in half and passing between the two halves) or by the patient spitting on it, or eating it, or being covered with it (its blood), or by merely having the animal in proximity to the affected person. The scapegoat ritual was often used by the military and sometimes by cities to remove the scourge of a plague [27].

Animal figurines could be used for scapegoat rituals or as apotropaic figurines that were buried under the floors of domestic dwellings, barracks or temples to ward off evil [21]. Elaborate rituals describing an array of figurines to use (including the goat-fish), and the numbers of figurines that are required, have been documented [21].

4.2.3 Group C: goats as signifiers of specific political/social ideas of human society

The name 'Enki' literally means Lord, en, of the earth or the netherworld, ki, the patron deity of the apkallus (fish-men), who lived in the underground sweetwaters, the Abzu (Sumerian) or Apsu (Akkadian) [28]. In this imagery, the god Enki/Ea was associated with the 'Sacred tree' (often erroneously called the 'Tree of life').

The Anzu/Apsu was considered, a not altogether unpleasant intermediary place, between the earth and the netherworld (almost literally the place of spring water from which life springs). This idea may be suggested by the imagery of the goat in the tree (as shown in **Figure 9**). This was possibly a libation device, and used as temple furniture.

What is important to note here is that although the goat in the tree represents a certain idea known to the community (Enki and the Sacred tree), and goat imagery is used in furniture or libation devices, the animals themselves were not worshipped [18].

4.2.4 Group D: goats as figures in cosmic contests and 'performances'

Two examples of the use of goats in this manner were found.

Figure 9.
The lapis-lazulli goat buck in the tree from the Royal Cemetery at Ur, belonging to the Uruk period c 2600–2500 B.C.E. was probably temple furniture—possibly a stand (housed in the British Museum).

4.2.4.1 Ishtar or the mistress of the beasts?

In Anatolian art and folklore, a 'mistress of the beasts' occurs, often associated with the hunt. This mistress (and sometimes master) is associated with a feline (usually a lion) and a wild goat, ibex or gazelle [29]. This goddess may have been Cybele (or Dali in Armenia) and may also be related to the goddess associated with the hunt of the Caucasus (Georgians who are believed to be descendants of the Hittites) who is always associated with goats, ibex or turs (*Capra cylindricornis* or *Capra* [ibex] *caucasica*) [30]. However, representations showing similar iconography (a female figure associated with goats and lions or hunting or warfare) are attributed by some scholars as Ishtar: the goddess of warfare and sexuality. Some of these artefacts are shown in **Figures 10** and **11**.

4.2.4.2 Enki/Ea

The myths that incorporate Ea (or Enki) are of particular significance here since the primary sources reveal him to be associated with the goat. The spouse of Ea was Damkina and his cult centre was Eridu. Marduk was Ea's son. During the Kassite

Figure 10.
Goddess seated on a goat over two lions from Kultepe, Anatolia, from the Middle Bronze Age, 2000–1595 B.C.E. [37].

Figure 11.
Queen of animals feeds her wild goats, thirteenth B.C.E., from tomb III, Minet el-Beida, harbour of Ugarit, Syria. Lid of pyxis (round box with lid) (housed in the Louvre).

period, Marduk was elevated to the top of the Babylonian pantheon and his cult centre was Babylon [19].

Ea plays a role in several of the Mesopotamian myths. In the Epic of Gilgamesh, where aside from being mentioned as one of the gods that have made Gilgamesh wise, he is the god that breaks rank and warns the human Ut-napishtim (whom Gilgamesh seeks to reveal the secret of eternal life since Ut-napishtim survived the flood and has been made immortal) of the impending flood sent by the gods to destroy man. This role of Enki is again shown in the myth of Atrahasis, the Flood story. Here too, Enki warns man about the flood and gives him instruction to build a boat.

Enki plays a larger role in the Epic of Creation. Here, it is explained, in the beginning, there were only two gods, Apsu (who represents the primordial waters under the earth) and Tiamat (the personification of the sea). They beget four generations of gods, who become noisy and unbearable. Apsu decides to put an end to their troublesome ways, but the plot is discovered by Ea 'who knows everything'. He puts Apsu and his evil vizier, Mummu, to sleep and then slays them. He then assumes the belt, crown and mantle of radiance, takes over the dwelling place of Apsu as his own, and there, with his spouse Damkina, creates Marduk. Marduk then proceeds to win all sorts of fantastic battles with the encouragement of his father, Ea, and is finally made the king of the gods. One of Marduk's actions is to create man (to do the work of the gods so that the gods can be at leisure).

In shorter myths, again Ea plays a role. Mostly as the 'one who knows everything'. These include the myth of Adapa (a priest of Ea in his cult temple at Eridu); the Epic of Anzu; the Descent of Ishtar to the Underworld and the myth of Nergal and Ereshkigal.

The relief and apotropaic figures below (**Figure 12**) depict the god Enki (Sumerian) or Ea (Akkadian). Enki was the god of productivity [31] and freshwater streams, springs and lakes, as well as the abzu (or apsu – the subterranean freshwater ocean on which the earth supposedly floated; [8, 31]) and, in this guise, was symbolized as the (or a) fish [9].

Enki was also associated with wisdom, science, craftsmanship and magic and this part of his nature was symbolised by a goat [9]. Several stone reliefs and cylinder seal impressions were found showing goat bearers, a goat in the scene, or a goat shown below the god with water or fishes also represented.

Figure 12.
(a) Enki represented as a fish-man in stone relief and (b) as an apotropaic figure (source unknown).

This 'dual' nature of the god ultimately resulted in the use of the symbol of the goat-fish (literally 'Carp-goat') for the god Enki or Ea [32] (Akkadian suḫurmašû; Neo-Sumerian Selekuid). Figures of this deity are named in certain apotropaic (averting evil) rituals [21]. Although no Assyrian monumental art of this deity has been found, the requirements for their manufacture (dimensions, gold leaf required etc.) are alluded to in Nimrud texts for a temple of Nabu at Kalhu [32]. Artefacts representing this deity are shown in **Figures 13–15**.

The boundary stones each show celestial objects (stars and crescent moons), monuments or temples and deities. On all three boundary stones, the goat-fish (curved or twisted horns and hooves) can be clearly distinguished from the dragon (which is generally depicted with straight horns, talons or claws and a snake-like body).

Similarities between the renditions of goat-fish include one front leg bent back and the other forward (slightly bent and lifted) (although both left leg and right leg forward can be seen), cross-hatchings used to indicate the scales of a fish, twisted splayed horns (except the foundation figurine, which may have had horns that are now broken off). All the boundary stones' goat-fish are without beards (goatees).

Figure 13.
(a–c) Mesopotamian boundary stones of the Kassite era, 1600–1150 B.C.E. [38]. In (a) the goat-fish can be seen on the bottom right, in (b) in the top register, and in (c) in the top register.

Figure 14.
(a) A goat-fish from Assur (housed in the Lowie Museum of Anthropology, University of California, Berkeley: [24]: Plate XV). (b) Foundation figurine of a suḫurmašû, from Assur (Of beige sun-dried clay and had an original coating of black wash). On the left side of the figurine is a one-line inscription that reads 'Come in, favourable hearing and compliance!' ([32]: Plate V).

Figure 15.
A cylinder seal, from the late Babylonian era, possibly depicts a worshipper before divine images, including the suḫurmašû ([32]: Plate X) (housed in the Brooklyn Museum).

5. Discussion

From the preceding source material, several inferences relating to the perception of ANE societies regarding goats can be made. The images shown by the material artefacts, in which goats are portrayed, possess a decorative, symbolic, religious or mythological motive. It is clearly discernible when goats are merely portrayed as a livestock species. These include the goatherd tablets, the agricultural scene in the cylinder seal from Mari, and the battle scene where goats and sheep probably represent booty. It is clear from the (quantitatively) numerous depictions of goats in domestic scenes that goats played an important role in the household and temple economies of the time. In these scenes, it is clear that the goat represents itself and no underlying 'motif' or meaning is intended.

Also, generally, goats are rendered very realistically (long, straight or curved horns and upright tail) and in their characteristic attitudes since they were a familiar sight in everyday life. This can be expected, since, in general, variations are most often found in animals that the artists were not as familiar with (such as elephants or giraffes) [33].

The animal-animal hybrid, the goat-fish, representing Ea or Enki, is most probably the basis of the constellation Capricorn. According to Roy [34], all evidence points to the Sumero-Akkadian astronomer priests as the makers of the constellations as we know them. Mesopotamia is found on the required latitude to have seen all the constellations (some are not visible from the southern hemisphere), the position of the stars at that time (3000–2000 B.C.E.) would provide a perfect fit for their observations, and the constellations themselves match almost every deity in the Mesopotamian pantheon, including the goat-fish of Ea, now known as Capricorn (so-named by the Greeks [35]).

In the myth of the creation of the world, Marduk, aside from creating man, also defined the calendar, setting up the Zodiac and the sequence of celestial events that would signify the changing seasons [34]. Star lists in cuneiform have been found, detailing these constellations and their positions relative to each other. The positions of the stars were used for navigation, divining the future and as a means to map boundaries (constellations often appear on boundary stones). Gurshtein [35] agrees that the goat-fish constellation has Sumerian origins. It is interesting to note that the goat-fish icon is called a suḫurmašû [32], whereas Capricorn is called SUHUR.MAS in tablets from Uruk [36].

The use of goat imagery in the artefacts described show the goat in association with the god Enki or Ea, and is used in libation vessels, temple furniture, plaques and votive objects used in the worship of this god. But, it should be noted that it is not the goat that is worshipped.

In literature too, although the goat is associated with the god Enki or Ea, it is the god in his human form that acts in the myths—not the god in animal form. The goat is used to represent the god in visual material or in association with him. This finding is corroborated by Breniquet [18] who states that in iconography, the animal is closely related to the god and acts as his substitute. Of more interest is her statement that the facial features or appearance (physiognomy) and behaviour are also those of the god. The animal is not merely an accessory, enabling the illiterate to interpret the portrayals; the placement of the animal with the god renders the reading unequivocal and is part of the essence of the god.

The Sumerian texts [16, 17] reveal that goats were considered intelligent, wise and cunning. The genetic characteristics of goats such as their ability to reproduce at a young age, their physical appearance (goatees) and their bawdiness are also alluded to in everyday proverbs. Goats are thus used as metaphors for intelligence, mischievousness, virility and fertility.

In each of the Mesopotamian myths described above, Ea or Enki plays the role of the wise god, offering solutions to a myriad of problems. He is described as the god 'who knows everything' and 'the Lord of intelligence'. In the myth of Adapa, it may be suggested that the role of Ea 'who knows everything' is to show man that it is better not to have eternal life. Alternatively, here Ea could be assuming the role of the 'trickster' often ascribed to goats in later myth and alluded to again in the Aesopian-type dialogues with the lion and the fox in the Sumerian inscriptions shown above.

In the Descent of Ishtar to the Underworld, the role of Ea in creating a 'playboy' may allude to the sexual nature of goats. And again in the myth of Nergal and Ereshkigal, the story has an overtly sexual nature.

It is suggested by Root [20] that the use of rhyton as libation vessels originated in the notion that imbibing liquid from a vessel resembling one of the more vital animals would magically convey some of the animal's own vitality to the drinker. It is perhaps these qualities of intelligence and fertility that worshippers intended to obtain when drinking from rhyton shaped as goats or from libation devices decorated with goat motifs.

6. Conclusion

The depiction of goats in the art and literature of the Ancient Near Eastern cultures provides us with a means to understand man's attitudes towards goats during this period in time. From the resources used, it is clear that goats fulfilled an immensely important utilitarian function. The heritage of Enki (Ea) as the constellation of Capricorn is significant. The use of goats in ritual and symbolism has provided us with many motifs related to goats that are still in use today: these include the motifs of fertility, intelligence and craftiness. From all accounts, Enki (Ea) was a benevolent god, always available to solve problems, and often assisting mankind to avert extinction. The imagery associated with Enki/Ea, as in the sacred tree, the sweet waters, the apotropaic suḫurmašû and ultimately the goat, communicates Enki as a symbol of life and an averter of evil.

These are powerfully hopeful and positive images.

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Chapter 2

The Goat Sector in Spain: Situation, Local Breeds, and Production Systems

Ana Guerrero, José Alfonso Abecia and Carlos Sañudo

Abstract

Goats throughout history have been adapted to the different orographic and climatological conditions of diverse continents and regions, in which they have been widely spread. Consequently, this species has developed different aptitudes and specialties (meat, milk, hair, etc.) depending on the specific necessities that are covered. This specialization and its geographical conditions have created a great variety of breeds that have been adapted to different production systems. This chapter compiles the evolution and present situation of the goat sector in Spain and the perspectives for its future, describing the most important production systems currently used for different aptitudes in the country (dairy and meat) and compiling the characteristics of the main national autochthonous breeds.

Keywords: dairy, meat, census, morphology

1. Introduction

Goats are one of most antiquated domesticated species in the world, and have been associated with human settlements for at least 10,000 years [1]. The huge capacity of adaptation that the species presents to different and sometimes really harsh environmental conditions (such as desert locations) has benefited their constant increase and spread around the world, being the species (together with the dog) with the highest world diffusion [2]. This is observable from the continuing increment of its census population over the last century [3].

Due to its versatility and the possibility of being reared in different production systems, goats have different functions in developing and developed countries, being an important resource for food supply for the former and focused mainly on intensive production and elaboration of products with different qualities for the latter [4]. However, in all regions, goats have kept the function of maintaining the rural population using available local resources, being a resilient species that has become a source of income that has sustained life in rural areas, and with adequate management can help to maintain sustainability in diverse regions [5].

However, in many countries the species is highly dependent on external aids (such as economic supports) to guarantee its progress. So, the increase in information that provides the specific and current situation of the species in diverse contexts will help to design specific strategies to improve animal production and the quality of life of goat producers around the world.

2. Materials and methods: research methodology

In this chapter, documentary research was carried out to compile and analyze the main available official data regarding the goat sector in Spain. The main sources of information came from official statistical databases (the Spanish government's Ministry of Agriculture and Fisheries, Food and Environment, the Statistical Office of the European Commission (Eurostat), and the Food and Agriculture Organization of the United Nations database (FAOSTAT)). Also, technical reports from various journals and research from scientific articles and books were reviewed, as well as data generated by the authors from their professional careers and own experience.

3. An overview of the Spanish goat sector's current status

3.1 Census, distribution, and husbandry

The last available goat census shows that the world goat population in 2016 already exceeded 1 billion (1,002,810,368 heads) [3]: 55.4% of the census was located in Asia, 38.7% in Africa, 3.8% in America, 1.7% in Europe, and 0.4% in Oceania.

Spain had approximately 3,088,000 registered heads in 2016 (state official census), representing 24.9% of the total European Union (EU) goat census (12,392,000 heads), occupying the second position in the ranking of countries with the highest goat numbers in the EU after Greece (3,990,000—32.2%) [6].

From the total number of Spanish goats, the majority (74.69%) is classified as reproductive females and only 3.23% are reproductive males; the rest of the livestock census are animals younger than 12 months (771,628 heads).

With respect to census evolution, as compiled in **Figure 1**, over the last decade the number of animals has presented yearly oscillations between 1 and 7%, mainly associated with differences in the female census (**Figure 2**). The total census increased considerably from less than 1.8 million heads (previous years to 2007) to exceed the 3 million individuals in 2016/2017 [6], increasing all the cited groups, especially those from reproductive females, which increased from 1.3 million in 2006 to almost 2.2 million in 2007; the number of reproductive males is quite constant over the studied period in the figures.

Related to evolution over the last century (**Figure 3**), the census presents several cyclical oscillations, showing nowadays a similar number of heads to those registered at the beginning of the 1960s. A peak in the years that followed the incorporation of Spain into the EU (1986) can be seen; the oscillation on the census was probably related to the way the data were compiled according to the new European statistics.

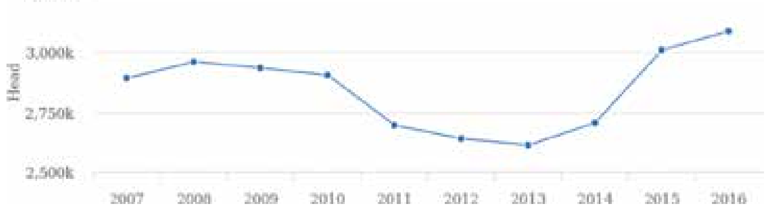


Figure 1.
Evolution of the goat census in Spain (2007–2016). Source: [3].

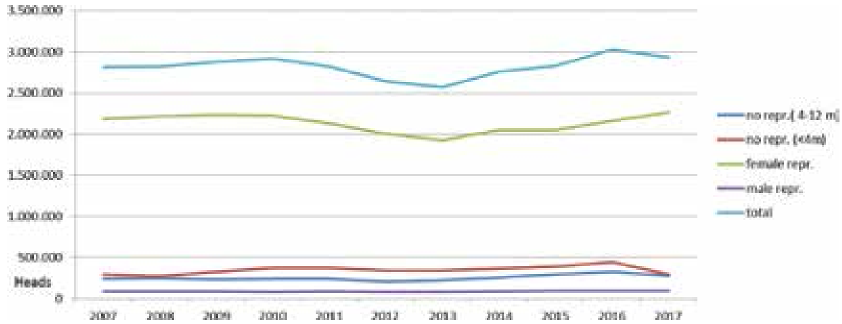


Figure 2.
Evolution of the goat census in Spain segmented by type of animal (2007–2017). Source: [6].

Figure 3.
Evolution of the goat census in Spain (1961–2016). Source: [3].

In Spain, the distribution of the goat census is not homogeneous throughout the country, for example the south (Andalusia) presents the higher concentration of heads (37.7%), followed by the center-east (Castilla la Mancha) (15.4%) and the west (Extremadura) (10.4%), followed by the southeast region (Murcia) (9.0%) and the Canary Islands (7.4%). Castilla la Mancha is the region with the greater increment of census during the last decade, which almost duplicates the presence of goats from 314,941 to 614,879 heads, ranking itself as the first region with the higher number of reproductive females for meat production (38.0% of the total census). However, the south is the region with the highest percentage of dairy goat females (39.0% of the total on this category) [6, 7].

There was a small decrease in the number of farms between the years 2010 and 2012, from 68,789 to 65,981, and afterwards the number of farms increased progressively until 2016, when it reached a total of 78,756. The number of goat farms at the beginning of 2017 was 77,218 [7]. The evolution of the different farms depends on their productive orientation. While the number of dairy farms has decreased by 26.4% (from 9150 to 6733), the other farm categories (meat and dual purpose) have increased (11.2% and 17.3%, respectively), where in 2017 the total number meat farms was 55,954 and those focused on dual-purpose products reached 10,071 farms. Also, the number of fattening farms has decreased by 18.1% from 776 to 635 during the period 2010–2017 [7]. In 2017, of the total number of farms, 0.82% are dedicated to fattening, 8.72% to milk production, 13.04% to double production (dual purpose), and the majority are focused on meat production (72.46%). Those percentages represent 95.04% of the total registered farms; 5% of farms are not officially classified according to their aptitude.

In 2016 the number of live animals exported was 1,112,240, with the main destinations being Libya (69.02%) and France (15.76%). Related to the imports of live animals, from a total of 297,329 heads, 88.75% came from France [6].

3.2 Meat production sector

Due to the morphology the species (amyotrophic) has not a noticeable meat aptitude; however, there are some breeds with certain muscular development, and consequently they are considered as meat breeds, where their main purpose is to produce kids for slaughtering [2].

The main meat types produced in Spain are:

1. Kids or suckling kids (called *cabrito*): animals that are reared by their mothers and weaned and slaughtered between 20 and 60 days of age with live weights from 5 to 14 kg.

2. Chevron (called *chivo*): males slaughtered between 4 and 6 months old with live weights from 20 to 45 kg; comparatively, production is much lower than kids and usually the consumption of this kind of meat is limited to several ethnic minorities present in Spain.

The world production of goat meat (2016) was estimated by FAOSTAT at 5,621,333 metric tonne (Tm) [3]. The majority is produced in Asia (73.18%), followed by Africa (22.14%), and America (2.26%) according to the previous census distribution. In Europe, production was 98,934 Tm, representing 1.76% of world production. In the cited census, Russia is included by the FAO as a European country, reaching the second position on meat production (18,567 Tm—18.77% of European production) after Greece (21,785 Tm—22.02%). Values for Spanish goat meat production are located after France, Albania, and Romania, representing 9.17% of European production [3].

During the period 1990–2005 according to FAOSTAT, in Spain for each kg of goat meat, between 14 and 16 kg of lamb meat was produced [1]. Production of goat meat for that period ranged from 14,000 to –16,000 Tm versus 211,000 to 232,000 Tm lamb meat produced [3]. The evolution of goat meat in Spain over the last few decades according to a Spanish official database is compiled in **Figure 4**.

Nowadays the ratio has changed to 11.89 kg of ovine for each kg of goat meat produced, according to national data on goat and lamb meat production at 9800 and 117,000 Tm, respectively, in both species (2016). Goat meat production had an increment of 7.3% related to its production on the previous year (2015) according to

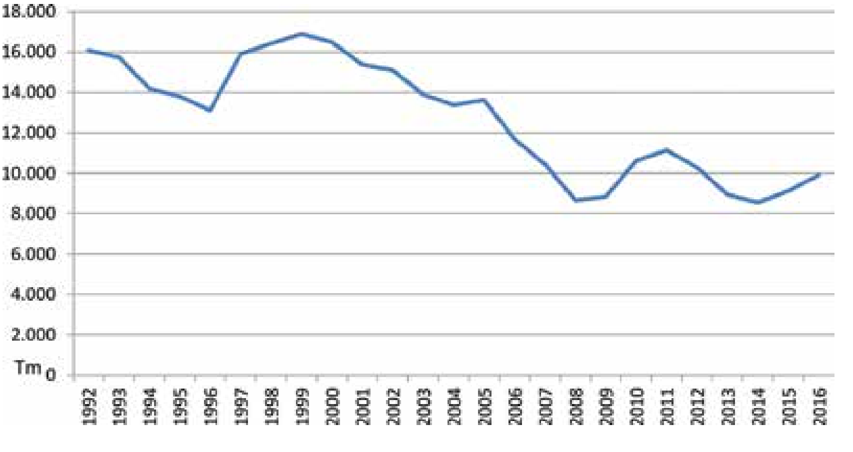


Figure 4.
Evolution of goat meat production in Spain (1992–2016). Source: [7].

a national database [7]. Eighty-one percent of slaughtered animals came from the commercial category kid, 4% from chevron, and 15% from adult animals.

South (Andalusia), Canary Islands, southeast (Murcia), and northeast (Cataluña) are the four regions where more than 60% of the total animals were slaughtered (1,296,981 heads—9842 Tm of goat meat, **Figure 4**). Almost one-quarter of goat meat produced was exported (2244 Tm) and the main destinations were inside the EU (36.7% France, 22.0% UK, and 9.4% Portugal) [6].

In 2016, goat meat represented 2.9% of the total commercial value of exports and imports of small ruminants (which included live animals and fresh and frozen meat from goat and ovine). The values of exportations reached 8.61 million euros and importations represented 1.98 million euros [7].

Total production of 5.6% (519.6 Tm) is commercialized as organic production certification, 66% coming from Andalusia and 26% from Castilla la Mancha. Also, the incorporation of new logotypes as "autochthons breed" (**Figure 5**) is a current initiative applied in the sector to improve commercialization and consumer information [7]. In this sense, there are two types of labels: one common for any species and another label specific for each species.

Spanish data concerning only goat meat consumption is not available because in the national reports values are presented with ovine meat. The consumption of small ruminant meat has declined progressively during the last decade, decreasing from 2.67 kg/person/year in 2006 to 1.55 kg/person/year in 2016 [6].

For a promising future for the goat sector in Spain it would be necessary to implement consumer education using awareness campaigns [9]. Those activities would have as foal increase sensibility about goat species and encourage the consumption of this type of meat, which currently is frequently associated with special occasions. Effective strategies to promote the national goat sector would be to transmit to the general public the characteristics, social values, and functions that this species has on national territory, as well as the development of diverse national or international strategies, along with the support and promotion of different products according to their quality, characteristics, and origin.

3.3 Dairy sector

Related to milk production, the situation is very different to meat production. Thus, there are some really specialized breeds with remarkable milk yields.

Figure 5.
Logotype "autochthonous Spanish breed: for goat and general". Source: [8].

Fresh whole milk around the world was estimated by the FAO at 1,526,211,600 ton in 2016 [3]. Again, the majority of production is found in Asia (52.7%) and Africa (25.7%). Europe represents the third continent (with 2,537,787 Tm; 16.63%), an important value compared to the lower census of other regions such as America. This reflects the great potential and production of European dairy breeds, as will be shown in the followig paragraphs.

At the European level, France was first with goat milk production at 603,040 tons, representing 23.76% of European production, followed by Spain (410,977 tons; 16.19%) and Greece (384,903 tons; 15.17%).

According to data from the FAO summarized in [1], goat milk production in Spain in the period 1990–2005 was higher for goats than ewes with 473 versus 320 million liters in 1990; in 2005 it was 469 versus 409 million liters. For each liter of goat milk produced there were between 0.67 and 0.87 liters of ovine milk. This shows the traditional good milking aptitude and use of goats in the country. Estimated milk production by lactation for some dairy Spanish breeds is shown in **Table 1**. Currently, national data on goat and ewe milk production show that in 2016 there were 480 and 560 million of liters, respectively, for those species, which modified the previous ratio to 1.16 liters of ovine milk for each liter of goat milk. It was in the year 2009 when the production of ovine milk exceeded goat milk yields, due to restructuring of the systems, replacing in large scale autochthonous ovine dairy breeds with other more productive breeds such as Assaf or Lacaune, and modifying the productive profile [7]. However, since 2012, as shown the **Figure 6**, goat milk production has increased.

South (Andalusia: 41%), center-east (Castilla la Mancha: 17%), Canary Islands (12%), and southeast (Murcia: 9%) are the four national regions where goat milk is produced. It is remarkable to see that the volume of goat milk obtained from farms from the center-east during the last 5 years has been doubled [7].

As indicated above, the quantity of goat milk production is increasing in the country; however, the number of producers in this sector has progressively decreased. Farms tend to be more technologically advanced and specialized, with a higher number of heads with improved productive efficiency [10].

The value of goat milk produced in 2016 was 305 million euros, 7% lower than the previous year due to the decrease in the price of this kind of milk, although production continued to progressively increase [6, 7].

The price of goat milk has a seasonal behavior, reaching a maximum during winter season where there is a productive deficit on farms [7]. In 2016 the average prize of goat milk in Spain was 0.64 euros/liter, 7.25% lower than the average of the previous year [7].

	MG (1)	MA (2)	FL (3)	MJ (4)	PA (5)	GU (6)	Source
Milk yield (kg) (lactation days)	530 (250)	503 (268)	—	—	416 (210)	—	[14]
	513 (210)	541 (210)	593 (210)	530 (210)	432 (210)	325 (210)	[2]
Fat (%)	4.8	5.6	—	—	4.2	—	[14]
	5.5	5.4	5.3	3.9	4.2	4.6	[2]
Range estimated by breed (kg)	450–550	400–500	450–550	400–600	300–450	300–400	[13]

MG: Murciano Granadina; MA: Malagueña; FL: Florida; MJ: Majorera; PA: Payoya; GU: Guadarrama.

Table 1.
Milk production of Spanish goat breeds.

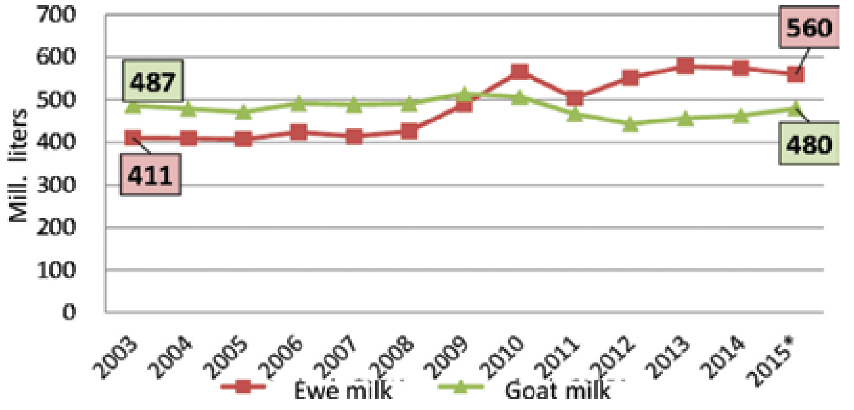


Figure 6.
Evolution of goat and ewe milk production in Spain (2003–2015). Source: [10].*

The main destination of goat milk is the transformation of cheese (pure or mixed with sheep milk). Spain has more than 150 varieties of cheeses from small ruminant milk, and many of them are produced under quality labels such as Protected Geographic Indication or Protected Designation of Origin. From the different types of cheeses consumed in Spanish homes, 12.7% belong to the category pure goat breeds, versus 17.6% of ewe, with respect to total cheese consumption [7]. Cheese consumption by person and year is estimated to be 280 g for goat cheese and 380 g for sheep cheese.

Globally, it could be said that the goat processing sector in Spain is characterized by the presence of a small number of different large industries that are involved in the main national industrial production, and a large number of small regional industries that produce more specialized products, which are frequently produced in small artisan cheese factories and sold in local markets [11].

The future and stability of the milk sector is very dependent of the price of milk and its global offer/availability on the national market, therefore some experts see exportation as a possible strategy to improve the sector. Thus, the sale of fresh milk to France or powdered milk to China to supply the demand of these markets would be favorable for the future of the sector [11].

Summarizing, the goat sector presents a good potential in the European and international markets, related to quantity and quality. Spain has a high variety of breeds that are appreciated in different countries, which are vital and strategic for Spanish rural development [9].

4. Goat breed characterization

4.1 Global approaches

Officially in Spain, following the Spanish Ministry of Agriculture, Food and Environment (Orden APM/26/2018) [12], there are 22 different breeds, all of them autochthonous, which means that the country is in fifth position in genetic variability in the world, after Italy, China, Pakistan, and India. The breeds are divided into two groups: breeds with a “no-conflictive” census (called foment breeds) and breeds with a “limited” census (called endangered breeds).

In the first group, three breeds are included, all of them dairy breeds. Two (Florida and Malagueña) have their origin from the south (Andalusia region) and one (Murciano Granadina) is spread all over the country. Also, they have some presence in Hispano-America and in North Africa countries.

In the second group, 19 breeds are included: 10 that could be considered as dairy or mainly dairy aptitude and nine meat or mainly meat aptitude breeds.

4.2 Breed characterization

In this chapter we will describe some of the Spanish goat breeds, indicating their geographical origin and main distribution (represented with a number in **Figure** 7), some of their morphological and coat characteristics, and productive qualities. They have been classified according to their main aptitude. Information on breeds has been extracted from research and published sources, articles, and books from [2, 13, 14].

4.2.1 Dairy breeds

4.2.1.1 Murciano Granadina (1, pictures 1 and 2)

This breed is in census and geographical distribution. It is the most important goat breed in the country, and has been exported to other European, American, and African countries. In 1975 it was recreated by the union of the Murciana (mahogany colored) and Granadina (black coat) goats, and was associated in 1997. It has typical milk morphology with a fine skeleton, good development of the mammary system,

Figure 7.
Geographical distribution of Spanish goat breeds.

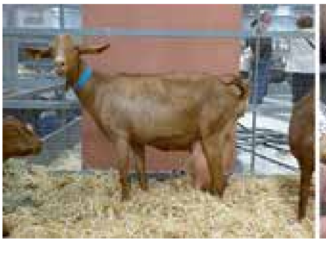
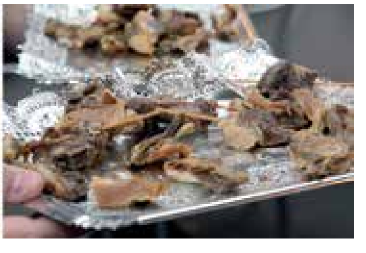
	Cold carcass weight (kg)	Muscle (%)	Fat (%)	Bone (%)
Blanca Celtibérica (13)	6.56 d	60.6 a	16.7 b	21.4 a
Negra Serrana (17)	5.83 cd	63.0 ab	12.3 a	23.0 b
Moncaina (16)	5.32 bc	64.2 b	12.2 a	21.8 a
Murciano-Granadina (1)	4.38 a	62.2 a	11.9 a	23.7 b
Pirenaica (9)	4.71 ab	64.0 b	13.0 a	21.3 a
Milk lamb (Churra breed)	5.49 bc	61.3 a	11.9 a	25.0 c
SED	0.12	0.12	0.44	0.20

Source: [17]; percentage of tissue composition calculated on the shoulder. SED: standard error deviation. Letters mean statistical differences between breeds in the same column (P < 0.050).

Table 2.
Carcass weight and tissue composition of some Spanish goat breeds.

skin, and hair little developed and ears in "V" disposition, existing animals polled and horned. See productive performance in **Tables 1** and **2**. Some comparative studies have demonstrated the high consumer acceptability of this breed, together with others like Moncaina and Blanca Celtiberica [15], qualities that could be partially related to differences in fatty acids [16].

4.2.1.2 Malagueña (2, pictures 3 and 4)

Placed mainly in Malaga (in the Andalusia region), the breed, which has Maltese blood, has an important geographical distribution. It has a sandy to red coat and some variability in its morphological characteristics, but with a tendency, in the improved variety, to be similar to the most important world dairy breeds, such as the previous one or the Saanen. Malaga cheese ("Queso de Cabra de Málaga") is one of its more known milk products.

4.2.1.3 Florida (3, picture 5)

Situated mainly in Sevilla, in the south of Spain, this breed has its origin in crosses (Nubian blood and autochthonous animals) in the 1920–1930s, having its herd established in 2003. It has a nice red and white speckled coat and, as the previous ones, a milk aptitude morphology.

4.2.1.4 Majorera (4, pictures 6 and 7)


This breed is included in the Canary Islands breeds, together with Tinerfeña and Palmera (*Agrupación Caprina Canaria*—ACC in Spanish). The Majorera breed is placed mainly in the east islands, and shows some traces of Nubian and Maltese influence. It often has a pied coat and saber horns, good milk performance destined to make "majorero" cheese, and good rusticity.

4.2.2 Dual-purpose breeds

4.2.2.1 Payoya (5, pictures 8 and 9)


Payoya is a dairy and meat goat from the mountainous areas of Cadiz (Andalusia). It is well adapted to the extreme humidity and fluctuating temperatures of its local environment. The coat of the breed is very variable: mainly a combination of white, red, black, brown or cream, and it has a large size.

4.2.2.2 Guadarrama (6, picture 10)

Placed in the center of the Iberian mountain system, near Madrid, this breed has been influenced by hair breeds. The breed presents four varieties, with a long coat, mainly black or dark with white or clearer face stripes on the lower legs and feet. It is very rustic and known for its good health, prolificacy, and milk product quality, such as cheese and yoghurt.

4.2.3 Meat breeds

A comparative carcass composition of some of these breeds is presented in **Table 2**.

4.2.3.1 Azpi Gorri (7, picture 11)

Placed in the north of Spain, in Basque country, the breed has small numbers with around 1000 heads; its name reflects its red color. It has a medium size, horizontal ears, and short coat, deep red and gleaming black with chestnut face stripes, legs, abdomen, and the underside of the tail. Its main use is for kid meat production, though it is also to a certain extent milked.

4.2.3.2 Bermeya (8, picture 12)

This endangered breed with around 2500 animals included in its herd book is placed in the Cantabrian coast and mountains of the north of Spain, having its herd book registered in 1999. It has a fine, mainly short coat; some animals have pantaloons and a variable intensity red coat (harsher and longer in males) and horizontal ears and arched horns. It is bred mainly for meat but also for milk for local cheeses such as "Cabrales."

4.2.3.3 Pirenaica (9, picture 13)

This breed is located in the French and Spanish Pyrenees. On the Spanish slopes the breed shows a predominant meat aptitude; however, in France the aptitude is more focused on milk production. In Spain, the coat (usually long) is preferred black or dark brown, with paler abdomen, lower legs, and face stripes. The breed has high prolificacy, very good adaptation to the high mountain production systems, and good potential for milk production.

4.2.3.4 Retinta Extremeña (10, picture 14)

The breed is located in the west of Spain. The coat is short and variable red, mainly dark, and it has twisted horns. Dedicated to meat it is also milked and characterized by being well adapted to extreme conditions. It has a quiet temperament.

4.2.3.5 Verata (11, picture 15)

The Verata breed is mainly located in the area called "La Vera." The coat has different colors: chestnut brown, black, blackish brown, or gray, frequently with the muzzle clearer, presenting big twisted horns. As with many other breeds, it has meat and milk aptitude, so could be considered as a double aptitude animal.

4.2.3.6 Blanca Andaluza (12, picture 16)

This breed is mainly placed in the mountains of the northern region of Andalusia. It has a characteristic convex profile, with long twisted lyre-shaped horns, and a white coat. It has a noticeable sexual dimorphism. The breed has very high rusticity "live with the deer" and a clear meat aptitude. In some areas it is also milked, as are many other rustic breeds.

4.2.3.7 Blanca Celtibérica (13, pictures 17 and 18)


This old breed is quite similar to the previous one, but it has a wider diffusion, and it is slightly smaller presenting a less convex profile. Its main use is for producing meat; the females are rarely milked. "Tronchón" cheese is associated with the Blanca Celtibética breed. Exceptionally, it is supplemented due to its enormous adaptation and rusticity.

4.2.3.8 Blanca de la Rasquera (14, pictures 19 and 20)


Closely related to Blanca Celtibérica [14], this breed lives in the mountains near to the Catalonian coast. It has a white color, but frequently has black spots on a white coat and very twisted horns that sometimes look like ovine ones. Also, rusticity and kid meat are their main productive characteristics.

4.2.3.9 Mallorquina (15, picture 21)

This breed lives in the higher steep areas of the Balearic Islands, 800 m above sea level in the "Trasmontana Hills." In the past they have even been hunted, although nowadays they are included in conservation programs, living in semi-extensive production systems. The breed resembles the Markhor, with long horns, beards in both sexes, and a red and black coat. Associated with the diet and genotype, these meat aptitude and feral animals have darker, but tenderer, meat than milk lambs [4].

4.2.3.10 Moncaina (16, pictures 22 and 23)

Placed in a mountain area in the Aragón region ("Moncayo"), this breed has genetic connections with the Pirenaica y Guadarrama breeds. It was recognized as a breed in 2002. It has arched horns and a black or chestnut long coat with clearer areas. Meat is its main production, although the breed has been recognized as an acceptable milk producer.

4.2.3.11 Negra Serrana (17, picture 24)

This black, sometimes with a mixture of black and white hairs, breed lives between the Andalusia region and its north border areas with Castilian la Mancha. It has a convex profile, large weight, and a morphology that could be compared with the Boer breed. A peculiarity is a noticeable lop skin under the gorge. It has a clear meat aptitude, and low milk production, which could generate a low maternal instinct in young females [13].

5. Goat production systems in Spain

5.1 Introduction

Spanish goat systems show a great diversity of farms, although there are several common aspects, such as their familiar character, the lack of technical-economic management, and the lack of a clear structure of the sector [18]. Spanish goat breeds are farmed under different extensive, semi-extensive, semi-intensive, or intensive systems, depending on their productive aptitude and performance.

Thus, in general, those breeds with a high milk production, which can be classified as dairy breeds, are reared under the most intensive systems, in plain geographical areas, with high forage availability to cover their nutritional demands. Sometimes kids are considered as a by-product in these farms. On the other hand, those breeds with a lower milk potential used to be reared in marginal mountainous areas, under extensive or semi-extensive models, following traditional pastoral systems, where kids are the main product (meat breeds). When a particular breed is also milked, it is considered as a dual-purpose goat breed, whose characteristics have been previously defined.

In addition to the genetic base, there is also great heterogeneity in terms of other characteristics of the systems, as are the management of food and reproduction, and the degree of technification, which determines the type of system. Ultimately goat production systems in Spain are mainly determined by the aptitude of the breed such as farm facilities, housing systems, and feeding strategies.

5.2 Milk production

Both semi-extensive and intensive farms are focused on milk production as the main economical resource. The main differences between the two opposite poles lie, in general, in the number of goats (small-medium farms in the most extensive systems, with 250–450 heads, and large intensive farms, with 700–1500 heads), and the reproductive system (from one kidding to three to four kidding seasons per year, respectively). Under this perspective, semi-extensive farms present periods of total absence of milk production; meanwhile intensive farms, with a planned reproductive schedule, are theoretically able to offer milk all year round. However, despite the intensification process of some farms, milk production continues to be seasonal, with maximum production in spring and minimum at the end of summer and beginning of autumn, which is opposite to milk prices, which are lower in spring and higher in autumn and early winter.

5.3 Intensive systems

Most of the farms under this system can be considered as dairy farms. These farms follow a permanent housing of the animals, generally in communal yards that have uncovered areas. Feeding used to be indoors. Different paddocks keep animals in the same phase of lactation or with the same level of production.

The minimum number of heads is around 300, with a mean milk production of 400 liters per lactation. They have milking parlors, usually with electronic identification systems to record individual milk production.

From a reproductive point of view, these farmers are integrated in a breeders' association, under a genetic improvement plan, where artificial insemination with semen from the best bucks is usual.

Kids are like a by-product, and they contribute to around 20% of the income of the farm. Colostrum is provided by esophageal cannulas and kids are fed by automatic milk feeders.

5.4 Semi-extensive systems

These farms are based on the production of kid meat, but goats are also milked for up to 5–7 months, so that they use dual-purpose breeds. Kids are reared by their mothers, and after weaning start manual or mechanical milking.

The reproductive calendar follows in general one kidding per year, although some farmers try to reach three kidding seasons in 2 years.

Traditionally, farms under this semi-extensive program are located in two different geographical areas: mountains and valleys. Goat farms in the mountainous areas have a higher number of heads (>100) and grazing in communal pastures. Animals receive an energy supplement at the end of pregnancy and during lactation. Milking used to be manual. Lowland farms are smaller (25–50 females), using in general by-products from the industry as a supplementary feeding to grazing [19–20].

5.5 Extensive systems

Extensive farms are based on a natural land use, with a low amount of external income and with grazing as the main food resource for the animals. In general, farmers rear autochthonous breeds, well adapted to these areas [9].

The main goal of these farms is the production of young animals as described in Section 3.2. However, sometimes, very traditional farmers milk their goats for 1–2 months to manufacture small amounts of cheese.

This system includes small farms (150–200 goats), located in mountain areas, with limited/old facilities. Usually, housing is only overnight in rustic/old buildings. The flock is accompanied by the shepherd, with around 0.5–2 goats/ha.

The reproductive system is limited to one kidding per year.

6. Conclusions

In Spain, the goat sector has the potential to continue growing. At a national level the development of several certified products with quality trades/labels on meat or on elaborated products such as cheeses would allow increases and improvements to production, the value of the products and globally breeders recognition, profitability, and income. Also exportation of Spanish goat milk or meat to other countries together with higher and more common or traditional goat consumption would be a possible growth strategy.

The high genetic variability of breeds has been identified and characterized in the Spanish goat population. Each one has been adapted to the conditions of the rearing region and specific production systems according to their main aptitude (meat, dairy, dual purpose) and environmental resources.

Versatility of the species lets them adapt to different orographic and technical conditions, presenting adequate performance since extensive rural areas to on the newest specialized and intensified farms.

Institutional support from the government, from the small ruminant sectors and breeders' associations is essential for the progress of the species. Also, the increase in studies of the characteristics, possibilities of production of different breeds, and goodness of their products would be desirable. It is essential to transmit such knowledge to the population, which needs to be sensitized, informed, and educated about nutritional, environmental, social, and economic virtues of this species.

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Chapter 3

Local Goat Breeds in the United States

D. Phillip Sponenberg

Abstract

Goat production in the United States has largely relied upon breed resources imported less than a century ago. In addition to these imported breeds that are commonly used for production are a few local breeds that have been developed over centuries in the USA and other developed more recently. These include Spanish and Myotonic goats for meat production, Lamancha goats for dairy production, and an archaic type of Navajo Angora goat that still finds a role in mohair production. Additional genetic resources reside in a few populations of feral goats, although these now persist in domestication after having been eliminated from their feral ranges. The local breeds are increasingly the target of investigations into their genetics and levels of production. Results of those investigations are finding these local breeds to be productive and valuable additions to agricultural systems.

Keywords: breed, goat, Spanish goat, myotonic goat, feral goat

1. Introduction

Goat production in the USA generally involves a variety of breed resources that are each tailored to fit different needs within goat-producing agricultural systems. Among those systems are dairy production, meat production, brush control, mohair production, a limited amount of cashmere production, and companion animals. These systems are all dominated by breeds imported into the USA since 1900, although a few breeds persist that have origins in local goats that predate these importations. In addition to the formal and controlled herds involved in goat production are a few feral goat populations that persist in various locations. Some of these feral populations are of special genetic interest due to their unique foundation and subsequent genetic isolation.

2. Methods

Investigations of local goats in the USA have been undertaken throughout the last four decades by the Livestock Conservancy (LC), a nonprofit organization working in the United States to assess and document the status of breed populations and the population structures of each of them. The LC does its assessment by a periodic census of all breeds and candidate breed populations for both privately held and institutional herds. Local populations are often encountered that have no history of formal breeder organization or breed definition. These populations are each assessed for inclusion as breeds by documenting their history, phenotype, and any available genetic results in order to make decisions as to their validity as populations with sufficient genetic uniformity to serve effectively as genetic resources. Once accepted as genetic resources (more formally as "breeds"), each is then further supported by organization of breeders and development of conservation strategies that are appropriate for the breed based on history and cultural factors. This may involve herdbooks and individual animal registration, or other strategies for more local breeds kept in more extensive situations where individual registration is not realistic. The background factors for each breed, along with the census, allow the Livestock Conservancy to establish priorities as well as strategies for effective conservation and promotion.

3. Dairy goats

Dairy producers in the USA generally use goats from a limited array of imported breeds. These goats are either purebred or high-grade, and breeders and registries closely track the ancestry of these goats. These imported breeds include Nubian, Alpine, Saanen (and its colored derivative named Sable), Toggenburg, and Oberhasli. In each of these breeds performance recording is routine, registrations and pedigrees are tracked, and they are used for milk production as well as for exhibition and competition in livestock shows.

The Nigerian Dwarf Goat stands apart from these others. It is, as the name suggests, a small goat originally from Africa that is now used for home-scale dairy production. It is derived from imports of landrace-type goats from Nigeria in the 1950s and 1960s. Breeders organized and defined the breed from these imported sources, even though the breed is much less organized or documented in its country of origin. Its small size and modest levels of production make it a breed more fitted for home milk production than for commercial goat dairying. The record for a 305-day lactation is 798 kg [1]. The census figures for 2013 included 8589 new registrations for the year, implying a total population size of 30,000 or so.

The American Lamancha is the only dairy goat breed with a local American origin, having been developed from a foundation based on local goats in California beginning in the 1930s and gaining breed recognition in the 1950s. These original goats were reputedly of Spanish origin via the colonial period during which the region was under Spanish and Mexican control. This history has contributed the name to the breed, even though no such breed exists in Spain under this name. The Lamancha breed was deliberately developed by adding successive influences from the other recognized dairy breeds to the original genetic base of local goats. These influences are all from imported breeds, and are therefore not local in a strict sense. These additions over generations were to the extent that they now vastly predominate over that original base of local goats. The Lamancha breed is a composite of these influences, most of which are imported. The breed has now been selected for dairy production from within this discrete population, and has been relatively closed for multiple generations.

The nomenclature of dairy goat breeding in the USA can become confusing and warrants some explanation when discussing the American Lamancha. The tracking of registered breeds of dairy goats in the USA takes a form of companion sections in the registries. One of these sections is for purebreds, and goes by whatever breed name is appropriate. A second section is for goats that have been graded up to relatively high levels of the breed from an original base of ordinary goats. In this section the goats are referred to as the breed name preceded by "American" as a modifier. In this system a "Toggenburg" is a purebred Toggenburg tracing back to the original imports in all lines of descent. In contrast, an "American Toggenburg"

Figure 1.
The American Lamancha is characterized by short ears. Photo by J. Beranger.

is a grade goat, although in most cases one that has very little breeding external to the imported lines. American goats, regardless of how small that outside influence is, can never be moved over into the purebred section. The case of the American Lamancha is therefore slightly different, because it is a breed that was formed in the USA, and as a result the only herdbook section is "American." Therefore upgraded goats are fully included into the registry in this single section, and can participate fully within the breed.

The most distinctive feature of Lamancha goats is their short ears, which pass along generation to generation as a dominant genetic trait. Homozygotes have shorter ears that are nearly vestigial, while heterozygotes generally have a more obvious remnant of the pinna. The "gopher ear" is the shorter of the two, up to 2.5 cm but preferably shorter. The "elf ear" is up to 5 cm long.

Originally Lamancha goats were especially prized for their ability to milk continuously through several years after a single kidding. This trait is used less now than in years past, with most Lamanchas currently being mated for annual kid production and then milked for the subsequent lactation that is generally standardized at 305 days long. Milk production in the breed includes a record of 2770 kg in 2017 [1]. Also in 2017 the breed leader in butterfat produced 100 kg (8.1%), and the breed leader for protein production had a record of 58 kg (3.3%). Lamancha does should weigh at least 59 kg, and bucks 70 kg. The breed comes in a wide variety of colors. The hair coat is short, and the conformation is a typical dairy type. The census figures for 2013 included 11,518 new registrations, implying a total population in the range of 50,000 or so (**Figure 1**).

4. Fiber goats

Mohair production in the USA is all from Angora goats, and the Edwards Plateau in Texas is one of the main regions in which this international breed is raised. The Angora goat does not qualify as local by virtue of its importation early in the 1900s. A distinct archaic type does persist in the USA, mainly among breeders of the indigenous Navajo nation. This is a type close to that represented in the early importations and distinct from the more modern type. The Navajo Angora has a flatter lock type in contrast to the more pencil locks favored in modern Angoras. In addition the horns tend to twist upward or outward rather than having the lower pronounced curl of the modern Angora.

An increasing number of breeders, especially among artisans and hand-crafters, are concerned that this type of goat with its distinctive fiber is in danger of being completely absorbed by the more modern type. In response there is increasing

Figure 2.
The Navajo Angora goat is often colored, and has different fleece and horn structure than the more typical commercial modern Angora type. Photo by D.P. Sponenberg.

interest in organizing the breeding and recognition of this type which has generally persisted outside of the registries. In the early days of the formation of the Colored Angora Goat Breeders' Association most of the goats accepted into the registry were of the Navajo type, which often includes colored goats. However, in this Association the past decades have seen increasing use of the colored goats that rarely segregate from registered white Angora herds and tend to be of the more modern type. This breeding strategy has changed the overall breed type within the colored Angoras from the original Navajo type towards the more modern type. The colored goats have become increasingly fine-fleeced, which is the goal for most breeders of modern Angoras. As a reaction to this the breeders that prefer the Navajo type are beginning to organize breeding programs targeting this archaic type. There are no current estimates on population size for this type of Angora goat, but it is likely to number no more than 1000 head (**Figure 2**).

Goats used specifically for cashmere production are rare in the USA. A few breeders have imported cashmere-producing goats from international sources, but these continue to be present in very low numbers. Some specific bloodlines of Spanish goats have been used for cashmere production, and in this case the cashmere production is secondary to the usual meat-producing role of this breed. A few breeders of Spanish goats do specifically put emphasis on cashmere production, but the economics of this in the USA make it secondary to the income produced by meat production.

5. Meat goats

Local landraces in the USA have long been used for meat production. Production of goat meat has been very much a local enterprise throughout most of history, but has more recently emerged as a main focus of goat production for many breeders. Local breeds have met this demand but face increasing competition from the imported Boer and Kiko goats that are broadly considered to be more specific for meat production. Despite this popular opinion, research evidence points to advantages of the local breeds over the imported breeds [2, 3].

5.1 Spanish goat

The Spanish goat has a long history in the USA, having been brought to North America early in Spanish domination of both the southwest and the southeast. Due to long residence in these challenging environments the Spanish goat today has a high level of adaptation. In the southwest this adaptation is to arid environments and extensive production systems. In the southeast the numbers of these goats are very much lower, but their adaptation to a humid subtropical environment makes them an important target for documentation and conservation.

Formal, organized conservation of Spanish goats became necessary after the breed began to be used for upgrading programs following the introduction of the Boer goat in the last decades of the 1900s. Several breeders of Spanish goats became alarmed that numbers of purebred landrace Spanish goats were dwindling, the does having been used for crossing with Boer goats with little or no purebred breeding occurring in most herds for recruitment back into the Spanish goat populations. A later challenge was a similar strategy used with the introduced Kiko goats. As is typical of many local genetic resources, little documentation of the productive potential of the Spanish goat was available, and this combined with the notoriety and high prices of any imported breed created an incentive for breeders to use Spanish does with the imported breeds rather than in pure breeding.

Fortunately, some breeders of Spanish goats had undertaken long-term selection programs to enhance to productivity of these goats without sacrificing their level of adaptation. This occurred mainly in Texas, where herds of up to 1500 head of Spanish goats can still be encountered. Breeders that were committed to the local breed generally started their herds with does that were about 35 kg mature weight. Through selection over decades they were able to increase weights, in some cases up to 70 kg. At this point breeders in some environments noticed that adaptation and general productivity began to suffer, but also noted that when mature doe weight was capped at about 57 kg it was possible to have productive, efficient goats that were also well-adapted to the dry and challenging West Texas environment [4].

Breeders tended to select from within their large herds, and rarely or never resorted to introduction of animals from outside their own lines. When they did add in new genetic material, bucks were chosen to be as similar in type as could be had. As a result of these breeding practices, several distinctive bloodlines have emerged, all of which have phenotypic similarities to one another. Importantly, this phenotype is distinct from other breed resources available to these breeders. The wisdom of conserving this type and selecting it for production have been proven by this breed's increased acceptance as a valuable component of commercial goat meat production, both as a purebred and as a base for crossbreeding.

The locally derived Spanish goat fortunately has a distinctive phenotype that has been the focus of breeders and conservators. This phenotype is easily disrupted by crossbreeding to other resources commonly available, including Nubian, Boer, Kiko, Angora, and the Swiss Dairy breeds.

The local Spanish goat has a rangy body. The ears are horizontal and carried forward up alongside the head. The horns tend to be long and have a distinctive twist to them. The facial profile is straight or slightly convex. This is the most distinctive phenotype, and was chosen as the one to conserve because it tends to quickly reveal crossbreeding. While phenotype in Iberian breeds is more variable, some of those phenotypes would fail to reveal crossbreeding. While they may indeed be purely Iberian they were not the target of conservation for this reason (**Figure 3**).

The approach of evaluating goats by this external phenotype has been validated by DNA testing, revealing that this phenotype, which occurs throughout the Americas, does reflect an underlying genotypic similarity. This indicates that the history and development of this type of goat traces back to a common foundation centuries ago [5, 6].

The status and history of the Spanish goat in the USA illustrates several important aspects of the conservation of local breeds of livestock. These goats very much

Figure 3.
These are young Spanish bucks from different bloodlines showing the consistent horn and ear carriage of the breed. Photo by D.P. Sponenberg.

fit into the framework of a landrace population that had a specific foundation followed by long-term genetic isolation and exposure to a selection environment imposed both by natural influences as well as human owners. This resource, in both the southwest and southeast, continued as a local resource that was not much changed due to geographic and cultural isolation. The only real threat to its integrity for most of its history was Angora goats in Texas, and the final fiber and general phenotype is so different in that case that there was little incentive for such crossing.

In such a situation, the goals of production and the relative isolation provide an environment that favors conservation of the traditional type with little need to impose organization or direction upon the breeders. This static but effective situation changed in the final decades of the 1900s, because the numbers and economic strength of various ethnic and cultural minorities increased, and many of these had a strong preference for goat meat. As a result the market changed from one that was primarily local to one that was national. In addition a few breeders imported Boer, and then later on Kiko, Savannah, and other exotic genetic resources. As is typical of most situations with imported breeds, these arrived with promotion from powerful economic forces that touted superior performance, while the local resource had never been truly evaluated. The assumption is that the imported resource offers significant advantages, even in the absence of documentation of the local resource.

Local producers found that they could take advantage of the promotion of these exotic resources by crossing to them, and gaining a premium in prices over the base price of goat meat as a commodity. This worked to erode the genetic resource of the local Spanish goat. Many breeders of Spanish goats no longer used Spanish bucks on their doe herds. The result was plummeting breed numbers.

As is also typical of landraces, an important group of breeders held on to the local resource and kept selection programs going. These breeders lacked formal organization, and most had herds of at least several hundred head. As a result, exchange of breeding stock was of minimal importance in the genetic management of the resource. Many breeders operated in isolation from the others. Especially among the breeders of large herds, selection has varied enough for color and amounts of cashmere that distinctive strains have emerged, all fitting under the unifying aspects of the general conformation of the Spanish goat. These differences are the reason for breeders avoiding a tightly prescriptive breed standard, and instead opting for a descriptive approach that encompasses the variations in the breed.

Efforts at organization began as a low-level effort that encouraged documentation and participation in nothing more than a list of breeders indicating that they had pure Spanish goats and were committed to the breed. The candidate herds were evaluated for overall type, and those that fit a general history of good isolation and attention to the traditional type were included. The phenotype was assessed by a matrix of characteristics that evaluated the various conformational details outlined above. This loose level of organization allowed new breeders to have access to genetic material that would be accepted as purebred. The result was a loose structure of foundation lines, generally from large traditional herds but also including a few smaller herds. From these a second generation of breeders that purchased animals from these foundation lines began their own breeding programs.

Research is now documenting that Spanish goats are generally superior to Boer goats in overall productivity measured on a herd-wide basis, and are on a par with Kiko goats [5, 6]. This documentation points to the need to carefully evaluate local resources before replacing them with exotic resources, because local resources may indeed be equal or superior due to environmental adaptation.

The current stage of development within the breed is an increasing move towards individual registration of animals, with pedigrees and single-sire mating. This brings with it a subtle but important move from the original landrace concept for this breed, especially because the traditional approach has long been one of large herds raised extensively on vast ranges. Multi-sire breeding precludes accurate pedigrees, although the large herd sizes do offer insurance against high levels of inbreeding that could lead to inbreeding depression. Coordinating this traditional approach with a registry system that caters to smaller more intensively managed herds is a challenge in many landrace situations, and meeting it effectively and constructively is an important issue.

The census figures for 2018 included about 18,000 goats. This high figure is at least somewhat misleading, because of a handful of very large herds (over 1000 head each). A second tier consists of relatively large herds (100 to a few 100 s), and then finally herds numbers around 10 to 50 or so. Each of these herd sizes has different needs for validation and documentation. Importantly, the very large herds give an overall census value that is quite high and therefore seemingly secure from threats. Some large herds, however, are in the hands of elderly breeders and if these herds cease breeding, then the influence on the census will be very quickly felt and numbers will plummet precipitously and with little warning. This census value is therefore not as secure as it might seem to be on first thought, although the breed definitely does benefit greatly from the selection pressures put on it in those very large herds managed under extensive conditions. That selection environment is nearly impossible to duplicate outside of that specific situation.

Within the Spanish goats are a few foundation strains from the Southeast. These include goats from Mississippi, Florida, and South Carolina. These are all adapted to humid subtropical environments, which is distinct from the more numerous Texas goats. These southeast goats have a very similar phenotype, if a somewhat smaller average size. A few breeders are dedicated to the conservation of this subtype within the breed in order to not lose its distinctiveness (**Figure 4**).

5.2 Myotonic goat

Another local landrace for meat production is the Myotonic, or Fainting, goat. This goat is very much local, and has the medical condition of *myotonia congenita*. This condition is caused by changes in ion channels in skeletal muscle that make it impossible for rapidly firing muscles to relax rapidly after contraction [7]. This causes the goat's muscles to stiffen if it moves suddenly, usually in response to a surprising stimulus. A consequence of this trait is a visual appearance of increased muscle mass, which leads to a common citation of a meat-to-bone ratio of 4:1

Figure 4.
This Spanish buck from the Florida Partin strain has phenotypic features typical of the general breed. Photo by R. Wright, used by permission.

instead of the more common 3:1 of most goats. However, this value has not been substantiated by controlled research results and is therefore suspect.

Myotonic goats arrived in Tennessee in the 1880s in the care of an itinerant worker. The earlier origin of the goats is cloaked in mystery and similar goats have not been documented in other areas. Once introduced to Tennessee they were used as a local source of meat due to their muscular conformation. The *myotonia congenita* has other advantages because it impedes the goats as they try to climb or jump, so they are easier to fence in than other goats. This, along with the meat-to-bone ratio, was one of the reasons producers favored this goat over others. These goats served local purposes for most of their history.

Following the departure of the original itinerant worker, the goats were left with the landowner in Tennessee, and from that origin the goats developed as a local genetic resource. Subsistence production and use entailed very little selection along with very little promotion. This selection environment worked to produce a resource well-adapted to the local environment.

The long-term selection of these goats in Tennessee and other neighboring states with a humid subtropical or warm temperate climate has resulted in a high degree of resistance to parasites, which is a distinct advantage to the breed [6]. The goats also have good mothering ability and a quiet demeanor. Most of the goats within the breed are nonseasonal breeders making accelerated production schedules possible.

The development of the breed was strictly local up until the 1950s, with little to no organization of breeders. In the 1950s a few of the goats were brought to Texas, partly as a novelty and partly as production animals. During this time many Texas ranches were importing exotic wild hoofed stock from around the world. This was both for conservation as well as sport-hunting purposes. In this system the Myotonic goats were used to distract predators from the more valuable exotic stock, and many large ranches with exotic hoofed stock also ran herds of Myotonic goats.

Both the Tennessee and Texas portions of the breed remained unorganized as local landraces up until about the 1980s, when a variety of organizational efforts began. These involved the development of breed associations and breed standards. This was largely a response to a broadly based cultural phenomenon at that time for interest in novel and exotic varieties of domesticated breeds. The *myotonia congenita* of the goats fit that description quite well, and selection began to diverge in a few

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different directions. Selection for the goats as companion animals emphasized small size, extreme degrees of stiffness, and good temperament. At the other extreme, selection for meat purposes preferred larger goats that could navigate the environment well and produce meat in low-input systems. In general the more exotic small form became the preferred selection target, and deliberate selection for meat production lagged.

A few different registries have been established for the breed. Most registries focused on the muscle condition and not on the underlying uniformity of the breed's overall phenotypic package. The one muscular trait became confused with the identity of the entire breed. The condition of *myotonia* is fortunately recessive so that crossbred goats usually do not exhibit the trait. While this helps to reduce the influx of outside breeding, when the focus is only on the *myotonia*, this threat is not completely eliminated. Different breeders have gone in different directions with this breed, and to an extent so have the registries and breeder associations. Selection for small, very stiff goats resulted in a high level of expression of the *myotonia*, but with little utility in commercial meat production. Others have selected for success in the show-ring, which tends to reward extremes of width and muscular development along with smooth conformation. Other breeders have selected for odd colors, blue eyes, or other conformational details such as the form of the ear and freedom from supernumerary teats. Yet others have favored selection for the goats as practical meat-producing goats under low-input management. An independent direction for selection is for small goats with silky long hair. These have now become "Mini Silky Fainting goats" and are the target of a selection process that is independent of the main breed.

The breed still encompasses a large range of sizes and overall styles. Each of these has advocates, with some of the groups having very strong opinions over what the original goat looked like and functioned like.

The main features that unify the breed are a quiet demeanor as well as the heavy muscling that comes directly from the *myotonia congenita*. In addition, many of the goats are resistant to the effects of *Haemonchus contortus* [6]. The relative sizes of the breed are difficult to ascertain because they are so variable. Does go up to about 75 kg pounds, and bucks sometimes over 100 kg, but these are usually animals that have been heavily fed and are fat. The more usual larger goats of the breed are about 50 kg does and 70 kg bucks. Most of the breed matures slowly, not achieving full mature weight until about three or four years old. The breed is generally nonseasonal for reproduction, although this varies individual to individual. Prolificacy varies widely, with most producing singles or twins but with triplets and quadruplets routine enough to not be all that unusual. The smallest examples of the breed are at the miniature end, and some does are only about 25 kg.

Coat color is variable, although black and white spotted is common. Many breeders consider this combination to be the original color pattern for the breed and they therefore avoid other colors. This combination is recessive in this breed, and once fixed is fairly repeatable. Other breeders refer back to early photographs of the breed that showed a broader range of colors, and do not discriminate against colors that vary from the common black and white. Eye color also varies. The light gold color common to most goats is the most common within the breed, although many breeders specifically select for blue eyes which seem to pass along as a dominant trait within the breed.

Hair length varies. Most of the breed has short sleek hair in summer, and many grow a heavy coat of cashmere in the winter that is shed out in spring. A minority of the breed has long hair over most of the body, while a slightly greater number has longer hair along the topline, backs of thighs, and lower legs. Some animals are polled, although most are horned. Horns, when present, are usually long and have an outward and upward twist in mature bucks, although the relative length and character of the horns is quite variable.

Figure 5.
These young Myotonic bucklings show the stout conformation and heavy muscling typical of the breed, as well as a portion of the range of colors. Photo by D.P. Sponenberg.

Figure 6.
Hair length and quality varies in the Myotonic breed. Photo by D.P. Sponenberg.

Census figures from 2015 include 3500 new registrations. When mature stock is also considered, the final numbers of goats within the breed are likely to be around 10,000 or more. This was a rare breed 30 years ago, but has now become more popular and these population figures indicate that the breed is now secure from threats of extinction. Only a few large herds exist (100 head or more), and consequently the breed is exposed to many different breeding programs, each with a different selection goal. This helps to maintain diversity within the breed (**Figures 5** and **6**).

6. Feral goats

Feral goats are not common in the USA. A few strains do occur on islands, and some of these have a history of long-term isolation after a foundation event. These few have been targeted for conservation efforts due to their status as legitimate genetic resources. The long-term isolation provides for genetic adaptation to local conditions as well as for the development of a repeatable genetic package that is predictable. Populations with consistent introduction of new animals fail to achieve this.

6.1 San Clemente goat

The San Clemente goat hails from the island of that name, having been introduced long ago from the neighboring Santa Catalina island. These islands are off the coast of California. The San Clemente goat was determined to have adverse effects on its island environment, and as a result was targeted for removal. After removal, a small representative group of these goats became the focus of a conservation effort in order to not completely lose the strain.

The majority of San Clemente goats have a specific color pattern that is basically tan on the rear half of the body, and black on the front half. There are tan facial stripes, and also black stripes on the fronts of the legs. This pattern is so common among these goats that when other color patterns arise they are usually targeted for elimination, even though early photographs of the goats from the island did show color variation. This pattern, though typical of San Clemente goats, also occurs in numerous other breeds worldwide.

The San Clemente goat is a small goat, with does about 30 kg and bucks about 45 kg. They have horns, and the character and shape of the horns does vary among the goats of the breed. Teat conformation has been a target of some selection, with breeders culling any that have extra teats or split teats. In a rare breed this may be overly harsh because this action removes entire genomes from the conservation effort.

Genetic studies on the San Clemente goat have not been all that helpful in untangling its relationship to other geographic sources of goats [2, 3]. This is likely due to genetic drift following long isolation after a founding event of relatively few goats. They have a few phenotypic similarities to Spanish goats, but are distinct enough to warrant their own independent conservation effort.

The most recent census figures for San Clemente goats are from 2015, when there were 229 males registered and 425 females registered. These resided on 79 different farms, indicating that the breed is generally found in relatively small herds which contributes to reasonably broad variation in the use of breeding males (**Figure 7**).

6.2 Southeast Islands goat

The barrier islands off of South Carolina and North Carolina include a few with small populations of feral goats. The few of these with decent histories of isolation are generally a phenotype that fits within the Spanish goat, and these are included in the conservation efforts for that breed. A few others show influences of Nubian or other recent introductions, and are therefore not included as conservation priorities.

Figure 7.
San Clemente goats generally come in variations on a single color, although other variations do occur occasionally and were also typical of goats originally from the island. Photo by D.P. Sponenberg.

The goats from the barrier islands face a host of challenges, not least of which is the relatively recent introduction of feral hogs onto some of the islands. These can prey upon young kids, so recruitment in these populations is now falling below replacement levels.

No census figures are available for these goats, but the total is unlikely to be over 50 total.

6.3 Hawaiian goat

Hawaii also includes some feral goat populations. These are usually of a Spanish phenotype, but have been fairly poorly characterized or studied. As is typical of island feral populations they are controversial for their impact on native flora and fauna, while at the same time being of at least some conservation interest due to their long-term genetic isolation and adaptation. These are both legitimate concerns but tug in opposite directions, and a long-term solution is yet to be achieved.

No census figures are available for these goats.

7. Conclusion

The United States has only a handful of local breeds of goats that have a history of long standing. These few have been important contributors to goat production in the country, which has generally been at a fairly low level but is now increasing dramatically. These breeds, especially Spanish and Myotonic goats, are now finding acceptance and use in commercial goat production, which has worked to secure their numbers as well as the genetic structure of the breeds. This has depended on research into the true productive potential of these breeds, which is likely to be overlooked as increasing numbers of exotic resources are imported into the country. Fortunately research has documented the role that Spanish and Myotonic goats can play in rational production systems. As these breeds move from local resources to more broadly distribute, it will change their overall popularity and status among the genetic resources available to American goat producers.

Conflicts of interest

The author declares no conflict of interest.

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Chapter 4

Breeds and Breeding System of Indigenous and Crossbred Goats in Nepal

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Abstract

Goats are the indispensable component of rural economy in Nepal where 10.98 million goats accounting for 45.3% of total ruminants contribute to 20.3% of the total meat production and 49.2 million US dollar in the national economy. Being popular as “poor man’s cow” and “living cheque,” they significantly contribute to food, nutritional, and economic security of the marginalized farmers creating employment opportunities in the country. This chapter has tried to review the existing breeds, their breeding systems, challenges and way forward to enhance production and productivity of goats. Findings revealed that Nepal is endowed with four major indigenous genetic resources of goats and their crosses with Boer, Jamnapari, Barbari, Sirohi, etc. Occasionally, native goat breeds of Nepal were crossed with Kiko and Damascus as well. Breeding of goats in Nepal is mainly based on selection, pure breeding within indigenous flock, and crossbreeding to the available exotic breeds. There have been some biotechnological approaches applied in goat breeding and evaluation of native breeds. Estrus synchronization followed by artificial insemination is currently being practiced. Goats, being the most popular and easy source of household income and family nutrition in Nepal, could be the important source of national revenue provided with improved breeding and other husbandry practices.

Keywords: goats, indigenous, breeds, growth, nucleus, multiplier herd

1. Introduction

Livestock production is the most important source of livelihood for about 120 million pastoralists worldwide [1], which provides draught power for more than 320 million hectares of farmland. Animal enterprise is one of the principal agricultural sub-sectors in Nepal that contributes about 11% to the national gross domestic product (GDP) and 27% to agricultural GDP [2]. According to the Ministry of Agriculture and Livestock Development [3, 4], goat alone contributes about 5% of AGDP. Goats therefore are the indispensable component of livestock in the country with 10.25 million goat population that accounts for 45.3% of the national ruminant population. Goat population has increased by 3.52% per annum from 2012 to 2017 and placed itself as the second largest consumed meat (20.3%) after the buffalo meat [3, 5], which is about 49.2 billion rupees in the national economy. Being popular as "poor man's cow" or "living cheque," it significantly contributes to food and nutritional and economic security of the marginalized smallholder farmers and provides good employment and self-employment opportunities in the country.

There are four indigenous breeds of goats in Nepal, namely, Chyangra (in mountain), Sinhal (in high hills and low mountains), Khari (in hills and mid hills), and Terai mostly distributed in lower plains. The largest concentration of goats is topographically in the hills (52.2%) and regionally in central development region. Chyangra and Sinhal are the means of livelihood and family nutrition in high hills and mountain ecosystem where there are about 1% Chyangra and 15% Sinhal [3]. The most popular exotic breeds of goats are Boer, Jamnapari, Barbari, and Beetal which are mainly used for crossbreeding and upgrading of indigenous Khari and Terai breeds of goats.

In recent years, indigenous breeds of goats are preferred less by the commercial goat entrepreneurs. The major reason is considered to be the low production and productivity potential of native as compared to other exotic breeds. For five decades, studies are being made on various dynamics of goat production mainly aiming at increasing its production and productivity by improved feeding, breeding, health, and other management practices. With regard to the genetic improvement of goats, selection within the native breeds was popular among the herders in the past years. However, upgrading of the native goats by crossbreeding with the exotic breeds such as Boer and Jamnapari is being commonly practiced by the farmers since few decades expecting significantly increased production and productivity within a short time period.

With the country's entrance into the global market, many great opportunities resulted. It was also soon evident that foreign organizations flooded our country and took advantage of our lack of expertise in global promotion and marketing, since the Nepalese goat AnGR did not have documentation of the evidence of its potential and, therefore, failed effective marketing of its genetic materials. As a consequence, the population of the indigenous AnGR is diminishing drastically. The chapter aims to promote these valuable AnGR and to rectify the situation and to review the existing breeds of Nepalese goats and their breeding systems, challenges, and future way forward to enhance production and productivity of goats through scientific breeding practices.

2. Materials and methods

This chapter is mainly based on the information gathered and compiled through desktop review of available scientific publications including journals, proceedings, annual progress reports of various national institutions, technical bulletins, statistical year books, master and doctorate dissertations, project compilation reports, etc. This chapter covers general introduction, materials and methods, population and its distribution of goats, and diversity of goat genetic resources in Nepal. In addition, present review includes breeding management, variation in genetic parameters, and biotechnological approaches for goat development. Authentication of data available from different sources was carefully checked while preparing this chapter. Quantitative information used in this chapter were retrieved from authentic sources including published journals and reports of the Central Bureau of Statistics, Ministry of Agriculture and Livestock Development, Department of Livestock Services, Nepal Agricultural Research Council, universities, and other government organizations. For the validation of information collected for this chapter, authors also tried to triangulate the data from different sources.

3. Population and its distribution of goats in Nepal

According to the livestock census 2015/2016, the total goat population in Nepal was 10.98 million [6]. Province-wise goat population and distribution of goats per unit of area in Nepal is presented hereunder (see **Table 1**). Distribution of goat population was highest for Province No. 1 (2.28 millions—20.8%) followed by Province No. 3 (2.11 millions—19.2%) and 5 (1.96 millions—17.8%) with lowest for Province No. 6 (1 million—9.2%). However, the density of goats per unit area was found highest for Province No. 2 (146 goats/km^2) with lowest density for Province No. 6 (36 goats/km^2).

Similarly, 65,583 Mt of goat meat was produced in 2016 which was about 20.4% of total meat production in the country [6]. The largest amount of goat meat was produced from Province No. 5 followed by Province No. 1 and 3 with 14,595, 12,243, and 10,367 Mt meat productions, respectively. But the percentage contribution to total meat production was observed highest for Province No. 6 (25.9%) followed by Province No. 2 (24%) and was found lowest for Province No. 3 (14.3%).

More than 50% (5.74 millions) of the total goat population was distributed in mid-hill regions with 36 (3.98 millions) in Terai and 11.5% (1.26 millions) in high hills and Himalayan regions of Nepal (**Table 2**). However, according to percentage contribution related to meat production, in total goat meat contributes about 20.4% standing in second position after Buffalo meat (54%).

Province No.	Area (km^2)	Goat population	Density of goats per unit area (no./km^2)	Percentage of total population	Goat meat production (Mt)	Total meat production (Mt)	Percentage contribution
1	25,905	2,285,180	88.2	20.8	12,243	62,932	19.5
2	9661	1,406,039	145.5	12.8	10,012	41,748	24.0
3	20,300	2,108,581	103.9	19.2	10,367	72,253	14.3
4	21,504	1,144,030	53.2	10.4	6416	37,422	17.1
5	22,288	1,958,984	87.9	17.8	14,595	59,083	24.7
6	27,984	1,005,011	35.9	9.2	5058	19,515	25.9
7	19,539	1,078,290	55.2	9.8	6893	29,107	23.7
Total	147,181	10,986,114	—	100	65,583	322,059	20.4

Source: [6, 7].

Table 1.
Province-wise distribution of goat population, density of goats per unit area, meat production (Mt), and its contribution in Nepal.

Agroecological zones	Goat population	Percentage distribution	Goat meat production (Mt)	Total meat production (Mt)	Percentage contribution
Terai	3,983,886	36.3	30,117	145,798	20.7
Midhills	5,736,831	52.2	29,109	153,265	19.0
High hills	1,265,397	11.5	6357	22,996	27.6
Total	10,986,114	100	65,583	322,059	20.4

Source: [6].

Table 2.
Agroecological zone (AEZ)-wise distribution of goat population (number) and goat meat production (Mt) in Nepal.

4. Diversity of goat genetic resources in Nepal

4.1 Existing indigenous genetic resources

In Nepal, four indigenous breeds of goat have been identified and characterized. These breeds are distributed across various ecological domains of the country. They include Chyangra, Sinhal, Khari, and Terai [8–12] (see **Figure 1**). Characterization of these breeds is done based on morphological traits and mitochondrial DNA study (**Table 3**). Terai goats are predominantly found across southern plains and inner Terai (100–500 masl) from east to west of the country. Khari goats, also known as hill goat, are the principal goat breed found across the mid-hill region of Nepal at an altitude of 500–1500 masl. Kuwar [14] reported three distinct strains (small, medium, and large) existed among Khari population. Sinhal goats are abundantly available in high hills and mountain regions from 1500 to 2400 masl, whereas Chyangra goats are the dominant breeds across northern trans-Himalayan regions from an altitude of 2500–5000 masl from east to west.

4.1.1 Terai

Terai goats are found in the Terai region and inner valleys (tropical and subtropical climate) of the country and are reared as the meat-type animals [9]. They have been characterized at phenotypic, chromosomal, and mitochondrial levels [4, 12, 15]. They are heavily crossed with Indian breeds including Jamnapari, Barbari, Ajmeri/Sirohi, and Beetal; and thus population of pure Terai goats is at risk from the conservation point of view. This breed constitutes 27% [16] or less than that of the total goat

Figure 1.
Indigenous goat breeds of Nepal (photo courtesy: Animal Breeding Division, NARC).

Breeds	Positive attributes	Distribution	Status	Characterization
Terai	Hardy, good size, suitable for Terai	Across the Terai	Population declining	Phenotypic + chromosomal + mtDNA
Khari/Hill	Principal breed, suitable for hills, hardy, prolific, meat animal	Across the midhills	Population declining	Phenotypic + chromosomal + mtDNA
Sinhal	Hardy, suitable for high hills, pack animal, large size	Across the high hills	Population declining	Phenotypic + mtDNA
Chyangra	Hardy, suitable for transhumance system, multipurpose (meat, pack, and pashmina)	Across the Himalayas	Population declining	Phenotypic + mtDNA

Source: [12, 13].

Table 3.
Positive attributes, distribution, and population status of Nepalese goats.

population of the country. Body color of Terai goats varies from pure white to pure black with mixed patches of different colors. Its compact body weight is around 30 kg with 60 cm body length, 65 cm chest girth, and 58 cm wither height. Body weight varies from 30 to 35 kg for male and 25–30 kg for female.

4.1.2 Khari

Khari goats (hill goats) are the principal goat breed and are found across the hills and midhills from east to west of the country. They are prolific with higher twinning ability and shorter kidding interval and good for meat purpose. They are hardy and well adapted to local environments and represent more than 50% of the total goat population in the country [16, 17]. They have been characterized at phenotypic, chromosomal, and mitochondrial DNA levels [12, 18]. They are normal from a conservation point of view.

Khari goats have great variation in coat color from white to black. It has been reported that there are six sub-types within Khari goats based on coat color. They are Seti (pure white), Kali (pure black), Khairi (brown), Ghorli (brown with white and other color patches), Singari (black with white stripes on face), and Dhobini (ash color) [19]. Dhobini sub-type is bigger in size than the other five sub-types, weighing around 30 kg, with 63, 65, and 56 cm length, chest girth, and wither height, respectively. Khari goats from different clusters of eastern, western, and midwestern regions of Nepal show that the Khari goats' body size are heavier in midwestern (Salyan and Surkhet) from those found in western and eastern regions (see **Table 4**).

4.1.3 Sinhal

Sinhal goats are the heaviest native goat breed and represent 16% of the total goat population [16] and are the predominant breeds of high hills in Nepal. They are good for meat production and transportation as pack animals under transhumance system provided with low-input management system. They are large-sized hardy and well-adapted animals to local harsh conditions. They have been characterized at phenotypic and mitochondrial levels. The farmers are conserving them in situ, but an increased focus is needed on better management practices on breeding, feeding, housing, and health. They are at risk from conservation point of view.

Parameters	Cluster A (46)	Cluster B (70)	Cluster C (73)
Body length (cm)	69.3 ± 0.3[a]	66.5 ± 0.2[b]	64.9 ± 0.2[c]
Wither height (cm)	66.9 ± 0.2[a]	64.7 ± 0.1[b]	59.2 ± 0.2[c]
Heart girth (cm)	69.9 ± 0.3[a]	66.5 ± 0.2[b]	65.9 ± 0.2[c]
Flank girth (cm)	81.7 ± 0.2[a]	80.1 ± 0.2[b]	71.4 ± 0.1[c]
Flank height (cm)	68.9 ± 0.2[a]	67.3 ± 0.1[b]	61.1 ± 0.2[c]
Ear length (cm)	15.6 ± 0.2[a]	13.3 ± 0.2[b]	13.3 ± 0.1[b]
Horn length (cm)	16.7 ± 0.6[a]	10.7 ± 0.5[b]	11.3 ± 0.3[b]
Adult weight (kg)	38.6 ± 0.8[a]	31.8 ± 0.4[b]	27.7 ± 0.5[c]

Note: Number in parenthesis indicates the number of observations. Cluster A, goats from midwestern region (Salyan and Surkhet); Cluster B, goats from west (Lumle and Bandipur); and Cluster C, goats from east (Sindhuli and Pakhribas) of Nepal. Means with different superscripts differ significantly. Source: [14].

Table 4.
Khari goats from different clusters of eastern, western, and midwestern regions of Nepal.

Sinhal varies in its coat color from black to white, where gray, black, and white mixed are the common coat colors of this breed. Average adult body weight of Sinhal is reported as 35 kg for male and 29 kg for doe, with 69 cm body length, 78 cm heart girth, and 59 cm wither height on an average.

4.1.4 Chyangra

Chyangra goats are the mountain goat originating from Tibet reared in trans-Himalayan region along with Bhyanglung, a type of sheep in high mountain and trans-Himal region 2500 meters above sea level. They have been reared in situ condition by farmers themselves. They are suitable for meat and pack and are popular for high value as well as fine quality called *Chyangra* fiber known as *Pashmina* [20]. Their population is declining and hence needs attention. They have been characterized at phenotypic and mitochondrial levels. Chyangra fiber has high market potentials, as they have unique blend and qualities and hence are popular within and outside the country. Chyangra population is estimated to be around 1% of the total goat population, i.e., 0.11 million heads in Nepal [6]. Body color varies from pure white to pure black with mixed patch of different colors. Its compact body weighs around 30 kg with body length of 62 cm and chest girth of 71 cm. Wither height is 62 cm. Body weight varies from 29 to 32 kg for females and 35–40 kg for males. The morphological variation of four indigenous breeds of goats in Nepal is presented hereunder (see **Table 5**).

Owing to the remoteness, harsh climatic condition and transhumance system of management Chyangra goat are not getting due consideration from public and private institutions. Thus, productivity and population of this breed is dwindling rapidly. The goat is used for meat and for pack purpose in mountain terrace where road facilities are seldom. The breed is also used for production of precious *pashmina* (Chyangra cashmere). Besides their incomparable contribution in mountain farming system, the breed has not been understood completely in the sense of their quantitative and qualitative attributes. Limited information are available on morphological characteristics and growth traits. The breed is not fully utilized for its Chyangra cashmere production, and this is an area of importance where focus is required [25].

4.1.5 Chitwan local goats

Apart from above indigenous breeds, there are niche specific breed studied at inner Terai region, that is, Chitwan District of Nepal, referred to as Chitwan local

Parameters	Terai	Khari	Sinhal	Chyangra
Body length	60.6 ± 0.87	63.1 ± 0.39	68.7 ± 0.44	62.3 ± 0.36
Heart girth	65.2 ± 0.44	65.5 ± 0.37	77.8 ± 0.44	71.3 ± 0.37
Height at wither	57.9 ± 0.32	55.9 ± 0.28	59.2 ± 1.06	62.4 ± 0.23
Height at hip bone	60.8 ± 0.73	51.5 ± 1.76	M: 51.7 ± 1.27 F: 53.3 ± 0.72	M: 60.8 ± 0.78 F: 58.7 ± 0.85
Head length	18.3 ± 0.25	15.5 ± 0.56	16 ± 0.4	15.1 ± 0.6
Tail length	13.4 ± 0.2	12.6 ± 0.3	12.0 ± 0.4	15.1 ± 0.6
Horn length	8.37 ± 0.2	11.5 ± 1.3	15.3 ± 0.84	18.2 ± 0.7
Ear length	18.7 ± 0.30	16.2 ± 0.4	14.5 ± 0.5	10.5 ± 0.4
Neck length	25.7 ± 0.45	20.5 ± 0.56	20.7 ± 0.76	20.2 ± 0.7
Loin girth	74.1 ± 0.65	72.8 ± 0.53	73.5 ± 1.19	70.3 ± 0.43
Barrel girth	84.7 ± 5.8	86.7 ± 3.3	53.2 ± 4.7	75.3 ± 1.4
Fore legs above knee	19 ± 0.52	17.8 ± 0.47	18.7 ± 0.49	16.1 ± 0.51
Fore legs below knee	16.2 ± 0.3	16 ± 0.57	16.3 ± 0.33	15.2 ± 0.65
Rear legs above knee	23.2 ± 0.61	22 ± 0.58	23.2 ± 0.65	18.3 ± 0.54
Rear legs below knee	22.6 ± 0.49	19.8 ± 0.4	21.2 ± 0.3	17.8 ± 0.45
Adult body weight (kg)	F: 23.3 ± 0.1 M: 30–35	F: 24.1 ± 0.34 M: 28–40	F: 34.8 ± 0.12 M: 28–42	F: 29.1 ± 0.69 M: 35–40

Source: [16, 21–24].

Table 5.
Comparative morphometric measurements of indigenous breeds of goat (values are means in cm ± standard errors).

goats. Very limited information is available about this breed to date. These breeds have a medium-sized body having heavier body weight than Khari and Terai goat breeds with dominant white color with distribution of brown, black, and mixed color. It has been reported that the age at first conception, age at first kidding, gestation length, kidding interval, and postpartum estrus were 211, 356, 147, 236, and 87 days, respectively, for adult does of Chitwan local goats. The adult does of Chitwan local (31.1 kg) were significantly heavier ($p < 0.001$) than that of Terai goat (25.9 kg) and Khari goats (23.5 kg). It had been observed that the mean birth, weaning, and postweaning (8 months) weight for these breeds of goats were 2.48, 13.22, and 17.64 kg, respectively. Apart from above findings, it is also reported that the mean litter size at birth were 2.0, 1.53, and 1.48 kids per doe and at weaning were 1.94, 1.49, and 1.28 kids per doe for Chitwan local, Terai, and Khari goats, respectively [26, 27].

4.2 Popular exotic breeds of goats in Nepal

4.2.1 Jamnapari

Jamnapari is a breed of goat originating from the Indian subcontinent. It is a dual-purpose breed kept for both milk and meat. Jamnapari goats were mainly introduced in Nepal to upgrade and improve body weight of local Khari and Terai goats. Adult Jamunapari goat has a body weight of 45 kg for bucks and 38 kg for does along with wither height between 75 and 78 cm, body lengths of 75–77 cm, and heart girth of 76–79.5 cm (**Table 6**). Yearling weight of these goats in research stations was about 21 kg. The average age at first kidding and kidding interval in Jamnapari goats is 770 and 428 days, respectively.

Production performances	Jamnapari		Barbari		Beetal	
Birth weight (kg)	4.3		1.7		2.8	
Yearling wt (kg)	29.6		14.5		15.0	
Adult weight (kg)	44.7	38.0	35.8	22.6	59.1	35.0
Body length (cm)	77.4	75.2	70.4	56.2	85.5	70.4
Hearth girth (cm)	79.5	76.1	75.5	64.3	86.0	73.7
Wither height (cm)	78.2	75.2	70.7	56.2	91.6	77.1

Source: [28].

Table 6.
Comparative productive performance of exotic breeds of goat in Nepal.

4.2.2 Barbari

The Barbari goats are a meat-type breed that is found in Mathura District of Uttar Pradesh, in addition to Gujrat, Jhelum, and Sargodha districts in Punjab Province. Barbari goats are popular for its compact and small body with average adult weight ranging from 23–36 kg (**Table 6**). Body color is mainly white with brownish red spots and coat is short. The head is small, with small upward-pointing ears and small curled horns. Does have good reproductive performance and produce well in intensive system and at dry areas. Average age at first kidding and kidding interval in Barbari goats is 588 and 274 days, respectively. Triple kidding and early maturity are common features of these goats.

4.2.3 Sirohi/Ajmeri

The Sirohi and Ajmeri goats are a meat-type breed that is found in Sirohi District of Rajasthan. This breed also extends to Palanpur in Gujarat. Mature males weigh around 50 kg but females weigh only 25–30 kg (**Table 6**). These are compact, medium-sized animals. Coat color is predominantly brown, with light or dark brown patches; a very few individuals are completely white. Most animals are wattled. Ears are flat and leaf-like and medium-sized and have a drooping ear length of 18.8 cm. Both sexes have small horns, curved upward and backward. Tail is medium in length and curved upward. Udder is small and round, with small teats placed laterally. Some commercial farms and lead farmers have imported this breed and crossbred with Khari and Terai goats, but the information regarding the productive and reproductive performance is still to come.

4.2.4 Boer

The Boer is an improved breed with some infusion of European, Angora, and Indian goat breeding developed in South Africa in the early 1900s. The Boer goat is primarily a meat goat with several adaptations to the region in which it was developed. It is a horned breed with lop ears and showing a variety of color patterns. The most common color of this breed is white body with red head and large, muscular frame. The Boer goat is being popular for its browsing ability and limited impact on the grass cover. Producing weaning rates in excess of 160%, the Boer goat doe is a low-maintenance animal that has sufficient milk to rear a kid that is early maturing. The mature buck weighs between 110 and 135 kg and does between 90 and 100 kg. Performance records for this breed indicate exceptional individuals are capable of average daily gains over 200 g/day in feedlot. More standard performance would be 150–170 g/day.

The ovulation rate for Boer goats ranges from one to four eggs/doe with an average of 1.7. A kidding rate of 200% is common for this breed. Puberty is reached early, usually about 6 months for the males and 10–12 months for the females. The Boer goat also has an extended breeding season making possible three kids every 2 years.

It was introduced in Nepal from a private sector to improve growth performance of local goats. Recently, projects funded by the World Bank (WB) and International Fund for Agriculture Development (IFAD) implemented by the Ministry of Agriculture and Livestock Development specifically Agriculture Food Security Project (AFSP) and Kisan Ka Lagi Unnat Bui Bijan Karyakram (KUBK), respectively, are working on producing crossbreds with the local Khari/Hill goat, government, and breeders' farmers

Figure 2.
Different exotic goat breeds available in Nepal (photo courtesy: Animal Breeding Division, NARC).

of mid- and far-western regions. Goat Research Station, Bandipur; RARS, Khajura; and GDF, Budhitola, are the government-owned farms with nucleus herd of Boer goat in Nepal. However, a comprehensive study on survivability, growth, and reproductive performances as well as efficiency (economics) needs to be investigated.

4.2.5 Saanen

Saanen goats are dairy goats originating from Switzerland, in the Saanen Valley. Saanen does are heavy milk producers (on an average of 4 L/day) and usually yield 3–4% milk fat. It is medium to large in size (female weighing approximately 65–70 kg and males weighing about 80–90 kg) with rugged bone and plenty of vigor. Saanen goats are white or light cream in color, with white being preferred. The hairs are short and fine, although a fringe over the spine and thighs is often present. Ears are erect and alertly carried, preferably pointing forward. The face is straight or dished. A tendency toward having a Roman nose is being discriminated against. The breed is sensitive to excessive sunlight and performs best in cooler conditions.

4.2.6 Beetal

The Beetal is a breed used for meat and milk production found in Punjab, Pakistan, and India. The Beetal is usually black and the males have long twisting horns. The breed is similar to the Jamnapari but smaller. The adult male weighs around 60 kg and females are 35–40 kg (**Table 6**). The coat is short and lustrous. The face line is convex, with a typical Roman nose but not as prominent as in Jamnapari. Ears are long and flat, curled, and drooping with ear length of 24.8 cm. The udder is large and well developed, with large conical teats. Pictorial presentation of popular exotic breeds in Nepal is provided in **Figure 2**.

5. Breeding management

5.1 Selection

Genotype of an individual is determined by the genes received from the buck and doe at fertilization (union of sperm and ova) and remains the same throughout life except in few circumstances. Therefore improving genetic superiority of kids depends on the careful selection of superior bucks and does and mating them appropriately. Thus, selection is the most basic and common tool being practiced for genetic improvement in the major economic traits of goats. It is the process of choosing superior goats (male and female) from the herd that are likely to be the parents of the next generation.

Selection, whether based on individual, family, or pedigree, is dependent upon the economically important traits (meat, milk, pashmina, etc.) of the selected genes. Goats in Nepal have been mostly selected for meat production. However, the mountain goats are also being selected for pashmina (fiber) production, and in very rare cases, they are being selected for increased milk production. These traits are quantitative and are influenced by many genes (additive, dominance, and epistatic). Chyangra goats produce up to 2–3 kg pashmina fiber annually.

There is potential to develop dual-purpose meat and fiber producers but only under improved nutritional conditions compared to present day. Thus, there is great possibility of developing Chyangra as a dual-purpose goat breed in mountain ecosystem.

In selecting for fiber, one is interested in both quantity (weight) and quality of fiber (length, fineness, style, character, absence of Kemp, etc.). In addition to fiber, one must be concerned with traits that contribute to the survival or viability (soundness, fertility, etc.) of the individual and flocks.

The selection of any breed for a particular ecological domain may not give the desired result if the required care is not paid in selecting genetically superior individual as parents of future generation. Indigenous goat breeds (Chyangra, Sinhal, Khari, and Terai goats) and exotic breeds (Jamnapari, Barbari, Beetal, Saanen, Damascus, Kiko, etc.) have their own importance. Nepal government has focused mainly on selection and mating of the best to the best individuals within the existing indigenous goat population. However, recommendation of the appropriate breeds for the specific ecological belt of Nepal is not consistently working at farmers' level.

Here are the important selection criteria breeders are following to select the goats in general for their genetic for improvement:

- High growth rate (greater finishing weight at slaughter age)
- Prolificacy (twining)
- Kid rearing (less kid mortality—milking ability of does)
- Resistance to internal parasite—good growth
- Early age at maturity and regular kidding (3 times in 2 years)—good fertility
- Carcass yield and quality

Chyangra goats are being selected by the breeders and/or herders to some extent for improving:

- Quantity of pashmina fiber
- Quality of the fiber (fineness, length, color also matters)
- Body size and weight trait (correlated response larger body size—larger surface area and more Pashmina yield)

Selection for pashmina fiber quality includes primarily fiber diameter (finer fibers preferred), length (4 inches minimum), freedom from Kemp (coarse, brittle, chalky white hair mixed in the fleece), and desirable lock formation.

Selection for quantity of pashmina fiber is accomplished efficiently by using fiber weights of Chyangra goats which are being considered as breeding animals. However, history indicates that most producers practice visual selection. In this case the predicting indicators of fleece weight are:

- Size of the animal
- Completeness of cover
- Length of fiber
- Diameter fiber
- Differences in density

Traits	Genetic gain/year (a)	R	Genetic gain/year (b)	R
Birth weight (g)	105	6.4	58	3.5
Weaned weight (g)	289	4.0	159	2.2
6-month weight (g)	276	3.4	152	1.9
36-week weight (g)	295	2.9	162	1.6
48-week weight (g)	394	3.2	216	1.8
LS at birth (no)	0.008	0.5	0.005	0.3
LS at weaning (no)	0.008	0.6	0.004	0.3
LW at birth (g)	120	4.6	66	2.5
LW at weaning (g)	247	2.5	136	1.4

(a) When both selected bucks and does are used; (b) when only selected bucks are used. R = response to selection per year (%). Source: [29].

Table 7.
Predicted response to selection for both growth and reproductive traits in Khari goat breed.

Genetic gain and response to selection have been studied for some weight and litter traits of Khari goats [29], and it is reported that these selection parameters were higher when both males and females are selected than when only males were selected (see **Table 7**).

5.2 Pure breeding

Pure breeding within the indigenous goat population is common practice among the herders especially in the mountain and high hill region. Thus, Chyangra and Sinhal goats are bred within themselves for maintaining genetic purity without losing the adaptation potentials of the flock. In some areas where goat improvement interventions are not implemented by the government and/or development agencies, pure breeding of Khari goat is common as well. This system of breeding helps maintain the genetic purity of native breeds un-deteriorated and could be conserved for long.

5.3 Crossbreeding

In the last few decades (1990s), Khari goats were massively crossed with the Indian Jamnapari and Barbari goat breeds for increasing growth and productivity of native breed, assuming that the crosses of Jamnapari and Barbari goats with Khari would give the better result. After some research works carried out by the Nepal Agricultural Research Council (NARC) at its agricultural research stations (ARSs), the Department of Livestock Services (DLS) again convinced that the Khari could be the best breed for meat production because of its better production characteristics, especially higher twinning percentage, prolificacy, lower kidding interval, efficient average daily gain (ADG), higher resistance against the diseases and parasites, etc.

Now, Khari goats are being crossbred with Boer either naturally or through artificial insemination with frozen semen in hilly regions across the country through the initiation of leading private goat entrepreneurs (Bagmati Goat Seeds Pvt. Ltd., Dhadhing; Bagaichha farm house, Nawalparasi; Jagatput Agro, Chitwan, etc.), Ministry of Agriculture and Livestock Development, and internationally funded projects including Agriculture and Food Security Project (AFSP) funded by the World Bank, Improved Seeds Program for Farmers (KUBK/IFSP) funded by IFAD, etc.

Breed	Body weight kg (mean ± SE)				
	At birth	4 M	6 M	9 M	12 M
Khari	1.75 ± 0.38	7.57 ± 2.33	11.02 ± 4.31	15.23 ± 6.17	19.24 ± 5.67
Sinhal	1.87 ± 0.10	11.22 ± 3.49	14.03 ± 3.12	17.34 ± 4.67	22.05 ± 5.68
Barberi	1.43 ± 0.42	7.35 ± 1.01	10.48 ± 1.88	14.40 ± 3.89	19.38 ± 4.89
50% Jamnapari	2.32 ± 0.65	9.11 ± 2.74	14.69 ± 4.60	18.38 ± 4.44	21.27 ± 5.06
50% Barberi	1.73 ± 0.28	6.87 ± 2.32	10.31 ± 1.26	14.35 ± 3.63	18.43 ± 4.21
50% Kiko	1.83 ± 0.72	7.86 ± 1.10	12.27 ± 3.68	17.81 ± 4.38	20.0 ± 3.97
50% Boer	2.20 ± 0.61	13.80 ± 3.29	17.85 ± 4.36	25.25 ± 5.88	34.10 ± 8.62

Source: [30].

Table 8.
Growth performance of indigenous and crossbred goats at Goat Research Station (GRS), Bandipur.

Fixed factors	No.	Birth (BWT)	Pre-weaning (PWW)	Weaning (WWT)	6 months (SMW)
Grand mean	772	2.48 ± 0.03	7.04 ± 0.12	12.09 ± 0.22	20.52 ± 0.16
25% Boer:75% Khari:0% JP	232	2.38 ± 0.04[b]	7.03 ± 0.14[ab]	11.72 ± 0.26[ab]	20.70 ± 0.15[b]
25% Boer:50% Khari:25% JP	10	2.21 ± 0.09[c]	6.37 ± 0.30[b]	10.53 ± 0.55[c]	20.63 ± 0.90[b]
50% Boer:50% Khari:0% JP	218	2.69 ± 0.04[ab]	7.68 ± 0.14[a]	13.45 ± 0.26[a]	23.40 ± 0.19[a]
50% Boer:25% Khari:25% JP	16	2.86 ± 0.10[a]	7.55 ± 0.33[a]	13.62 ± 0.60[a]	23.91 ± 0.58[a]
0% Boer:100% Khari:0% JP	296	2.26 ± 0.04[b]	6.58 ± 0.15[b]	11.11 ± 0.27[bc]	18.05 ± 0.11[c]
Significance		***	***	***	***
CV		9.73	10.30	11.12	9.34
R^2		0.61	0.53	0.54	0.58

*** *Significant at 0.1% level of significance.*
JP = Jamnapari. Source: [31].

Table 9.
Growth performance of Khari and its crossbred kids at different growth stages under farmers' field.

The preliminary results suggest that crossbreeding Boer with native Khari breed would give a better result with respect to higher growth rate maintaining twinning ability of the crossbred female kids. The growth and reproductive performance of Khari goats crossbred with different exotic breeds is presented hereunder (see **Tables 8** and **9**).

Growth performance of Khari and its crossbred kids with different blood levels of Boer and Jamnapari breeds were studied [31], and it was reported that there was a significant difference ($p < 0.001$) between the crossbred kids of different blood levels with respect to birth, pre-weaning, weaning, and 6 months weight at their respective ages. Accordingly, the crossbred kids of a three-way cross with 50% Boer:25% Khari:25% Jamnapari blood level has the best result in the weight traits at different stages as compared to other blood levels (see **Table 9**).

At Goat Research Station, Bandipur, under Nepal Agricultural Research Council, 50% crossbred kids of Khari and Boer were evaluated. Preliminary results suggested

Age	Male		Female		Overall
	Weight (kg)	ADWG (g)	Weight (kg)	ADWG (g)	weight (kg)
Birth	2.92 ± 0.66		2.44 ± 0.83		2.68
Weaning (4 months)	16.37 ± 3.5	109.5	14.96 ± 1.95	102.25	15.66
Postweaning (8 months)	29.48 ± 1.32	109.37	25.32 ± 1.46	94.29	27.40
Yearling (12 months)	42.32 ± 1.49	107.09	38.87 ± 1.29	99.12	40.59

Source: [32].

Table 10.
Growth performance of 50% Boer kids from birth to yearling age at Multiplier Herd, GRS, Bandipur.

S N	Reproductive traits	Khari × Jamnapari	Khari × Barbari	Khari × Kiko	Khari × Sannen	Khari × Boer
1	Age at first kidding (d)	577	564	576	423	
2	Kidding interval (d)	319	286	496	257	
3	Twinning percentage	45.50	58.33	33.00	91	
4	No of kids/doe/ annum	1.79	2.09		2.6	2.55
5	No of kids weaned per doe per annum	1.28	1.60	1.14		
6	Live weight gain per doe per annum (kg)	19.14	16.15	18.37		

Source: [28, 33].

Table 11.
Some reproductive parameters of crossbred goats in Nepal.

Figure 3.
Crossbred goats at Goat Research Station, Bandipur (photo courtesy: Goat Research Station, Bandipur, Nepal).

that there is great scope and possibility of enhancing growth and productivity (average daily weight gain) of native Khari goat in later generation by producing crossbred kids of Boer goat. Body weight of 50% Boer crossbred kids at different stages of growth from birth to yearling age is presented hereunder (see **Table 10**).

Furthermore, reproductive traits of Khari and its crossbred female kids are expressed differently in different genotypes (see **Table 11**). The trait value for important reproductive traits of female kids of different crosses is presented hereunder. Pictorial presentation of different crossbred goats in Nepal is provided in **Figure 3**.

6. Variation in genetic parameters

6.1 Heritability

Limited research has been carried out to estimate the genetic parameters of goat flocks in Nepal. Findings indicate that most of the desirable economic traits of goats in Nepal are moderately to highly heritable (see **Table 12**). Moderate to high heritability of the weight traits of *Khari* goat kids [17] indicated a relatively large contribution of additive genetic variance and potentiality for improving body weight in goats by selection. Similarly, increasing heritability of body weights of kids at the later stages of growth indicated that environmental factors have more influence on birth weight than on the weights achieved on the later stage of growth.

6.2 Genetic and phenotypic correlation

Past studies have revealed the genetic correlation among the weight traits at different stages of growth of *Khari* goat kids ranging from 0.61 to 0.96 (see **Table 13**). The high and positive genetic correlations of weaning weight at 6, 9, and 12 months of *Khari* goat kids indicate that they are all being controlled by similar genes, and thus selection for any one of these traits would lead to positive changes in the other [35, 36].

Traits	Heritability (Harvey)
Birth weight	0.37 ± 0.12 [17]
Pre-weaning weigh	0.42 ± 0.13 [17]
Weaning weight	0.42 ± 0.13 [17]
6-month weight	0.46 ± 0.14 [17]
9-month weight	0.44 ± 0.13 [17]
12-month weight	0.40 ± 0.12 [17]
15-month weight	0.39 ± 0.12 [17]
Litter size at birth	0.10 ± 0.093 [34]
Litter size at weaning	0.05 ± 0.097 [34]
Litter weight at birth	0.44 ± 0.155 [34]
Litter weight at weaning	0.66 ± 0.202 [34]
Kidding interval	0.03 ± 0.099 [34]
Gestation length	0.21 ± 0.118 [34]

Source: [17, 34].

Table 12.
Heritability estimates for different traits of hill goat.

Body weight at	Body weight at						
	Birth	Pre-weaning	Weaning	6 months	9 months	12 months	15 months
Birth	—	0.61**	0.71**	0.72**	0.76***	0.79***	0.78***
Pre-weaning	0.64**	—	0.81***	0.80***	0.75***	0.65**	0.55*
Weaning	0.67**	0.80***	—	0.95***	0.86***	0.78***	0.68**
6 months	0.68**	0.75***	0.91***	—	0.93***	0.85***	0.76***
9 months	0.71**	0.69**	0.81***	0.92***	—	0.96***	0.85***
12 months	0.70**	0.62**	0.75***	0.83***	0.94***	—	0.95***
15 months	0.72**	0.56*	0.66**	0.76***	0.86***	0.94***	—

*Significant at 5% level (i.e., $p < 0.05$).
**Significant at 1% level (i.e., $p < 0.01$).
***Significant at 0.1% level (i.e., $p < 0.001$).
Source: [17].

Table 13.
Genetic correlation (above diagonal) and phenotypic correlation (below the diagonal) between the weight traits of Khari *goat kids at different stages of growth in Nawalparasi, Nepal.*

Similarly, phenotypic correlation among the weight traits at different stages of growth of *Khari* goat kids ranged from 0.56 to 0.94 (see **Table 13**). Strong positive association among the weight traits of kids at all stages of growth indicates that selection for increased weight at earlier age will result in increased weight of kids at later stage of growth as reported by earlier studies [37].

7. Biotechnological approaches

Biotechnological advances particularly estrus synchronization, artificial insemination (AI), and embryo transfer (ET) have not been exploited widely so far in the country and could be the avenue of future goat development program. Lack of goat breeding centers for quality seed and ever-increasing demand on breeding stocks and chevon strongly justify the massive use of AI and ET in goat. National Livestock Breeding Center, Pokhara, and Animal Breeding Division, NARC, are being stepped up in the direction.

7.1 Estrus synchronization and artificial insemination

Synchronization of estrus allows the farmers to shorten the breeding season of their flock by bringing all of their does into heat around the same time so that they will kid at the same time. Other advantages of this technique include reducing the time required to check heat, reducing the time required for intensive care of the herd or flock, and pregnancy being able to be shifted to coincide with favorable marketing patterns. Controlled Internal Drug Release (CIDR) device is being used in conjunction with gonadotropin (pregnant mare serum gonadotropin) hormone to bring does into estrus.

Artificial insemination, in the developed countries, is the good example of how tremendous improvements can be made in both genetics and reproductive management of goats by using synchronization methods. In Nepal, frozen Boer goat semen (both pellet and straw) is being imported from India and Australia to upgrade Khari goats through AI at research stations, government farms, and multiplier herd identified at mid- and far-western regions of Nepal. However, the result of AI and conception obtained till date is not so convincing due to lack of skilled technicians, timely unavailability of liquid nitrogen at remote areas, and improper husbandry practices followed by farmers (grazing and feeding). Thus, AI program needs to be reviewed and practiced on station first to improve the conception rate before wide dissemination.

7.2 Embryo transfer

The Government of Nepal has established embryo transfer facilities at National Livestock Breeding Office (NLBO), Pokhara. Works have been started in dairy cattle and importation of live embryo, and transferring them to the recipient is being practiced occasionally in this species. However, this technology is not being tested in the case of goats to date in the country.

7.3 Biochemical analysis

It has been reported that the Khari/Hill goats across the mid-hill region from east to west of the country has three distinct types with respect to genetic distance. The goats of the midwestern are bigger in body size followed by western region with eastern region having a smaller body size. Also a report on protein analysis indicated that hemoglobin was polymorphic in Khari/Hill goats with two genotypes, HbAA and HbAB, in the sampled population. The gene frequency of HbA was higher than HbB, which was more in the goats sampled from eastern Nepal. Also, it has been reported that the four genotypes of transferrin, TfAA, TfAB, TfBB, and TfAC, were found in the Khari/Hill goats with decreasing frequencies. The gene frequency of TfA was the highest followed by TfB and TfC. The gene frequencies of TfB and TfC were higher in the goats of eastern Nepal. Both polymorphisms of these two principal blood proteins including differences in gene frequencies between the populations of Khari/Hill goats found in different locations indicated the genetic variation in Khari/Hill goats [38].

7.4 Mitochondrial DNA study

Nepal has a sizeable indigenous goat population with four identified breeds (Chyangra, Sinhal, Khari, and Terai) and many nondescript goats. The study on genetic diversity and phylogeography of these identified breeds' mitochondrial DNA (mtDNA) hypervariable (HVI) region has shown high mtDNA diversity among Nepalese goat breeds with haplotype diversity ranging from 0.86 to 0.99, and all haplotypes could be classified into four haplogroups (A–D) (see **Figure 4** and **Table 14**). mtDNA haplogroup A was observed in most of the Nepalese goat populations, whereas only one breed (Chyangra) contained all four haplogroups [12]. Chyangra has been classified in the haplogroup B2 which is found in Tibetan goats which exhibits their genetic relationship. The four mtDNA haplogroups A–D found in Nepalese goats further supported the previous view of multiple maternal origins of domestic goats. These results indicated that there was no correspondence between the geographic regions of origin and relationships among goat breeds. These sequences were compared with published data of other domestic goats from neighboring countries (Bhutan, India, Pakistan, and China) to determine the relationship of Nepalese goats among goat resources of the region. The study revealed certain level of gene flow among the neighboring goat populations. The complex mtDNA diversity and structure identified among indigenous Nepalese goats can be explained by the gene flow through ancient trading and current "free" movement of goats from/to the geographic vicinities in India and China.

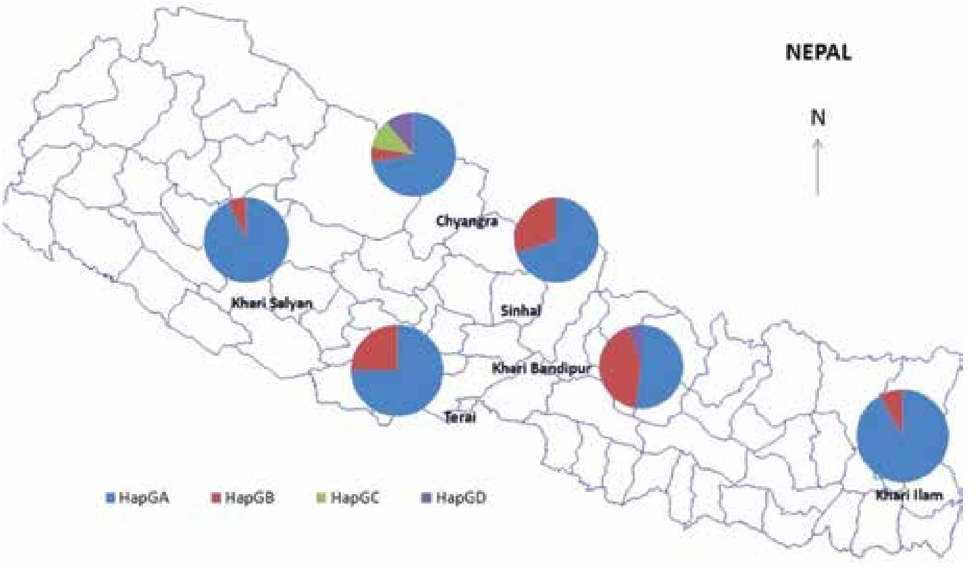

Figure 4.
Haplogroups of Nepalese goats (haplogroups A–D). Source: [12].

Breed/population	No. of goats per haplogroups					Haplotype diversity (h ± SD)	Nucleotide diversity (π ± SD)
	A	B1	B2	C	D		
Chyangra	13	—	1	2	2	0.99 ± 0.02	0.03 ± 0.01
Sinhal	7	3	—	—	—	0.87 ± 0.09	0.03 ± 0.01
Khari—Ilam	11	1	—	—	—	0.86 ± 0.08	0.02 ± 0.01
Khari—Bandipur	10	8	—	—	1	0.94 ± 0.04	0.03 ± 0.03
Khari—Salyan	13	1	—	—	—	0.95 ± 0.05	0.02 ± 0.01
Terai	15	5	—	—	—	0.97 ± 0.03	0.03 ± 0.02

Source: [12].

Table 14.
Distribution of mtDNA haplogroups in Nepalese goat breeds/populations.

These sequences were further compared with the published sequences of Asian domestic and wild goats to determine the relationship of Nepalese goats among goat resources in the region (Bhutan, Pakistan, India, and China). The results suggested that the genetic diversity and structure in mtDNA genome among indigenous Nepalese goats have been shaped not only by the intensive and continuous gene flow among goats distributed in middle and lowland in Nepal and geographical vicinity in India but also by the exchanges between goats found in high hill of Nepal (e.g., the B2 haplotype present in Chyangra goats) and Tibetan goats in China.

8. Conclusions

Goat industry in Nepal is becoming popular among the commercial farmers, and it is assumed that the future prospects of the species are quite promising. Goats, as an animal with multiple utilities, have high adaptability in diversified climatic condition right from extreme hot to extreme cold. However, goats in Nepal have limitations in terms of body weight gain and market weight. There is opportunity for improving productivity of existing goats without increasing the total population based on the application of animal breeding technology along with advances in husbandry and disease control measures that have demonstrated success, worldwide. The need to reorient development activities by adding value to indigenous breeds must be focused. Crossbreeding of native goat breeds such as Chyangra and Sinhal in the mountain region is not gainful so far. Selection and mating of the best male to the best doe is only the option to improve the genetic potentiality of these breeds in the region. The importation of exotic breeds for crossbreeding particularly in the hill and mid-hill regions may not be meaningful unless provision for feed with increased nutrient requirements and disease control measures are readily available to the herders.

- Genetic gain depends upon the selection difference, response to selection, heritability, and generation interval.

- Heritability of the reproductive traits is lower (<0.15), production traits such as milk production are medium (0.15–0.30), and growth-related traits are higher (>0.3).

- Selection can be one of the tools, but only selection cannot improve all the economic traits of goat.

- Attention should be given in the selection process for the appropriate traits, pedigree recording, feeding, health care, and management for the goat productivity enhancement in Nepal.

- Crossbreeding of Nepalese hill goat with Boer goat is giving a better result with respect to growth and reproductive performance initially. However, further evaluation is needed for valid conclusion.

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Conflict of interest

Authors do not have any conflict of interest.

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Section 2

Kashmir - Pashmina

Chapter 5

New Look on an Ancient Fiber of Cashmere

Seyed Abbas Rafat

Abstract

The word cashmere in particular refers to the fine fibers of goats that are grown in high and cold regions of the world. There is not a specific cashmere-producing goat in the world, that is, there are many breeds or ecotypes that produce cashmere fibers. Cashmere-producing goats are grown majorly in areas that are very limited in alternative sources of income, such as agriculture or industry. Therefore, raising goats will encourage the villagers to live in the same rural and nomadic areas and do not migrate to cities. Therefore, the socio-ecological aspects of cashmere goat farming are important and must be notified by animal scientists. Structure of hair and cashmere fibers, physiology, and genetic and nongenetic factors that influence cashmere goats has been mentioned. Challenges and problems facing the cashmere industry reviewed briefly in this chapter: In general, cashmere goat production has some very interesting aspects from interaction of animal science and textile industry's viewpoint. Cashmere goats are combined with many other human activities in low-density farming. In the world today, it is necessary to pay more attention to raising goats in less developed areas. We declared the importance of cashmere goats in a whole system of animal production, especially in extensive agriculture systems.

Keywords: cashmere, goats, livelihood, lux textile, agrotourism, fleece, hair, diameter, combing, fine fibers

1. Introduction

The word cashmere in particular refers to the fine fibers of goats that are grown in high and cold regions of the world. Cashmere industry has been noticed again in textile industry in recent years. Fashion designers are passionate about animal fibers including cashmere. So there are high demands for luxury animal fibers. But demand for cashmere sometimes gets sinusoidal. Demand has increased significantly since 2011. If cashmere production's comparative advantage has been considered by producing countries, a good economic result will have been obtained.

There is not a specific cashmere-producing goat in the world, that is, there are many breeds or ecotypes that produce cashmere fibers, so in this chapter our aim from "cashmere goat" is the "cashmere-producing goats." The term of "cashmere goat" refers to goats whose main production is cashmere fibers. Biologically, there are many goats that produce cashmere fibers from their secondary follicles in the skin, but their cashmere quantities are not sufficient as we could nomenclature them as "cashmere goats".

There are some advantages of natural fibers in comparison with synthetic fibers.

Some advantages of natural fibers including animal fibers have the following particular preferences:

- Natural fibers are a healthy choice: Natural fibers provide natural ventilation. Synthetic fibers occasionally cause skin sensitivities, and therefore people with severe skin eczema should be strictly prevented from long contact with synthetic made clothes.

- Natural fibers are a responsible choice: Natural fibers are of major economic importance to many developing countries and vital to the livelihoods and food security of millions of small-scale farmers and processors.

- Natural fibers are a sustainable choice as long as human have access to the sun and soil for agriculture: The emerging "green" economy is based on energy efficiency, renewable feed stocks in polymer products, industrial processes that reduce carbon emissions, and recyclable materials. More recent studies have shown that producing 1 ton of polypropylene—widely used in packaging, containers, and cordage—emits into the atmosphere more than 3 tons of carbon dioxide, the main greenhouse gas responsible for global warming.

- Natural fibers are a high-tech choice: Natural fibers have good mechanical strength, low weight, and low cost. They have some characteristics that make them exclusive in textile industry.

- Natural fibers are a fashionable choice: Natural fibers are at the heart of an eco-fashion or "sustainable clothing" movement that seeks to create garments that are sustainable at every stage of their life cycle, from production to disposal. For example, Cashmere wool is the best sustainable and renewable fiber with virtues to protect the user from the surrounding rudiments [1].

2. Importance of goat production

Perhaps the most important reason of goat keeping is its role in the livelihood of people. This role could not be replaced with other species of ruminants: Raising goats is the only way to save the life of millions of people around the world. Goats can be grown in the areas where it is not possible to breed other animals like cattle or sheep. Furthermore, in some situations, "goat" is the exclusive animal who transforms low-quality roughage to human food. There is some vegetation on steep, mountainous and rocky terrain that can be beneficiated only by goat production. Because other farm animals such as cattle or sheep cannot live there.

Cashmere-producing goats are grown majorly in areas that there are very limited in alternative sources of income, such as agriculture or industry. Therefore, raising goats will encourage the villagers to live in the same rural and nomadic areas and not migrate to cities.

There is an organ in the body of the goat called the rumen. The rumen can be named as a high-performance "bioreactor" because its output is higher than input! We consider rumen as a very large "Petri dish" that transforms efficiently nonprotein nitrogen to valuable animal protein consumable by human.

Estimation of goat population from FAO STAT is presented in **Figure 1**. Major cashmere-producing countries are China, Mongolia, Iran, Afghanistan, Kazakhstan, Kyrgyzstan, Pakistan, Turkey, and other minor producers such as New Zealand. China is the world's largest producer of cashmere production, accounting for more than 70% of world output; Mongolian cashmere production accounts for about 20% [2]. Other estimates showed that China and Mongolia produce 60–70%

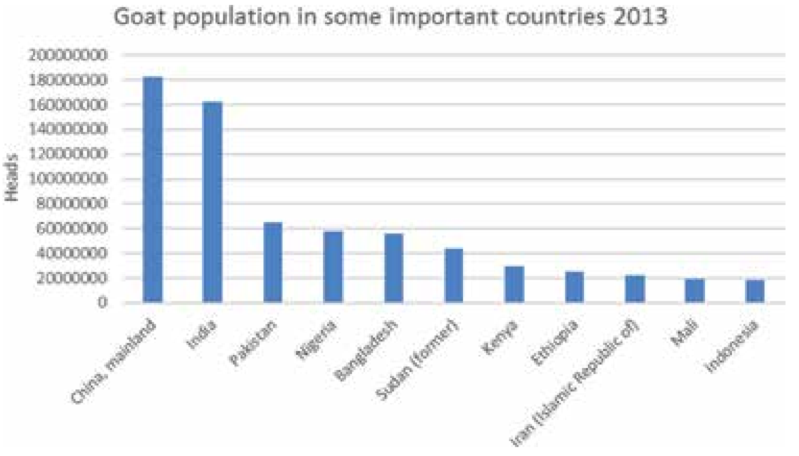

Figure 1.
Estimation of goat population. FAO stat 2019.

Source of cashmere	Price in 2000 (US$/kg)	Price in 2018	2005 #	2010 #	2015 #	2016 #	2017 #	2018 #	2019 #
China	*	600–800 UMB/KG	94	127	124	109	110	140	131
Mongolia (14–15.5 μm)	105	105.000–110.000 MNT/kg	74	98	88	82	78	118	95
Iran (17.5–18 μm)	75	*	58	87	86	73	69	97	108
Kazakhstan (19–19.5 μ)	17–50	*	*	*	*	*	*	*	*
Reference	D. B. Holdsworth	www.gschneider.com							

**Not available data.*
#Schneider index.

Table 1.
Price estimation of exported dehaired-cashmere in some countries.

of the world production of raw cashmere while and Iran and Afghanistan produce nearly y the rest (20–30%) [3].

Also there are some other estimations about cashmere production quantity. It is estimated that production of raw cashmere be nearly 8000 tons annually [4]. Australia and New Zealand between them produced just 45 tons of down [4]. **Table 1** shows an estimation of exported dehaired cashmere in some countries. Iran is one of the main producers and exporters of cashmere in the world, third after China and Mongolia. Of the 25 million goats in Iran, 5 million are cashmere-producing goats.

We have no access to any exact statistics about the cashmere production in the world. We can summarize the following reasons for this:

- The exact figures of cashmere amount are not available in the major cashmere-producing countries.

- This product is constantly traded between the producer countries. It's difficult to find the source of existing cashmere at trading time. For example, cashmere of Afghanistan is traded among Iran, Tajikistan, Kyrgyzstan and China:

- Cashmere is considered more likely as a by-product, so governments do not pay enough attention to collect exact data.

- The production of cashmere cannot be estimated from the number of goats. There is no direct relation between the number of animal or animal weight and the production of cashmere. For the reason of existing very different cashmere-producing breeds/ecotypes with diverse genetic potential of cashmere production, it is difficult to estimate total cashmere production from the data of animal numbers.

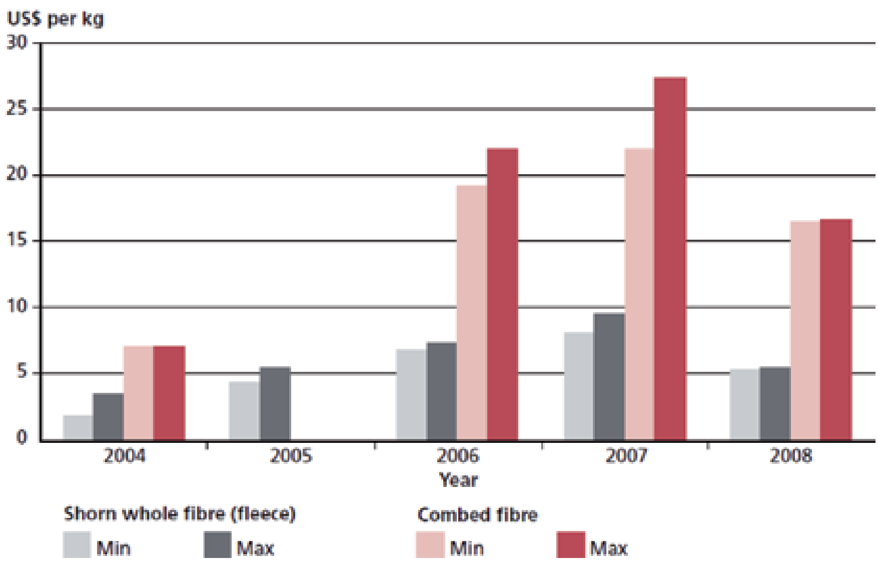

Figure 2.
Raw cashmere purchase price from farmers (LPP, LIFE Network, IUCN–WISP and FAO. 2010. Adding value to livestock diversity – Marketing to promote local breeds and improve livelihoods. FAO Animal Production and Health Paper. No. 168. Rome).

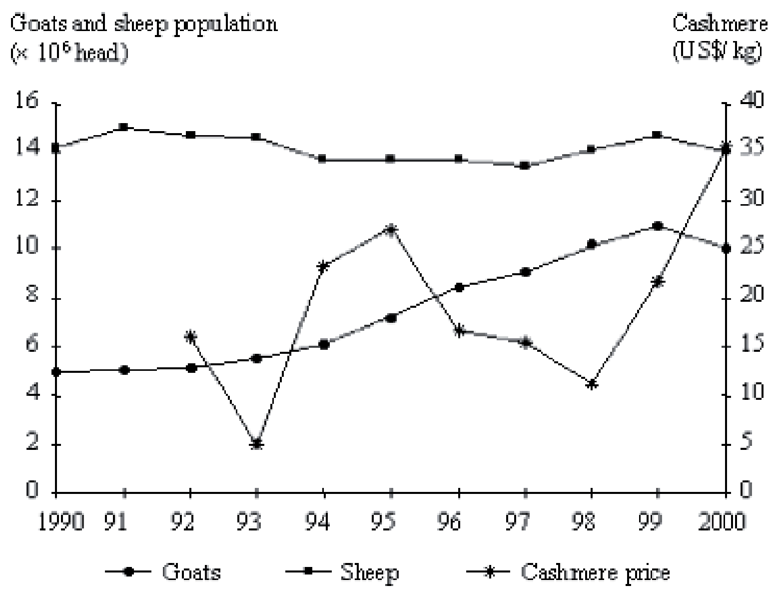

Figure 3.
Goats and sheep population and cashmere prices in Mongolia, 1992–2000, Sources: Bakey et al. (2001); FAO (2002).

- Demand and consumption diagram of cashmere has sinus form. Therefore, the cashmere warehouse has effect on exports and imports of cashmere. Sometimes cashmere has been deposit until rising of prices.
- The major areas of cashmere production are mountainous, in extensive system of animal production. So estimation or recording of cashmere production is not possible precisely. Exceptionally New Zealand and Australia publish their exact statistics about their low quantity of cashmere production.
- Due to the competition of textile companies among them, accurate information is not provided on the supply of raw materials. Cashmere harvest system in China (combing) is different in comparison with Iran and Afghanistan (Shearing), so it is difficult to compare quantity of cashmere production from fleece weight.

We mention here for example, two figures of estimation of raw cashmere purchase price from farmers (**Figure 2**) and cashmere prices in Mongolia, 1992–2000(**Figure 3**).

3. Biology

3.1 Most important cashmere-producing breeds

From a biological viewpoint, all of the dairy goats produce cashmere, but in some breed the production of cashmere is noticeable, so they have been nomenclatured as "cashmere-producing goats." Indeed, many breeds of goat have secondary follicles in their skin that produce "down coat" or cashmere. But the amount of this cashmere is very different among breeds. So, from each goat, we can harvest cashmere, but its quantity may be 10–500 gr/animals. In conclusion, the breeds with sufficient quantity of down fibers will be famous as cashmere goats. For example, some breeds are shown in **Figures 4–6**. In the literature, various words could be found for cashmere, e.g., Kork, Tuvet, and pashmina. Cashmere goat is named as Tibet goat in some bibliographies. Some cashmere-producing goats are Nningza, Soyan, Gansu, and Raeini. The wild goat of *Capra hircus blythi* found in Sind and Baluchistan is probably a ascendant of cashmere goats.

Figure 4.
Main cashmere goat breeds of Iran: Raeini (first row), Nadoushan (second row) and Birjandi (third row). (Ansari 2013).

Figure 5.
Cashmere goats in Herat, Afghanistan (photo by A. B. Hotak, cashmere world, 2014).

Figure 6.
A cashmere goat farm, Kirghizstan. S. A. Rafat 2012.

3.2 Terminology

For the readers it may be interesting to be familiarized a little about terminology of some animal fibers. General fiber's name, species, and scientific name of some important animals in the world of "animal fibers" are:

- Wool: From sheep (*Ovis aries*)

- Cashmere: From cashmere goats: *Capra hircus* Laniger

- Mohair: From Angora goats: *Capra hircus aegagrus*
- Cashgora: a crossbreed of cashmere and Angora (Mohair) goats
- Angora: From Angora rabbits: (*Oryctolagus cuniculus*)

3.3 Cashmere products

Cashmere is a delicate fiber of certain goats that are bred in high and cold regions of the world. The term of cashmere was named as it taken from countries of China, Iran, and Afghanistan to the Kashmir region. In Kashmir, these fibers has been transformed into precious shawls.

In the past few years, the cashmere industry has attracted the attention of the textile industry, which is referred to as "the renaissance of cashmere." The reasons for this reminiscent of cashmere are the interest of individuals and designers of natural fibers; global markets including China; the contribution to sustainable development and the global fight against poverty. According to some researchers, Central Asian countries are potential future suppliers of cashmere.

Cashmere is used in luxury textiles of niche markets, including shawls, coats, cushions, blankets, runners, sweaters, t-shirts, scarves, shawls, and so on (see **Figures 7–9**). A wide range of high-quality and expensive products are produced from cashmere. Cashmere's clothing is generally light and at the same time keeps the human body warm. Designers of clothing use this fiber as a good material that has a lot of design and color.

3.4 Structure of hair and cashmere fibers

The staple of cashmere goat is made up of two parts of the outer coat (hair) and inner coat (cashmere). The hair is thicker and longer and has a medulla channel in the center of the fiber, protecting the animal against physical damages, while cashmere protects the animal from the cold. The cashmere fibers are similar to true wool, which is like a cylinder full of keratin. Three types of medulla have been recognized in hair: Continuous, no breaks in the medulla; interrupted, few short breaks; and fragmented, few parts of medulla visible. Characteristics of these three types of hair in mixed final products of hair should be studied. For more information see *Silk, Mohair, Cashmere and Other Luxury Fibers* edited by Franck [5].

Figure 7.
Istanbul Cashmere Bazaar – Price of each Shwal is nearly 300–500 US $ - 2014 - Photo by seyed abbas rafat.

Figure 8.
Jewelry Stores in Istanbul beside cashmere product stores. "Cashmere = Gold". The nick name of cashmere in this Bazaar is "white gold" – 2014 – Photo by Seyed Abbas rafat.

Figure 9.
Left: SUSTAINABLE CASHMERE® HANDKNITTED SHAWL-: www.chianticashmere.com. Right: Cashmere fibers utilized for a traditional hat, Azerbaijan, Iran photo by: Abbas hüseynlu.

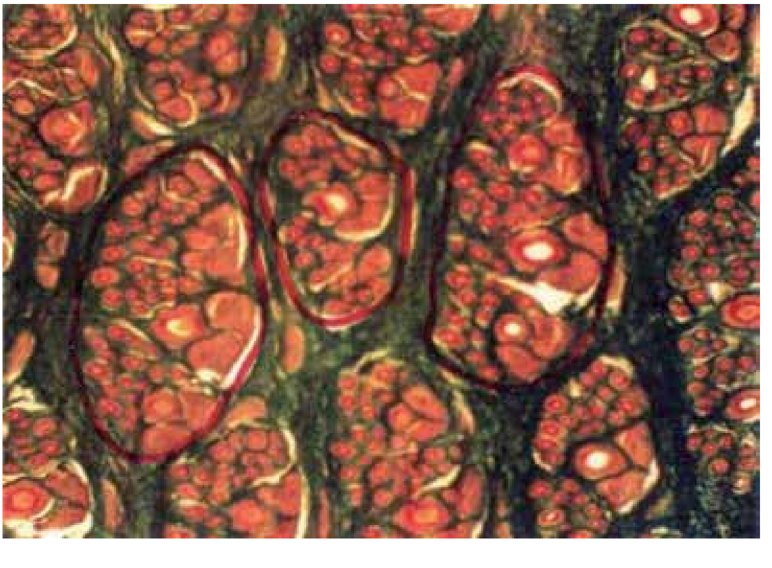

Figure 10.
"Trio" Follicle Groups of Cashmere Goat Skin, Raeini cashmere goat, Kerman, Iran. Rafat M Sc. Thesis.

Figure 11.
Follicle group in cashmere goat in cross section view. P = primary follicle. S = secondary follicle RAFAT M Sc. Thesis.

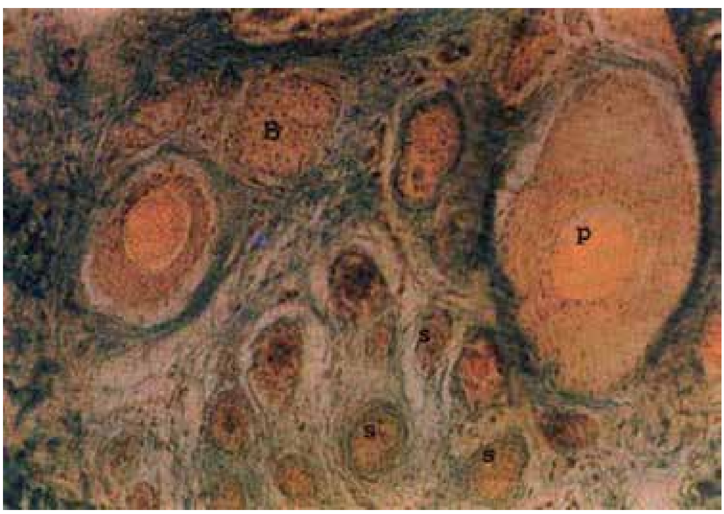

Figure 12.
Inactive Secondary Follicles (s), Primary follicle (p) and sebaceous gland (B). Rafat M Sc. Thesis.

The growth of hair in the staple of cashmere goats occurs seasonally. That means cashmere, in general, takes 6 months to grow (anagen) and then enter the growth stop (telogen) with a middle stage of catagen. The shedding of cashmere from the body depends on some factors, such as the length of the day of photoperiod, nutrition, and the physiological state of the animal, and cashmere begins to grow from late spring, and in the winter it stops growing, and with the arrival of spring, cashmere is separated from the body until the next growth period begins. The large variation of shedding time exists among and between breeds.

Hair follicle or "small factory of keratin production" has an organized structure with the name of "trio group." Each group has normally between 1 and 3 first follicle and some secondary follicle (5–50). Primary follicles, sweat glands, sebaceous glands, and arrector pili muscle are other small organs within a trio group (**Figures 10–12**). By verifying the structure of skin in histological studies, we can distinguish some traits of follicles, e.g., secondary to primary ratio, percentage of inactive secondary follicles, diameter of follicles and density of follicles per surface of skin.

4. Genetic and nongenetic effects

4.1 Nongenetic factors

Fiber producing animals majorly divided into two categories:

1 One-coat (e.g., Angora goats, Merinos sheep)

2 Two-coat: (a) Outer coat for summer, physical protection, and (b) inner coat for winter thermal insulation, e.g., cashmere goats, Angora rabbits, camel, wild sheep.

The most important characteristics of cashmere are means of fiber diameter, length, and color. Definition of cashmere quality depends on yield, diameter, length, and color. Microscopic measurements of fiber characteristics are projection microscope and OFDA. The first method, although it is a basic method, is very time-consuming and can have an operator bias. The second method of OFDA is a very fast method that measures about 2000 fibers in a few minutes. Mean fiber diameter, standard deviation, and percentage of hair could be measured rapidly with OFDA.

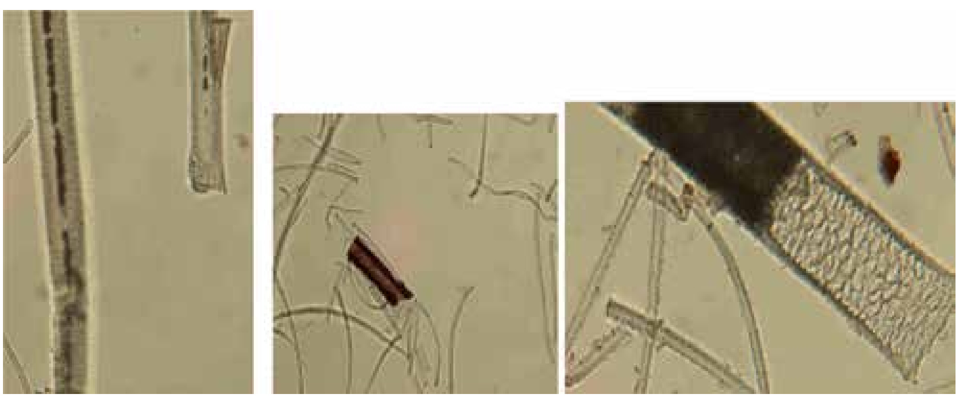

Figure 13.
Cashmere and hair fibers under light microscopy – University of Tabriz.

Figure 14.
Cotton (left), true wool (middle) and colored (right) carpet wool fibers. University of Tabriz.

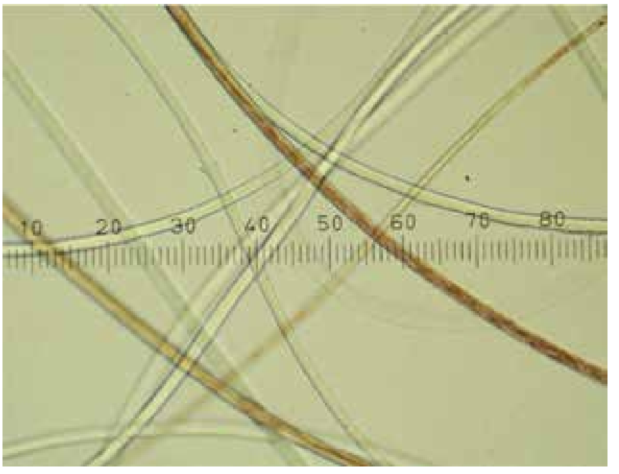

Figure 15.
Cashmere, light and dark gray, 100x. University of Tabriz.

Microscopic study of cashmere shows us the specific structures of fine fibers and modulation forms. Furthermore we can distinguish different types of fibers that may be mixed within cashmere tops of fabrics (**Figures 13–15**).

Characteristics of Iranian cashmere as an example of cashmere goat are measured as [6]:

- Raw fleece weight: 540 gr (100–700 gr)
- Yield: 56.5 ± 12.2%
- Mean fiber diameter 19.7 ± 1.5 μm, range of 17–21
- Fiber diameter standard deviation of 4.5 ± 0.6 μm,
- Fiber curvature of 62.9 ± 8.5°/mm
- Staple length of 54.2 ± 7.0 mm

The diameter, length, color, and amount of impurities are the factors that affect cashmere price. High mean fiber diameter, colored fibers, short length of fiber, hair, and high percentage of impurities are factors which influence the prices of Iranian cashmere. Large changes in price of raw cashmere, low technology of cashmere end-products in the country, and lack of home market for cashmere products are the problems that face the cashmere goat breeding. A solution is upgrading the technologies related to cashmere processing, and this must be accompanied with collaboration of farmers. Also it must conserve genetic resources of cashmere goats and utilize animal breeding techniques for decreasing mean fiber diameter. Environment situation has some effects on cashmere growth. These effects are including nutrition and different proteins, energy to protein ratio, body condition score, body size, vitamins, minerals and hormones, The effect of fetal feeding on follicle formation during pregnancy period. Non genetic effects on cashmere could be age, flock, harvest technique, color, year, season, shedding, parasites, location of body, physiological state of pregnancy and lactation. For example, effect of sex, age, and flocks on cashmere diameter and staple length of Raieni goats has been studied by Shamsaddini et al. [7]. Interaction of sex and age has significantly effect on cashmere characteristics ($P < 0.05$) staple length between station and nomadic goats.

The age groups had a significant effect ($P < 0.05$) on coefficient of the variation of cashmere's fiber diameter. It was concluded that the first 15 days after birth is much more important to develop secondary follicles in Raeini cashmere kids and affects cashmere production of Raeini kids in the economic life span [8]. It was evident that cashmere mean fiber diameter and coefficient of variation of cashmere's fiber diameter were effected ($P < 0.05$) by different seasons. An outstanding researcher on the effects of nutrition on cashmere goats is B. McGregor. Readers are advised to see his article of [9].

4.2 Genetics

Generally, cashmere fibers are genetically similar to those of sheep wool, same as the rules governing quantitative genetic of cashmere. For example, the main trait of fiber production, i.e., wool yield and fiber diameter, is considered as a quantitative trait. But color trait of cashmere, similar to color of wool in the classic genetic, has been considered as a categorical trait, so its distribution is different from normal. There are many researches on cashmere production that showed nearly all important traits of cashmere are genetically heritable. Therefore with selection of the best reproduction candidate among goats, we can arrive to the improvement in cashmere traits. Heritability of cashmere production traits is similar to sheep wool, so the principals of quantitative genetics could be utilized in cashmere goats. However, some differences should be notified in cashmere in comparison with wool. Fleece of cashmere goat is a double coat, so it is very different from fleece of Merinos sheep. Merino sheep has one-coat fleece, but cashmere goat has a specific type of fleece in which two different fibers exist. Scale pattern of cashmere and fine wool is different, and that is a major reference distinguishing them from each other.

4.3 Selection aim

Cashmere is an ornamental product, special and luxurious, and the supply and demand in the international marketplace have influenced the domestic purchase prices of raw cashmere, and consequently the income of livestock farmers is affected by raw crude sales. The price of raw cashmere (fleece: majorly including hair and cashmere) purchase from the herd has been fluctuating every year, and as a result, their livelihood affects the breeding of cashmere goats. The consequence of this process is a challenge for genetic improvement of goats. Farmer changes his livestock composition when the price of cashmere decreasing. So he select his animals toward other traits of meat or milk prefer than cashmere.

Therefore, it is necessary to support the cashmere farmers stabilization of purchasing prices. Because farmer does not have the financial capability to pursue breeding programs and maintain breed purity in favorite of cashmere. A solutions for problems of the cashmere goat breeding is provision of scientific-technical supports and the formation of NGOs and breed associations. It must stabilize the purchase price of raw cashmere and minimize the negative effect of fluctuations in global prices on local goat production. It needs to establish cooperative factories to access more value-added products and identify domestic and foreign consumption markets. To achieve this, not only the livestock sector but also other sectors, such as textile, apparel and design, and art, should also work together in producer countries. Genetic markers has been found that help the animal breeders to use in selection of the more profitable cashmere goats. Furthermore, genome wide association studies has been started in goats which is an effective method for genetic improvement of cashmere goats.

The both method of classic best linear unbiased prediction (BLUP) and new genomic BLUP could be utilized in genetic improvement of cashmere goats. The important step of application of new methods of genomic selection is to measure

Figure 16.
Liaoning cashmere goats (left) and other breeds(right) from China(with thanks for photo provided by M. Yasen Xinjiang Animal Science Academy Tian Kechuan).

phenotypic traits as much as possible. There is need to record phenotype traits in cashmere goats in new area of genomic selection. The genetic improvement of cashmere goat is necessary through classic genetic and modern genomic approaches.

Genetic improvement of fiber-producing animals is accelerated by new genomic provided data. In the near future, beside classic genetics, molecular genetics-based sciences such as transcriptome, SNP chip, and "marker-assisted selection" will be applied in cashmere goat's genetic breeding programs. Crossbreeding of cashmere goats with Angora goats produces a specific type of fibers with the name of "Cashghora." For example, this type of crossbreeding is currently used in Asia, for example in Kirgizstan.

China has suitable experiences in genetic improvement of cashmere goats (**Figure 16**).

4.4 Cashmere harvest

Basically, there are two methods of removing fibers from the goat's body: manual scissors and combing method. For combing method please see video MOV08863.

Figure 17.
Harvesting of cashmere with combing method (Kirghizstan, photo by Rafat).

Figure 18.
Cashmere goat of Iran: Raeini breed. Left: Shedding of cashmere in spring. Middle and right: Cashmere goat covered by fabrics to protect animal from cold weather after natural shedding of cashmere in early winter, Baft, Kerman, Iran. Rafat M.Sc. Thesis.

Figure 19.
Cover for cashmere goat to protect them after shearing in cold weather of Tabriz, Tabriz, University of Tabriz, Khalat pooshan research center.

Scissors are used in Afghanistan, Iran, Kyrgyzstan, Tajikistan, and similar countries. The resulting harvested fleece is a mixture of cashmere and hair. Combing methods (**Figure 17**) produces more pure cashmere content among harvested fibers from animal in comparison with shearing. So the harvested fibers are mostly cashmere with less hair fibers content. Farmers that use scissors to harvest fibers, they does not paying attention to quality when buying and selling. The only trait of interest is weight of fibers. But in countries that farmers use combing method, qualitative criteria are considered when selling. Cashmere goats are very sensitive to cold weather after shearing of cashmere. So decision on the suitable time for cashmere shearing is important. Sometimes we see some animals that shed their fibers very early, so goat keepers have some technics to protect their animals from cold weather (**Figures 17–19**).

5. Agrotourism and challenges of cashmere production

Breeding goats can help develop agrotourism. Many tourists like to buy real cashmere from their main production site. This can lead to the employment of the villagers and prevent migration from rural to urban areas. It is also good for governments to strengthen cashmere's industry to solve the unemployment problem. Investing in the goat production industry and cashmere production results in profitability compared with other industries. Because cashmere production is consistent with sustainable agriculture, it has less environmental problems and is not polluting.

The tourism industry and agrotourism and ecotourism can also be considered in contributing to the developing of cashmere industry. In producer countries, the traditional textile industry structure should be developed with the participation of livestock producers, so that livestock farmers are directly beneficiated from the cost of buying and selling of final products. Research and educational centers can support livestock production in this field or provide technical and scientific information. In the province of Kurdistan of Iran, the goat breed of "Morkhoz" is a practical example of agrotourism with presentation of local cloths from goat fibers. Morkhoz goat produces a special type of fiber that is utilized in a type traditional handmade clothing. So, all process steps from goat keeping until final cloth preparation has been made within the region. For more information see Rafat 2001. In other countries, examples of this type can also be cited. Nora Kravis (Chianti Cashmere), a veterinarian in Italy who created a flock of goats in 1970s, has become one of the most successful cashmere-producing farms, selling products of cashmere, and is now emerging as an example of successful rural entrepreneurship. In some countries of cashmere production, such as Afghanistan, they established in 2007 the first ever scouring line, Herati Cashmere. In some cashmere production regions, the model of Mohair production in France may be examined.

However, despite these attractive conditions, goat keepers are increasingly abandoning their activity for higher-income jobs. The young generation is not interested in cashmere goat production. The cashmere-producing countries need to find solutions to make the profession more appealing to young people. One way would be to increase their income significantly. The other challenges of cashmere productions are:

- More attractive jobs in comparison with goat keeping
- Low price of cashmere from producer (e.g., 15–20 USD, spring 2012, Iran)
- Purchase fleeces without any attention to fitness, yield, staple length, color, and other quality criteria
- Ecological concerns about goat production
- Multivariate selection for genetic improvement of goats
- Introduction of genomic selection in goats
- How to learn the community, producers, utilizers, and students about the importance of animal fibers and cashmere
- Organization for workshop, seminars, video conference, email group, etc. for learning more

For increasing returns and to improve qualitative and quantitative characters of cashmere, cashmere producers and commercial trading partners need to complete the processing cycle.

Another challenge is how aware the goat keepers with principal methods of animal breeding are. It needs to learn to the farmer new techniques of animal selection. They must to consider color or fleece weight in selecting of reproductive animals. Furthermore, how we can select among reproductive animals for several traits together, e.g., selection for birth weight, fertility, mature weight, resistance to diseases beside fiber traits.

Ansari-Renani et al. [10] studied improving livelihoods of small farmers and rural women through value-added processing and export of cashmere. Small producers of cashmere goats in Tajikistan, Kyrgyzstan, and Iran share the problem of poor access to world fiber markets and as a result experience considerable losses of income. Many of the program activities targeting production and market constraints of the cashmere can be implicated based on following development program: Analysis of markets and farmers' access to market; improvement in goat management within households; improvement in shearing and classification of fiber; and standardization based on international quality standards.

6. Material and methods

The materials and methods used in this chapter of the book were (a) to do a bibliography including author's researches [11–16] on cashmere goats. In some of the author's researches, he measured fiber characteristics by himself with microprojection technic. For example, in one of them, we tried to know the effects of age and feeding level on fiber diameter of cashmere [12].

So in this bibliography, the author's experiences were the majority part of the chapter. These experiences included:

- Frequent visits to goat breeding areas and living with goat keepers.
- Contact with cashmere goat keepers. Their livelihood depends on cashmere production.
- Research on characteristics of cashmere and genetics of cashmere goats.
- The results of some of these activities helped to clarify the origin of goats in the world [11].

7. Conclusions

In this chapter, we tried to see the cashmere fiber from another perspective. This view was based on the dependence of the life of farmers on the production of cashmere. Economic significance, the principles of biology, the structure of cashmere goats, genetics, and fiber-based products were reviewed. The importance of raising goats for the production of cashmere is further noticed by the fact that in the modern life of today's world, there are those people whose livelihoods depend on the sale of cashmere. It is necessary to introduce cashmere to the new generation of students in the field of animal science. A lot of interesting research and achievements about cashmere happened 50 years ago. The task of the authors of livestock books is to familiarize young researchers with this subject. This chapter was an attempt to familiarizereaders with the main concepts of cashmere industry. There are issues in the textile industry that are related to raw materials. Solving the problem of raw materials is the responsibility of the animal breeders. The needs of the consumer and the cloth's fashion world should be identified. Then livestock scientists, including animal nutritionist, physiologists, and geneticist, try to produce the raw material of cashmere needed by the industry. At the same time, it will supply income for goat keepers. Cashmere production helps our world to live more peaceful.

Conflict of interest

We have not any "conflict of interest."

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Chapter 6

Pashmina Goat Farming in Cold Arid Desert of Changthang and Its Impact on Economy of Changpa Nomads of This Region

Akeel Bashir Beigh and Samina Bashir

Abstract

In Changthang, there is a trend towards increasing the livestock population, especially a breed of goat (*Capra sibirica*) that produces one of the finest natural fibres: pashmina, which is the mainstay of economy of Changpa nomads. The environmental condition of this region suits for the development of pashmina, therefore, these animals are reared in large numbers. Changthangi goats are reared under harsh climatic conditions (−40 to +40°C). Best quality pashmina is produced in this region and is economic mainstay of nomadic people of Changthang. Pashmina fibre is very expensive as it is being used for production of world's finest shawls. The Changthang region alone produces around 35,000 kg of raw pashmina fibre every year from about 0.15 million of Changthangi goats, which form 80% of the total pashmina production of the country. 90% of the population in Changthang area survives on the income from goat and sheep, which is nearly $8.4 million, annually.

Keywords: pashmina goats, Changthangi, Changpa, cold arid desert

1. Introduction

Goats, essentially an Asian animal are distributed in all ecologies and their fibres classified as mohair, pashmina and hair, but mohair and pashmina have the commercial importance. India's indomitable heritage is possession of goats in high altitude Himalayan cold arid region that produce pashmina (cashmere), which is fine, tough, warm and soft. Pashmina can also be defined as the down (undercoat) fibre derived from cashmere goats with a diameter of 30 microns or less. Pashmina has derived its name from the Persian word 'Pashm' meaning, soft gold, the king of fibres [1]. India produces the best pashmina of the world with an annual production of about 40 tons but this is merely <1% of the total world production [2, 3]. In India two pashmina breeds viz., Chegu and Changthangi are recognized. Changthangi goat is reared in Changthang and adjoining areas of Leh in an area of 20,000 sq. km at 3000–6000 m above MSL (−40 to +40°C) under extensive system. Pashmina is the economic mainstay of the people of Changthang, as almost 55% of the income is generated by this fibre [4]. With the increase in demand of raw pashmina the cost of this fibre is highest in the international market (90–180 Eu/kg in 2004) [5]. The present per annum production of pashmina from Ladakh is about 35,000 kg which is harvested from about 0.15 million Changthangi goats [6, 7].

Pashmina is a precious animal fibre for its warmth, firmness, lightness and softness apart from to dye absorbing property in comparison to mohair or wool. Pashmina is a valuable fibre for quality designer apparels. Guinness Book of World Records has accredited it with the reputation of being costliest cloth in the world after ban imposed on natural fibre Shahtoosh (called as King of fibre) produced from small Tibetan Antelope known as *Chiru*. Fifty tonnes of pashmina was produced in India during 2005–2006, 80% of which was obtained from *Changthangi* breed. Fibre obtained from goats with <19 μm of diameter is termed as cashmere however, the Changthangi fibre has average diameter of 10–14 μm, making it the best. Pashmina shawls which are brilliantly dyed are prepared from *Changthangi goats* are a fashion sensation with essential elements of style and comfort throughout the world [8].

Besides *Changthangi goats*, *Changluk* sheep (used for meat purpose) is an essential part of pashmina goat based trans-humance delivery system. It serves as alternative source of income for sustenance of *Changpa* when the production system fails. The Changpas rearing the pashmina goats in the Changthang region have a significant contribution to the economy of Ladakh (cold arid region, which accounts for 107,545 km^2 of the total 387,390 km^2 zone in the country). Rest of the region is a hot arid Indo-Gangetic plain and peninsular India [9]. Nomads encounter a myriad of problems, like, poor living standards, fodder shortage, no market accessibility and involvement of huge investments. These hindrances render nomads to generate very much lesser returns than its potential.

2. Breed characteristics

This goat (*Capra hircus*), a mammal belonging to subfamily Caprinae and family Bovidae produces fine, soft and much straighter double fleece of hair called guard hair. These goats are of medium type, their height ranges from 60 to 80 cm. The average weight of male and female pashmina goats is about 45 and 35 kg respectively. They possess wide horns; have blocky builds, and refined features. Pashmina goats occur in different colours. White tends to be dominant but black, brown, red, cream, grey and badger faced are very common. These goats tend to be alert and cautious, rather than docile and placid. These traits are largely due to their feral ancestry, relatively only a few generations back (**Figure 1**).

Figure 1.
Pashmina goats leaving for grazing. Source: Beigh (author of this chapter).

3. Morphological characters

Colour of Changthangi goats generally vary from white to light brown (88% of the goats are white in colour and only 12% have a light brown colour). The colour of the head of Changthangi goats ranges from white to black with a few animals spotting grey head. Birth parameters are: the length is about 26.0 ± 0.2 cm, the height at wither and girths at chest is 27.7 ± 2.0 and 29.9 ± 1.6 cm, respectively. The whole body of the animal is covered with undercoat of pashmina as well as long hair. The face and muzzle are without hair. The ears of Changthangi goats are small in size and erect while the horns possess a typical character. The horns are curved first upward and then backwards, downwards and onwards. The body is observed to be straight and heavy.

Goat size (avg.)	Changthangi male (adult)	Changthangi female (adult)
Body weight (kg)	30	28
Body length (cm)	52	53
Body height (cm)	53	52
Chest girth (cm)	66	65

3.1 Classification of pashmina goats

Based on the various physical parameters, the world pashmina goats can be classified into four main groups: (1) western, (2) eastern, (3) feral and northern, and (4) Pashmina-Mohair crossbred goats [3].

3.1.1 The western (Kirgiz) type

The principal characteristics are a higher production of undercoat and coarser undercoat fibres than Mongolian and feral goats and undercoat is often longer than the outer coat. Undercoat weight as a percentage of fleece weight is 75–80%, but there is some content of intermediate fibres. Undercoat fibre length is 9–11 cm, fibre diameter 18–20 μm, body weight of adult does 34–36 kg and body weight of adult bucks 55–60 kg.

3.1.2 The eastern (Mongolian) type

The principal characteristics are long outer coat fibres protecting a fine undercoat, and shorter undercoat fibres (5–6 cm) than in the Kirgiz type. Undercoat production is up to 350 g for does and 600 g for bucks, but more for the best animals. The principal aims of selection are a higher undercoat weight and longer undercoat fibres, but no change in undercoat diameter.

3.1.3 Feral and northern goats

Re-domesticated feral goats are relative newcomers in cashmere production, and the population is very heterogeneous and unimproved. Undercoat percentage and production are often smaller than the economics of single-purpose production would require, and the role of these goats in the economy should be viewed, at present at least, from the point of multipurpose production.

3.1.4 Pashmina-Mohair crossbred goats

Crossbreeding of cashmere goats with mohair goats leads to increases in fibre length, fleece weight and fibre diameter. Over-long undercoat, resulting from crossbreeding with mohair goats, is prone to weathering.

4. Management practices

The hardy and agile Changthangi animals are well adapted to the migratory life practiced under difficult conditions by Changpa. The Changpas reside in traditional circular tents called as 'Rebo' with a local heater arranged in the centre (**Figure 2**). The herds are moved out in open each day for grazing throughout the day and later returned to the villages by night. The grazing spots for summer and winter are properly earmarked although the herds remain migratory. The harsh climatic conditions induce the production of undercoat for insulation against the extreme weather. The animals have adapted well enough to survive on sparse diet where they prefer scrubs to richer grasses. The goats moult at the beginning of summer, by the end of winter combing is done using a combing device to obtain maximum yield of pashmina. The sexual cycle photoperiodism regulated, triggered by decreasing day length and the animals become sexually active from June. Breeding takes place during November and December and the kidding takes place during months of April and May. The kid mortality has been observed to be low, approximately 3%. For mating purpose one buck is sufficient enough to breed 40 does. Weaning of the young one is normally done at 4 months of age. Daily milk production averages 700 ml/animal with lactation length of about 5 months. The goats are kept in open air within stone fencing (**Figure 3**). Highland grazing is generally carried out during the month of July to September, while as the pasture grazing is done during months of May to June and October to December. Goats are restricted to stall feeding from January to April to avoid exposure to the very cold weather. In stall feeding, the average concentrate given to individual animals amounts to 400 g for does, 500 g for bucks and 300 g for young animals daily, while fodder given has been estimated to 1.5 kg to bucks and 1 kg to does as well as young animals daily.

4.1 Production parameters

Of total 15,000 metric tons pashmina wool produced in the world, China's share is 70% followed by Mongolia at 20%. India's yield constitutes a mere 1% of the world's pashmina production. Of this, 40 tones are derived from the around 1.6 lakh

Figure 2.
Outer view of Rebo. *Source: Beigh (author of this chapter).*

Figure 3.
Pashmina goat paddock fenced with stones. Source: Beigh (author of this chapter).

pashmina goats found in the Ladakh region of Jammu and Kashmir. Pashmina yield by bucks is lower and a relatively higher yield by does. These goats are very poor in milk production. On an average a female goat can produce 200–500 ml daily. Pashmina yield per annum in Changthangi goats is about 80 g at first clip, 150 g at second clip, 230 g at third clip, 200 g at fourth clip and 210 g at fifth clip. The length of fibre is observed as higher in males than females [10].

4.2 Reproductive parameters

The reproductive traits of the goats make up an essential part of the farmer's ability to maintain the farm population systematically making the farming enterprise profitable. The age of first tupping, age of first kidding, the gestation period, kidding interval and the litter size of Changthangi goats is 668 ± 18, 830 ± 13, 152, 397 ± 7 days and 1, respectively. Single kidding is more common in 99% cases and twinning is very rare in Changthangi goats. Gestation period of Changthangi goats is 150 days.

4.3 Properties of pashmina fibre

Fibre fineness is the most important quality parameter and it differentiates pashmina fibre from the sheep wool. The average fibre fineness of pashmina fibre is 12–13 μ. The average fibre length is 55–60 mm. The fibre length depends on its origin/genotypes, grade and source. The mean fibre length of guard hair varies from 25 to 93 mm [2]. The microscopic structure of the fibre is given in (**Figure 4**).

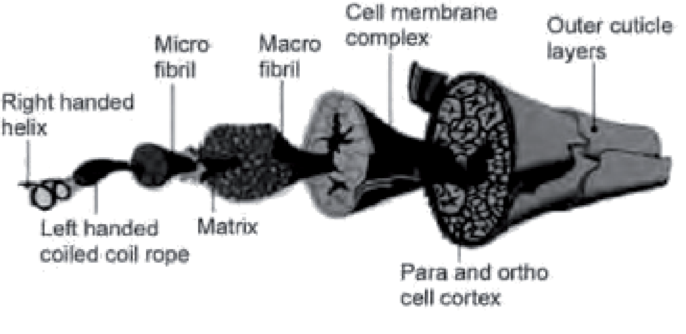

Figure 4.
Morphological structure of wool. Source: Shakyawar et al. [2].

5. Disease prevalence

Occurrence of diseases is quite rarely observed in Changthangi goats. Most common problems are related to stunted and retarded growth. Sometimes, animals suffer from diarrhoea which due to parasitic and poisonous grasses. In goat kids, tapeworms, roundworms and coccidian infestation has also been observed sometimes. In big farms, vaccination is followed for FMD, pox and clostridial infection. Gid is a common incidence in Changthangi goats. Tick infestation is commonly found. Deworming with anthelmintics and dipping with some antiparasitic drugs two times a year is being followed in some of the organized farms. However, these medical activities are not so common among the poor small village farmers, which has resulted in comparatively higher mortality in the animals. Sometimes, genetic defects like cryptorchidism, stumpy ear, short legs, prognathism and mixture of body colour is found in some animals.

6. Economics of Changthangi goat rearing

Changthangi goat rearers usually build up the flocks from their own animals over the period of productive life of animal and cull old/unproductive and dispose surplus animals. The most important benefits from *Changthangi goat* rearing is in the form of pashmina, animal sales, changes in flock inventory, milk and manure. The returns obtained from pashmina forms the major chunk of gross returns in *Changthangi goats* (>40%) which is followed by the sale and value addition in kids. Goat rearing not only generates income for the people living under harsh cold climatic extremes, but also provides a livelihood as well as food security to the nomads (*Changpa*) in the form of milk and meat. Pashmina enterprise being profitable also possesses self-employment potential and if proper attention and care is taken, it will prove helpful in increasing the family welfare of down trodden nomads rearing the breed under miserable conditions [8].

7. Material and method

Changthangi goats are mostly concentrated in Changthang sub-division (Nyoma and Durbuk blocks) of Ladakh which is also known as pashmina belt of Jammu and Kashmir. In addition non-descript goats and Changluk sheep are reared mainly for meat and milk in other parts of Leh. In this chapter information regarding birth weight, lactation period, calving period, age, kidding, yield of pashmina, disease occurrence, marketing values, etc. is provided.

8. Discussion

In India, pashmina is obtained from Ladakh region of Jammu and Kashmir, Lahul and Spiti valley of Himachal Pradesh, Uttar Kashi, Chamoli and Pithargarh districts of Uttaranchal. The pashmina obtained from Jammu and Kashmir is known as Changthangi pashmina whereas that obtained from HP and Uttaranchal is known as Chegu pashmina. Best quality pashmina is produced in Changthang region of Ladakh and is economic mainstay of nomadic people of Changthang.

9. Conclusion

Pashmina, as a valuable fibre being produced by Changthangi goat, should be marketed properly in order to help the farmers derive greater economic benefit.

The rearing of pashmina goats is economically viable in terms of gross, net, family labour income and employment generation. Fodder banks may be established to supply fodder to the farmers during lean periods. A proper management, health monitoring and well planned breeding programme should be adopted to enhance the performance of Changthangi goat.

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Section 3

Cheese Quality

Chapter 7

Goat Cheese Quality in North Macedonia

Erhan Sulejmani

Abstract

The most significant agricultural industry in North Macedonia is the dairy industry, and white-brined cheese is a popular dairy product with a great history and the most selling cheese in the country. Considering the climatic conditions and the experiences of other countries, the Republic of North Macedonia has capacity for adequate development of goat breeding by creating small-to-medium goat farms and application of intensive or semi-intensive goat farming systems. There are various breeds of goats in the Republic of Macedonia such as the domestic Balkan goat, Saanen, and Alpine and crossbreeds between these breeds. The official restriction of goat breeding in the territory of Macedonia in 1947 had disastrous consequences; however, in 1989, goat breeding was again allowed and has increased. There are three most significant kind of cheeses manufactured in Macedonia, like white-brined, beaten, and kashkaval. White cheese in Macedonia (belo sirenje) is a brine cheese type with salty taste and close texture similar to beyaz peynir (a Turkish white cheese).

Keywords: domestic Balkan goat, white cheese, kashkaval, beaten cheese

1. Introduction

The Republic of North Macedonia is a land-locked country in southeastern Europe in the Balkan Peninsula, with 850 km of frontier with five countries: Serbia, Kosovo, Montenegro, Albania, Bulgaria, and Greece. The country has a surface area of 25,713 km^2. Half of this area (1.26 Mio. ha) is agricultural land, out of which 560,000 ha are classified as cultivated land and 704,000 ha as permanent pastures. Mountainous forest land covers 37% of the country, and about 2% is covered by lakes. Livestock and goat farming is very important in the Polog area, in the foot of the Sharr Mountain. These areas represent a mountain chain stretching from the southern part of Kosovo and northwestern Macedonia to northeastern Albania. The Sharr Mountain represents the largest mountain massive in Macedonia and extends to these geographic coordinates, between 42°41′43″ and 42°16′34″ north latitude, as well as between 20°34′51″ and 21°16′00″. The mountain system is about 80 km long and 10–20 kilometers wide. It includes a number of high points, among which the highest peak of the Titov vrv is 2747 m, Mali Turc (2702 m), Ljuboten (2498 m), and Bistra (2641 m).

Goat breeding in Macedonia is defined by spontaneous and continuous development, and with each day, there is major concern of farmers for goat's growth as a market that provides secure subsistence and business. The breed structure of goats in the country is based on the domestic Balkan goat with a certain representation of the Alpine breed goats, Saanen, and crossbreds of these races. The basic product

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obtained from goats is goat's milk (which is commonly processed into white-brined cheese, yogurt, and kashkaval), kids, and goat meat [1]. The official restriction of goat breeding in the territory of Macedonia in 1947 resulted in disastrous consequences, which lasted for more than 40 years. The goats in the entire territory of the former Socialist Republic of Macedonia were slaughtered and rapidly reduced number from 516,800 in 1947 to 47,000 in 1949 or more than 90%. However, in 1989, goat production was again allowed, and since then, the interest of the farmers in goat production has increased [2].

Pacinovski et al. [3] reported that Goat livestock industry has a century-old tradition in Macedonia due to environmental factors and a type of vegetations suitable for goat breeding; wherefore, these animals have provided subsistence of the population in the past centuries. Historically, the number of goats bred in Macedonia was around 500,000 heads, with the law for prohibited goat breeding (Law for Prohibited Goat Breeding, 1948). This law had highly significant negative role in reducing the number of goats in the Republic of Macedonia. Petrovska et al. [4] emphasized that goat breeding in Macedonia is difficult due to a number of factors such as unfavorable racial composition and fragmentation of herds, unorganized and insecure sale of milk and dairy products, shortage of labor, weak and irregular application of selective measures in the herds, and more. However, compared with past years, it can be concluded that there is spontaneous and continuous development of the husbandry industry with growing interest of farmers for goat breeding. The total number of goats the Republic Macedonia is around 80,000 with a tendency to increase.

There are six genotypes (breeds) of goats present in Macedonia in the system for identification and marking of livestock within the Food and Veterinary Agency: domestic Balkan goat, Alpine, Saanen goat, crossbreeds with Alpine, crossbreeds with Saanen goat, and genotype registered under the name of other population. According the same agency, out of the total quantity in 2011, 48% of the total number of goats are domestic Balkan goats, 5.5% are Alpine goats, 7.9% are crossbreeds with Alpine goat, 7.8% are Saanen goats, 3.4% are crossbreeds with Saanen goat, and the rest are recorded as other breeds of goats [5].

According to Pacinovski et al. [6] and the data of the Food and Veterinary Agency, the department for identification and registering of domestic animals, there are six genotypes of goats in the Republic of Macedonia: domestic Balkan goat, Alpine, Saanen, Alpine crossbreed, crossbreeds with Saanen goat, and population registered under the term of other. The most represented goat breed in the country is domestic Balkan goat, with a number of around 38378 goats, goats registered as other with a number of 21772 goats, the number of crossbreeds with Alpine is 6330, Saanen with 6256 goats, Alpine is represented with 4193 and crossbreeds with Saanen are represented with 2735 goats. Balkan goat is well adopted to the existing climate conditions in the country as well as to the existing nutritional resources especially in the hilly mountainous areas of the Republic of Macedonia, which are not suitable for other domestic animals. It is the shrubbery vegetation which is especially attractive to goats. The excellent adaptability of the breed is due to the excellent health condition of goats manifested during the whole year. Compared to the other breeds (Alpine, Saanen, and crossbreeds between the same with other breeds), Balkan goat is extremely resistant to many diseases (chronic, bacterial, etc.). They are especially resistant to emergent climate changes that affect the goat health.

Traditional cheeses represent a cultural heritage and are the result of accumulated empirical knowledge passed from generation to generation [7]. Accurate and precise milk recording is one of the most significant moments for a successful selection of milking goats. In this context, breeders are constantly making efforts to find the most suitable and cheapest methods for conducting of tests for milk. According to Pacinovski et al. [8], in Macedonia predominate extensive goat dairy industry and machine milking are not widespread throughout the country. There is much to be done about the improvement of goat farms in respect to goat breeding and comprehensive mechanization of farm routines which both increase efficiency of the farms.

2. Milk and cheese analysis

Milk and cheese samples were analyzed in duplicate for moisture, fat, salt, pH, titratable acidity (as percentage of lactic acid), and total nitrogen [9]. Total nitrogen (TN) content was estimated by the Kjeldahl method using a Kjeldahl device (model DS1; Simsek Laborteknik, Ankara, Turkey) [10]. The water-soluble nitrogen (WSN) and 12% TCA-soluble nitrogen (TCA-SN) as percentage of TN and total free amino acid (FAA) of the cheeses were determined [11].

The water-insoluble fractions of the cheeses were freeze-dried and then analyzed by urea-PAGE using a Protean II XI vertical slab gel unit (Bio-Rad Laboratories Ltd., Watford, UK), and the gels were stained directly with Coomassie Brilliant Blue G-250 dye [12, 13].

After destaining using pure water, gel slabs were digitized using a scanner (HP Scanjet software, Scanjet G4010; Hewlett-Packard, Palo Alto, CA). Scans of the electrophoretograms were used to quantify bands using densitometric software (ImageMaster TotalLab Phoretix 1D Pro software; Keel House, Newcastle upon Tyne, UK).

The caseins and peptides were determined quantitatively by integration of peak volumes and areas using the densitometer. The WSN fractions of the cheeses were also freeze-dried for determination of peptide profiles. The analysis was realized by RP-HPLC using a Shimadzu LC 20 AD Prominence HPLC system (Shimadzu Corp., Kyoto, Japan) [14].

Solid-phase microextraction/GC-MS analysis of volatiles. Analysis of the volatiles was performed by a static solid-phase microextraction method, using aGC-MS system (Shimadzu Corp.). The identifications were based on comparing mass spectra of unknown compounds with those in the mass spectral library of John Wiley and Sons Inc. (2005) and the National Institute of Standards and Technology/Environmental Protection Agency/National Institutes of Health (NIST/EPA/NIH 02; http://www.nist.gov/srd/nist1a.cfm) mass spectral library. Identifications were also confirmed by comparing retention times with reference standards when available.

A total of 33 authentic standard compounds (Sigma Chemical Co., St. Louis, MO) were used to confirm the identities of volatile compounds in the cheese samples. The concentrations were calculated by the comparison of the peak areas of the internal standard containing mixture of 2-methyl-3-heptanone and 2-methyl-1-pentanoic acid in methanol (Sigma-Aldrich Co.) and unknown compounds. Each compound was expressed in micrograms per 100 g of cheese.

3. Goat milk quality and cheese varieties

Goat breeding is an important livestock branch, and great attention is paid to its development and industrialization in all Mediterranean countries. The composition of milk is of great importance for determining the technological properties of goat milk and for its further processing in a suitable type of cheese. According to the historiographic data, the golden period of the Macedonian livestock breeding was in the middle of the nineteenth century, when there were about 7–9 million sheep and 2 million goats in Macedonia's borders [8].

With the adoption of the Law on Goat Breeding in 1989, the goat again began to take its place in our livestock breeding. Today's situation of goat is heterogeneous, given the fact that the individual producers preserve 1–2 goats, but there are also those who breeds 20–30 goats, while the organized goat farms have 100 or more heads. It is estimated that in our country, there are under 100,000 goats with a major participation in the domestic Balkan goat and in a smaller proportion the Saanen, Alpine, and their half-bred [6].

Accordingly, the milk used for the production of cheese should be of a normal chemical composition in accordance with the rulebook on requirements for the quality of raw milk, quality standards for consumer milk, dairy products and the use of their names, quality and activity of starter cultures, curdling and other specific substances, and the manner of their use, the manner of additional labeling of milk and dairy products, as well as the permitted deviation of weight in relation to the declared [15]. Goat milk is often mixed with the cow or sheep's milk and as such is offered to the dairies so that its nutritional values are not properly valuated. A certain part is processed by farmers in white goat cheese, but due to its specific taste and smell, it consumes a certain number of the population, although it has higher nutritional and therapeutic values compared with other cheeses. Goat breeding has a good perspective, given the good natural conditions, but also because of the fact that goat milk is given greater importance nowadays, especially because of its dietary and nutritional properties.

The quantities of individual ingredients affect the technological characteristics of the curd, as well as the organoleptics and the quality of the finished product [16]. The physical-chemical characteristics of the used milk for the production of the white-brined goat cheese was 3.44 ± 0.10 g/100 g for protein, 3.00 ± 0.24 g/100 g for fat, 11.99 ± 0.17 g/100 g for total solid, and 4.79 ± 0.09 g/100 g for lactose; the total microbiological counts were 5.49 ± 2.119103 log cfu/mL, and the milk total somatic cell numbers were 85 ± 0.109103 cell/mL [10]. The pH of the milk was 6.60. From the obtained analysis, the raw goat milk fulfill the conditions according to the book of rules for hygienic criteria and milk quality [15, 17]. Given that the composition of milk is highly variable and depends on numerous genetic and paragenetic factors, its comparison shows great differences with the findings of other authors (**Table 1**).

Kashkaval, white-brined, and beaten cheese are the three main types of cheeses produced presently in Macedonia. The origin of beaten cheese is from the territory of Mariovo, produced in the past years on the pasture land only from ewe's milk. According to its salty taste and its hard consistency, it is an authentic product with characteristics that is preserved even in usual situations. The production of cheese

Characteristics	Mean ± SD (n = 30)
Total solids	12.64 ± 1.240
Fat	3.84 ± 0.360
Protein	3.21 ± 0.034
Casein	2.49 ± 0.031
Lactose	4.49 ± 0.077
Ash	0.75 ± 0.027
pH	6.65 ± 0.056

Adapted from [39]

Table 1.
Chemical composition of the goat milk.

has been carried out since the time of the Ottoman Empire. The “beaten” designation is originated from the one process step of the cheese production where the cheese curd is beaten to ensure proper draining (**Figure 4**) [18, 19].

Cilev et al. [5] investigated the chemical composition of goat milk on three farms during the month of April, and the highest percentage of milk fat is determined in milk from a farm in Kožle (3.85%), and the lowest percentage in milk is from a farm in Ajvatovci (3.50%). In terms of protein content, the highest percentage (3.70%) is determined to a farm in Taor, and the lowest is in the farm in Ajvatovci (3.05%). The content of lactose was highest in the farm in Ajvatovci (4.71%), while the lowest is from a farm in Taor (4.43%). The highest content of fat-free dry matter was found on the farm will be displayed (8.69%), while the lowest farm is Taor (8.26%). The total dry matter in milk was also highest in the farm will be displayed (12.42%) and the lowest farm is Taor (11.85%). In terms of the content of added water, the result charter in April in all three farms was zero, which indicated its full functionality in terms of physical water added.

Brined cheeses are with high salt content, which enables their preservation even in the warm periods of the year. They are produced from sheep, goat, and buffalo milk, as well as from their combinations. During the ripening, changes in the composition and properties of the cheeses are mutually dependent on changes in the brine [20–22].

In the last few years, the increased interest of the goat’s milk products on the marketplace and the scientific community is consistent with the general trend and efforts for the production of healthy food, since the goat’s milk has been well-known for its beneficial effects on human health [23]. According to statistics in 2011, white-brined cheeses are consumed in quantities of 7.4 kg per year, followed by 2.2 kg kashkaval cheese and urda (ricotta) with 2.1 kg by member of households [24].

Sulejmani [25] reported that white-brined cheeses have a high salt content that allows them to stay in the warm periods of the year. They are produced from sheep, goats, buffalo milk, and their combinations. In the ripening, changes in the composition and properties of the cheeses are mutually dependent on changes in the brine. Most varieties in this group are stored in closed containers, but some are stored in gas-permeable containers, which affect biochemical changes that occur in the process of ripening and storage.

The milk for beaten cheese manufacture is drained through cheesecloth (not obligatory) and poured into a curdling vessel. The curdling is most often done using enzymatic rennet with the strength of 1:5000 or the rennet chymosin CHY-MAX (2080 imcv/g) at the temperature of the milk of 25–35°C. In the past, for curdling homemade rennet was used obtained from the lamb’s stomach. The curdling process lasts 30–50 min. After that the curd is submitted to processing (churning or beating) using a wooden tool. The process of churning (beating) is done in 3 series of 50 strokes (150 strokes in total), and after each series, the curd is left to “rest” for 5–10 min. In this process it may come to separation of a part of the milk fat, in which case the fat is skimmed and removed from the vessel. When the beating process ends, the curdled mass is warmed up by adding warm water to the temperature of 53–90°C, depending on the particular manner of production [27] (**Figure 1**).

Recently consumers are more aware about the relationship between their eating habits and nutritional status. Consequently, they look for foods that are added with natural products rather than synthetic chemical compounds. Currently, they have interest in maintaining good health and an excellent body figure; therefore, they have become more careful in the food they choose to consume, looking for food with a high nutritional value, bioactive compounds, and antioxidant capacity, such as herbs, fruits, and vegetables. This is an opportunity for some local producers to manufacture cheese products with the partial or total replacement of those chemical additives by natural herbal not only because of their antioxidant but also antimicrobial properties (**Figure 2**).

Antioxidant capacities of beaten goat cheeses, of 7 and 20 days ripened cheese (matured cheese), were higher than beaten cheese without plants (Sulejmani and Hayaloglu, unpublished data). Therefore, it could be hypothesized that consumption of matured white cow cheese could notably contribute to the body's antioxidant defense and prevention of diseases related to oxidative stress. However, further research is needed to elucidate the role of herbs in the antimicrobial and anticancer protective functions in human. *Origanum vulgare* is a perennial herbaceous plant, with wood stalk. The stub is usually gray-eyed. The roots are superficial, with a multitude of roots reaching at depths of 3–4 cm, and the plant is easily pulled. The flowers are short-tailed, gathered in a long spike in the midst of strong scent bows. It flourishes from the end of June and continues until the end of August.

Figure 1.
Typical beaten cheese production with a mixture of goat milk. After Sulejmani [26].

Figure 2.
Beaten goat milk cheese with Origanum vulgare.

Red oregano has reddish flowers and a pleasant smell. The flowers are full of nectar and are always frequented by bees. It is aromatic and spicy medicinal plants. The excellent ethereal oil is extracted from this. From 100 kg of dry matter, 2–2.25 kg of ethereal oil is extracted. Oregano on leaves and flowers contains etheric oils in various quantities consisting of a series of special value components. Essential oil (maximum 4%) may contain variable amounts of phenol, carvacrol, and timol. In addition, there are variants of monoterpenes, hydrocarbons (limonene, terpene, ocimene, caryophyllene, β-bisabolene, and ρ-cymene) as well as alcoholic monoterpene (linalool 4-terpineol). It has important properties, as antioxidants, antibacterial, antifungal, and anti-inflammatory and, recently, as anticancer. Oregano possesses powerful properties like antioxidants comparable to those of ascorbic acid and vitamin E. Carvacrols, thymol, and rosemary acids are the main components of essential oil. Known as a food supplements, carvacrol is a potent and bacteriostatic useful against mold and bacteria.

The influence of different heat treatments on goat milk was studied in detail [16]. Multiple analyses confirmed that the heat treatment of goat milk delays the initial coagulation and syneresis, and it improves the retention of dry matter, fat, and proteins. Therefore, on the basis of this finding, technological approaches of white-brined cheese were developed (**Figure 3**). The characteristic ability of goat milk proteins to retain water; the specific structure and the rheological properties of the cheese curd enable optimal regulation of the fermentation process of cheese and its salting. Traditionally, this type of cheese has been produced by local farmers on a small scale for decades using raw milk, and traditional techniques handed down from generation to generation using only elementary equipment. Instead of using a commercial starter culture, artisan cheese makers relies on the indigenous natural present microorganisms in the raw non-pasteurized milk and adventitious contaminants from the soil, equipment, surfaces, and the environment in general.

Sulejmani and Hayaloglu [18] investigated the use of raw and pasteurized goat milk in the production of Macedonian white cheese. Milk was collected from a certified organic farm from a Saanen goat's herd of a Novacani village (Veles, Macedonia). Two batches of cheeses from pasteurized (80°C for 2 min) (GP) and raw (GR) goat milk were produced traditionally using artisanal protocols. Goat milk coagulation was attained with commercial enzyme (1 g/100 per L milk) with a stated power of coagulating from 2235 IMCU/g (Chr. Hansen, Powder Extract CHY-MAX, Hørsholm, Denmark). The milk was coagulated at 32°C for 45 and 120 min for GR and GP cheeses, respectively. The coagulum was cut to medium-size (1–2 cm) grains. After whey removal by pressing, cheeses with block form weighing 0.5–1.0 kg were pressed for 4 and 8 h for GR or GP cheeses, respectively. At last, both cheeses were ripened in brine (15% w/v at 4°C) for 120 days.

The chemical composition of white-brined goat cheese made from pasteurized (GP) or raw (GR) milk at the first day was as follows: pH, 5.25 and 6.27; fat-in-dry matter, 37.86% (w/w) and 43.36% (w/w); dry matter, 32.60% (w/ w) and 33.00% (w/w); fat, 12.38% (w/w) and 14.25% (w/ w); and salt, 2.02% (w/w) and 2.73% (w/w), respectively. The use of pasteurization significantly affected the total solid, fat, moisture, and fat-in-dry matter contents of the cheeses ($P < 0.05$). The white cheese chemical composition was in compliance with the official bulletin [15]. Higher cheese pH levels were found in the cheeses made from raw milk (GR) compared with pasteurized milk (GP) ($P < 0.05$).

The values of WSN and 12% TCA-SN (expressed as percentage of TN) of both white goat cheeses are presented in **Tables 2** and **3**. The quantity of WSN and TCA-SN in the cheeses increased during ripening (until 60 days); however, after that, the increase was not intense during the end of ripening. After 60 days of ripening, GR cheeses had higher quantity of WSN than GP cheeses; also the highest

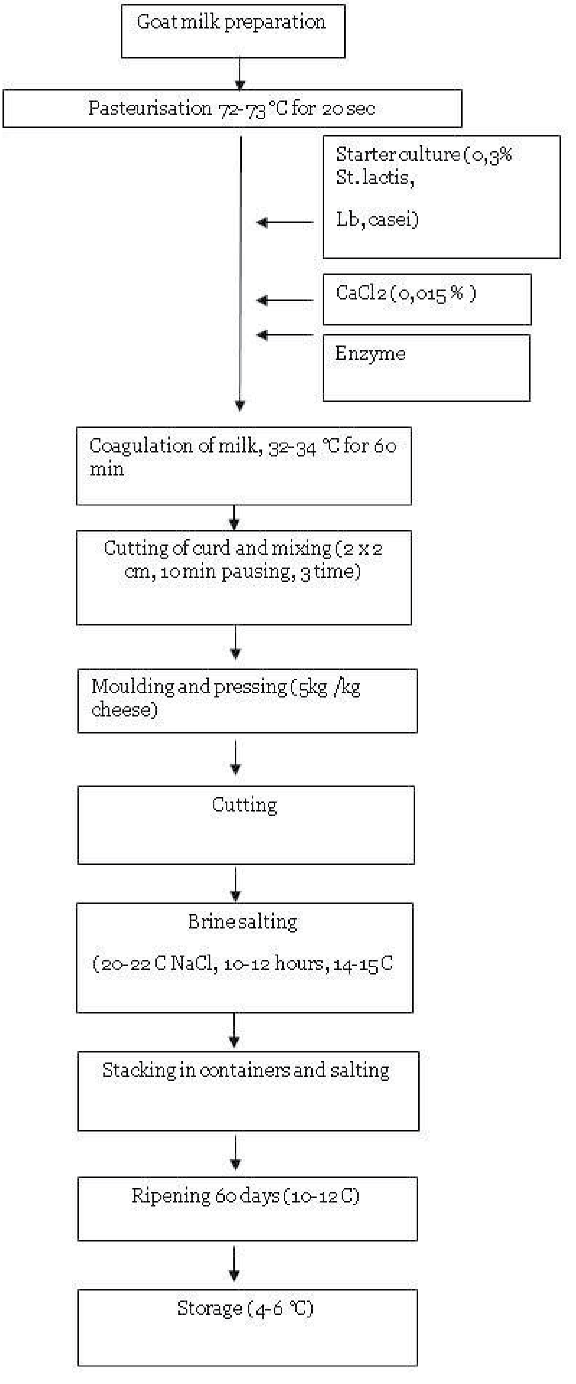

Figure 3.
Schematic illustration of white-brined cheese making [16].

TCA values were recorded at day 60 of ripening and then declined again. However, the quantities of WSN were higher in GR cheeses than in GP cheeses ($P < 0.05$). Higher and similar quantities of TCA-SN and WSN at 60 days of ripening were found in Teleme white-brined goat cheese, respectively [28].

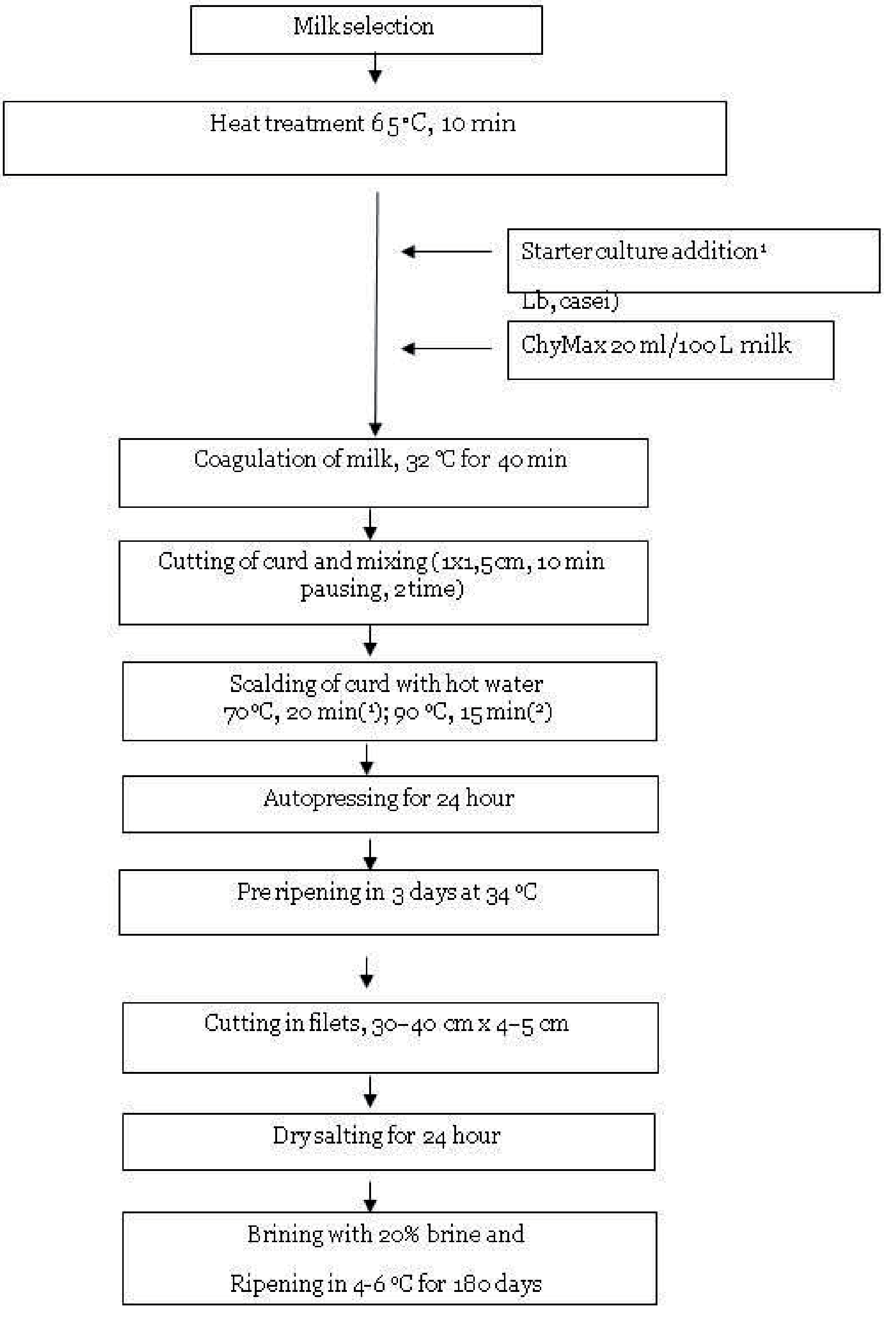

Figure 4.
Schematic illustration of industrial (1) and traditional (2) beaten cheese production using goat/ewes milk combination [26].

Most brine cheeses are dry-salted and are ripened and stored in brine, and the salting method is the basic difference in terms of varieties of cheeses. Traditionally, they are produced from sheep, cow, goat, or mixed raw milk [29, 30].

Parameters	Cheeses	Ripening time (days)		
		1	60	120
Total	GR	10.19 ± 0.95^{bA}	8.43 ± 0.04^{aA}	9.59 ± 0.79^{abA}
Protein	GP	10.13 ± 0.94^{aA}	9.90 ± 0.42^{aB}	10.88 ± 0.20^{aB}
WSN-SN	GR	7.74 ± 1.01^{aA}	8.64 ± 0.37^{aB}	7.31 ± 1.02^{aB}
(% of TN)	GP	5.82 ± 0.37^{bA}	6.22 ± 1.58^{bA}	2.93 ± 0.37^{aB}
TCA-SN	GR	2.44 ± 0.65^{aA}	3.05 ± 0.02^{aB}	2.92 ± 0.46^{aB}
(% of TN)	GP	1.71 ± 0.24^{abA}	2.39 ± 0.52^{bA}	1.44 ± 0.21^{aA}
TFAA	GR	0.41 ± 0.00^{eB}	0.30 ± 0.01^{aA}	0.44 ± 0.02^{dB}
mg Leu/g	GP	0.35 ± 0.00^{cA}	0.30 ± 0.00^{bA}	0.39 ± 0.01^{dA}

SD, standard deviation; TFAA, total free amino acid; DM, dry matter; WSN, water-soluble nitrogen. TN, total nitrogen; TCA, 12% trichloroacetic acid-soluble nitrogen. $^{a,\,d}$Means ± SD within a row and $^{A–B}$Means ± SD within a column with no common superscript capital letters differ (P < 0.05), respectively. Adapted from Sulejmani and Hayalogu [18]

Table 2.
Chemical parameters during ripening in raw (GR) and pasteurized (GP) white-brined goat cheeses.

Parameters	Kumanovo	Radovish
pH	5.01 ± 0.01	5.43 ± 0.05
% Lactic acid	1.73 ± 0.10	4.45 ± 0.13
Dry matter, %	68.43 ± 0.11	57.34 ± 0.21
Moisture, %	31.57 ± 0.11	42.67 ± 0.21
Fat, %	29.63 ± 0.25	26.00 ± 0.41
Fat(dm), %	43.29 ± 0.35	45.35 ± 0.84
Salt, %	4.11 ± 0.07	8.18 ± 0.38
Proteins, %	32.81 ± 1.09	21.32 ± 0.69
TN(g100 g^{-1} cheese)	5.15 ± 0.17	3.34 ± 0.11
WSN (% TN)	10.34 ± 1.06	32.76 ± 0.95
TCA-N (% TN)	6.37 ± 0.70	4.60 ± 0.04
TFAA(mgLeu/g)	3.18 ± 0.56	3.72 ± 0.13

Adapted from Sulejmani et al. [31]

Table 3.
Physical-chemical parameters of mixed goat/ewes milk cheese from different geographical locations.

At the beginning the ripening of white-brined goat cheese, as1-CN (f24–199) and c2-casein were produced, indicating high activity of chymosin and plasmin. However, it can be seen that b-casein reduction rate was smaller than as1-casein that of during ripening (**Figure 5**). After 60 days of ripening in the GR cheeses, the band corresponding to as1-I-casein (as1-CN f102–191) was present in all electrophoretograms of the samples, as a result of hydrolysis of as1- casein. A reduction of as1- and b-casein was obviously faster in the GR cheeses than in the GP cheeses, probably due to the native microorganisms and indigenous milk enzymes. Significantly inactivated indigenous and milk proteinases indicates on great impact that had pasteurization [30].

As it is obviously shown in **Figure 5**, the hydrolysis of as1-casein was faster in the GR cheeses during ripening obviously as a result of the higher activity of

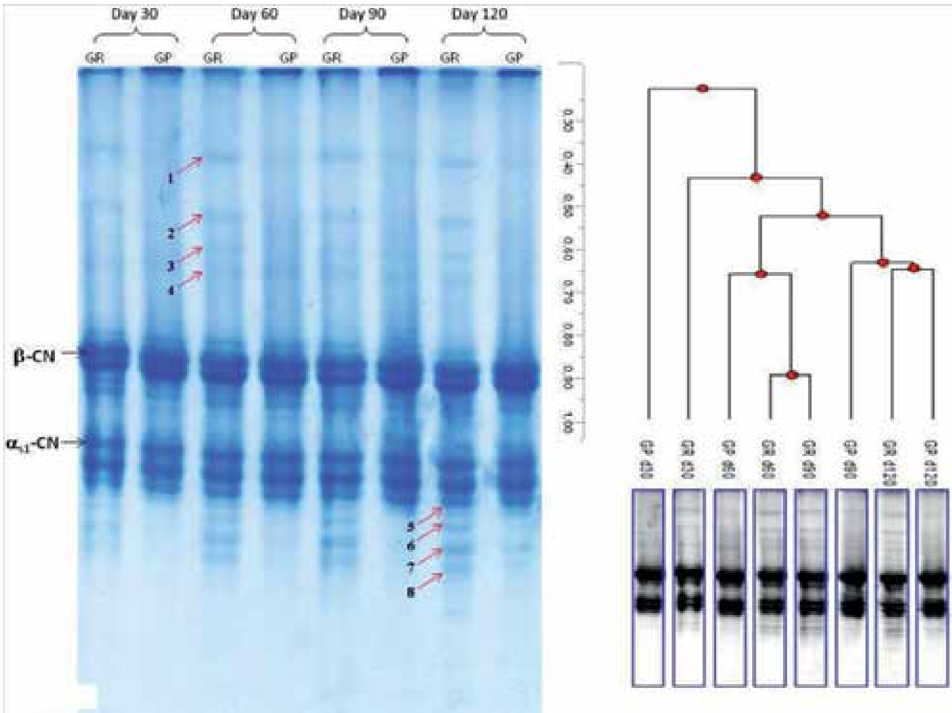

Figure 5.
(Left) Urea-PAGE of the water-insoluble fractions of white goat milk cheeses made using raw (GR) or pasteurized (GP) method during 120 days of ripening (right) (with permission from John Wiley and Sons) [10].

indigenous proteinases in the curd, which is exactly associated with the heat degree of the milk heat.

Some differences were observed during ripening for the fractions of peptides, which were eluted in the GR cheeses at higher quantity at the end of ripening than the beginning of ripening. Common peaks were evident in the 30 and 60 days of ripening in all of the chromatograms, with an increase in concentration of peptides during ripening, which were mainly eluted between the 56th and 76th min. In the chromatogram, between 64 and 74 min, the peak heights in the cheeses were generally much higher than in other cheese samples until the 120th day of ripening (**Figure 6**).

The analysis of free amino acids in white-brined goat cheese confirmed the presence of all amino acids except tyrosine (**Table 4**). The quantity of free amino acids is low because of particular process of fermentation. Due to the high concentration of salt and low ripening temperature of white brine, the participation of thermophilic lactic acid bacteria in ripening is minimal, and this cheese is defined by a weaker breakdown of paracasein.

The volatile components of white-brined goat cheeses have not previously been studied. They consisted of 12 acids, 14 esters, 6 ketones, 3 alcohols, 4 terpenes, and 6 miscellaneous compounds (**Table 2**). Acids, alcohols, and ketones constituted the principal chemical groups during ripening (mean volatile concentration of 51, 16, and 12% w/w of total compounds, respectively). The raw goat milk (GR) cheeses were by a higher quantity (78%) of total volatile compounds than the pasteurized goat milk (GP) cheeses, during ripening. Compared with day 1, a significant decrease in the total quantity of volatile compounds (except ketones and alcohols) was found after 120 days of ripening. Carboxylic acids are the principal volatile

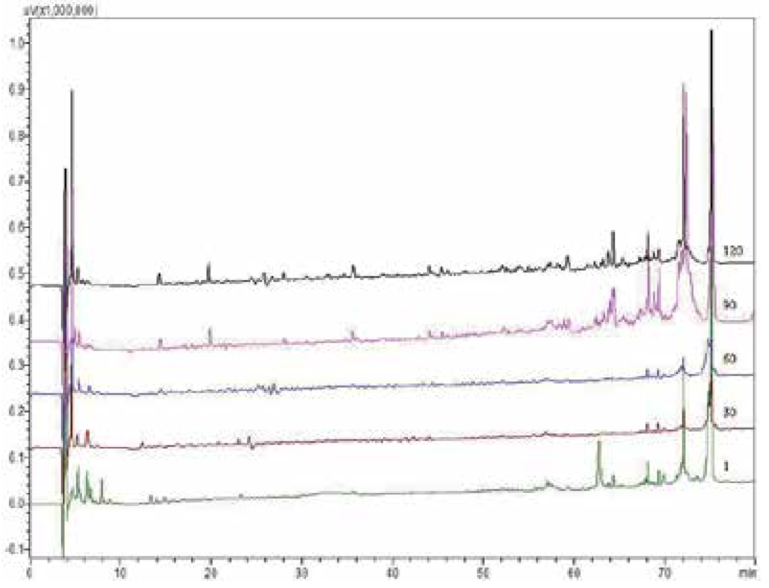

Figure 6.
Reverse-phase HPLC profiles of the water-soluble fraction of white goat milk cheeses made using raw milk during 120 days of ripening [10].

Free amino acids mg %	Ripening	
	Day 15	**Day 60**
Lysine	16.2 ± 0.31	33.11 ± 0.41
Histidine	2.2 ± 0.13	16.12 ± 0.71
Arginin	2.7 ± 0.71	4.85 ± 0.27
Threonine	2.60 ± 0.78	3.71 ± 0.62
Valin	11.78 ± 0.61	14.80 ± 0.16
Metionin	6.11 ± 0.43	8.71 ± 0.62
Isoleucin	3.21 ± 0.62	4.52 ± 0.27
Leucine	11.72 ± 0.31	21.57 ± 0.36
Phenylalanine	4.11 ± 0.62	15.61 ± 0.31
Total essential amino acids	**60.63 ± 0.64**	**123.01 ± 0.74**
Asparagin acid	3.8 ± 0.11	9.11 ± 0.37
Serin	6.10 ± 0.18	12.11 ± 0.38
Glutamic acid	6.70 ± 0.79	9.28 ± 0.65
Proline	1.50 ± 0.28	3.61 ± 0.33
Glycine	—	6.63 ± 0.58
Alanin	3.31 ± 0.41	4.11 ± 0.43
Cistin	4.81 ± 0.11	7.51 ± 0.38
Tirozin	—	—
Total nonessential amino acid	**26.22 ± 0.53**	**52.36 ± 0.59**
Total quantity	**89.18 ± 0.58**	**176.32 ± 0.71**
Adapted from Srbinovska [16]		

Table 4.
Free amino acid concentration in white-brined goat cheese.

class in Macedonian white goat cheese (with 51% of total volatile compounds). The raw goat milk (GR) cheeses were characterized by higher quantity (86%) of total acids than the pasteurized goat milk (GP) cheeses during ripening. Milk heat treatment significantly ($P < 0.05$) influenced the concentrations of two volatile fatty acids (hexanoic acid and octanoic acid) (**Table 2**). Similarly, these compounds have been shown to be the principal volatile class in other goat milk cheeses [32]. The main acid was hexanoic acid (40% of total acids), and this was identified at significantly higher quantity in GR cheeses at 60 days of ripening. 3-Methylbutanoic acid was the most abundant branched chain fatty acid found in Macedonian goat cheese. This is in agreement with the findings of Beuvier et al. [33]. During ripening, total acids were at a higher concentration in the GR cheeses (86%) in comparison with GP cheeses (14%).

Caproic acid is a product of lipolysis, which significantly contributes to the smell of goat cheese [33]. Karagul et al. [34] explored the level of proteolysis in "Ezine" cheese, produced from a mixture of goat milk(40%), sheep's milk (45–55%), and cow's milk (up to 15%) without starter culture, during 8 months ripening. Urea-PAGE assay confirmed that αs-casein decomposes very quickly, while the β-casein degradations are almost constant. Differences in the rate of degradation are associated with pH and salt content [35].

Flavor is the main properties that influence the selection and consumption of cheeses. The effect of fatty acids on the sensory properties of different types of goat milk cheese is essential. The concentration of butyric acid is increased during the ripening of cheeses mainly higher of 50% from the total concentration in the beginning of its production (mozarella 66.35%, white-brined 74.58%, and pecorino 51.28%) [9]. The reason for the lower degree of formation of butyric acid during ripening and especially at the end of ripening of the cheeses is assumed to be the lack of a free substrate for conversion into fatty acids by way of lipolysis or reduction of enzyme activity due to the change in the microstructure of the cheeses.

At the first day of ripening in the raw goat milk cheeses (GR), acetic acid was identified at a higher concentration. Alcohols are the second most significant volatiles (16%) isolated in Macedonian goat cheese. At the end of ripening, the concentration of alcohols decreased to 40%, while after 60 days of ripening their quantity was 50%. The total esters were at higher quantity (98%) in raw goat milk (GR) cheeses than pasteurized goat milk (GP) cheeses during ripening. At the 60th day of ripening, a very high quantity of 3-methyl-1-butanol was found in the GR cheeses (**Table 5**). Heat treatment of the curd did not affect branched alcohols (except 2-ethyl-1-hexanol). 2-Propanone and 2-heptanone were the most abundant ketones among total of six ketones representing 54% and 13% of the total quantity of ketones, respectively. Higher quantity (77%) of total esters was characterized in the raw goat milk (GR) cheeses rather than the pasteurized goat milk (GP) cheeses during ripening. Because of particular odors and low perception thresholds, ester is very significant compounds in dairy products [36]. 2-Propanone and 2-heptanone were predominant ketones among six ketones that were identified in the Macedonian white goat cheeses.

Five different acids that were identified in the Goat beaten cheese from Kumanovo region with concentration of 13347.2 μg 100 g^{-1} were reported. Six different acids were identified in the goat beaten cheese from the Radoviš region, and their concentration were 13773.8 μg 100 g^{-1}, respectively [31]. Hexanoic, octanoic, and decanoic acids were responsible for the characteristic aroma of goat cheeses, and their contribution to the volatile profile of beaten cheeses has been shown in this study as well, giving rise to the trivial terms caproic, caprylic, and capric acids, respectively. In addition 2-heptanone was identified at highest concentration in

Compounds	**RI**	**Day 1**		**Day 60**		***P (type)***
		GP	**GR**	**GP**	**GR**	***Type***
Acids						
2-Hydroxypropanoic acid	8186	0.28 ± 0.40	101.04 ± 12.89	ND	ND	NS
2-Ethylbutanoic acid	20,383	59.36 ± 8.95	ND	ND	ND	NS
Isobutyric acid	26,446	ND	13.75 ± 9.44	ND	ND	NS
Butanoic acid	28,317	ND	79.65 ± 12.64	47.89 ± 6.72	18.27 ± 9.73	NS
Pentanoic acid	28,405	ND	8.18 ± 1.57	ND	ND	NS
3-Methyl, butanoic acid	29,400	ND	1.35 ± 1.1	32.01 ± 3.64	16.19 ± 9.84	NS
Hexanoic acid	33,722	ND	182.58 ± 19.81	46.86 ± 6.91	260.64 ± 127.86	*
Acetic acid	37,692	ND	5.28 ± 7.47	ND	ND	NS
Octanoic acid	38,524	ND	112.40 ± 18.96	ND	180.47 ± 174.55	*
Isobutyric acid	41,235	ND	11.13 ± 1.74	ND	ND	NS
Decanoic acid	42,882	ND	45.36 ± 6.14	ND	ND	NS
2-Ethyl, caproic acid	45,717	ND	17.62 ± 13.39	ND	10.68 ± 5.10	NS
Total		*59.6 ± 9.3*	*578.3 ± 47.9*	*126.7 ± 16.2*	*486.2 ± 324.1*	
Ketones						
2-Propanone	6352	18.19 ± 3.11	64.82 ± 37.66	12.82 ± 5.71	51.55 ± 33.87	*
2-Butanone	7706	1.68 ± 0.49	4.23 ± 1.21	3.89 ± 0.26	3.76 ± 1.24	NS
2-Pentanone	9446	3.40 ± 2.46	7.22 ± 4.97	6.65 ± 1.36	8.65 ± 3.60	*
2-Heptanone	15,472	1.93 ± 2.16	3.48 ± 3.12	ND	19.87 ± 7.07	NS
2-Octanone	15,501	ND	ND	0.98 ± 0.39	ND	NS
2-Nonanone	21,938	ND	ND	ND	8.38 ± 7.24	NS

Compounds	RI	Day 1		Day 60		P (type)
		GP	GR	GP	GR	*Type*
Total		*25.12 ± 12.3*	*79.15 ± 55.8*	*24.3 ± 13.3*	*92.5 ± 55.9*	
Esters						
Methyl acetate	6521	3.35 ± 1.90	9.12 ± 1.90	3.17 ± 1.58	6.51 ± 1.12	*
Ethyl acetate	7447	19.43 ± 14.40	2.14 ± 3.03	2.24 ± 1.88	6.18 ± 6.79	NS
Methyl propanoate	7823	1.86 ± 0.86	4.56 ± 0.58	2.30 ± 1.69	3.71 ± 0.21	NS
Methyl butyrate	9645	2.28 ± 0.69	12.98 ± 5.42	3.69 ± 4.12	14.19 ± 6.39	*
Methyl carbonate	9785	0.15 ± 0.21	2.70 ± 0.18	ND	ND	NS
Ethyl butyrate	11,035	1.65 ± 2.34	ND	ND	ND	NS
n-Butyl acetate	12,024	1.04 ± 1.47	ND	ND	ND	NS
Isoamyl acetate	13,535	1.59 ± 2.24	ND	ND	ND	NS
Methyl caproate	15,544	0.34 ± 0.49	2.56 ± 3.63	ND	ND	NS
Ethyl heptanoate	15,973	ND	23.29 ± 32.93	ND	ND	NS
Isoamyl acetoacetate	16,141	0.72 ± 1.02	ND	ND	ND	NS
Ethyl n-caproate	17,021	0.17 ± 0.25	ND	ND	ND	NS
Dimethyl phthalate	24,779	1.74 ± 2.46	3.16 ± 4.47	ND	ND	NS
Diethyl phthalate	45,468	1.77 ± 1.18	25.06 ± 26.41	1.25 ± 1.77	1.11 ± 1.56	NS
Total		*36.10 ± 29.51*	*85.58 ± 78.56*	*12.65 ± 11.04*	*31.70 ± 16.07*	
Terpenes						
dl-Limonene	15,942	54.96 ± 7.07	ND	109.79 ± 31.99	ND	*
Cymene <para->	18,287	1.80 ± 2.54	ND	ND	ND	NS
Alph.-thujene	14,771	0.10 ± 0.14	ND	ND	ND	NS

Compounds	RI	Day 1		Day 60		P (type)
		GP	GR	GP	GR	*Type*
Alpha-pinene	10,644	15.61 ± 10.93	14.80 ± 6.62	49.14 ± 30.44	6.66 ± 0.37	NS
Total		*72.47 ± 20.67*	*14.80 ± 6.62*	*158.92 ± 62.44*	*6.66 ± 0.37*	
Alcohols						
Ethanol	8302	1.79 ± 0.05	3.85 ± 5.44	ND	1.70 ± 1.10	NS
3-methyl, 1-butanol	16,117	1.06 ± 1.50	49.01 ± 5.25	ND	233.12 ± 155.11	*
1-Pentanol	17,429	ND	2.66 ± 0.24	ND	ND	NS
Total		*2.84 ± 1.54*	*55.52 ± 11.93*	*ND*	*234.81 ± 156.22*	
Miscellaneous						
Pentane	4767	0.24 ± 0.34	6.08 ± 8.60	5.49 ± 4.21	ND	NS
Hexane	4905	7.67 ± 3.73	2.33 ± 0.31	4.56 ± 1.43	3.34 ± 2.89	NS
Dimethyl sulfide	5742	ND	6.56 ± 9.28	3.44 ± 3.20	ND	NS
Methylamine-D2	7583	1.22 ± 1.72	6.76 ± 0.88	9.96 ± 4.63	8.05 ± 4.23	NS
2-Methylbutanal	7976	0.48 ± 0.43	4.90 ± 4.14	ND	2.96 ± 3.21	*
3-Methylbutanal	8064	4.10 ± 3.57	35.28 ± 12.13	3.94 ± 1.56	29.09 ± 30.27	**
Total		*13.7 ± 5.7*	*61.5 ± 26.4*	*27.3 ± 9.3*	*45.0 ± 37.7*	NS

Mean data for three batches of pasteurized (GP) and raw (GR) goat cheese analyzed in triplicate. RI, retention index; ND, not identified; NS, not significant; P, probability. P age is probability for ripening period (i.e., 1, 60, or 120 days), P type is probability for cheese type (i.e., GP or GR) [10].
$P < 0.05$.
**$P < 0.01$.*
Adapted from Sulejmani and Hayaloglu, 2017

Table 5.
Mean values ± SD of volatile compounds identified in pasteurized (GP) and raw (GR) white goat's milk cheeses after 1 and 60 days of ripening (μg/100 g).

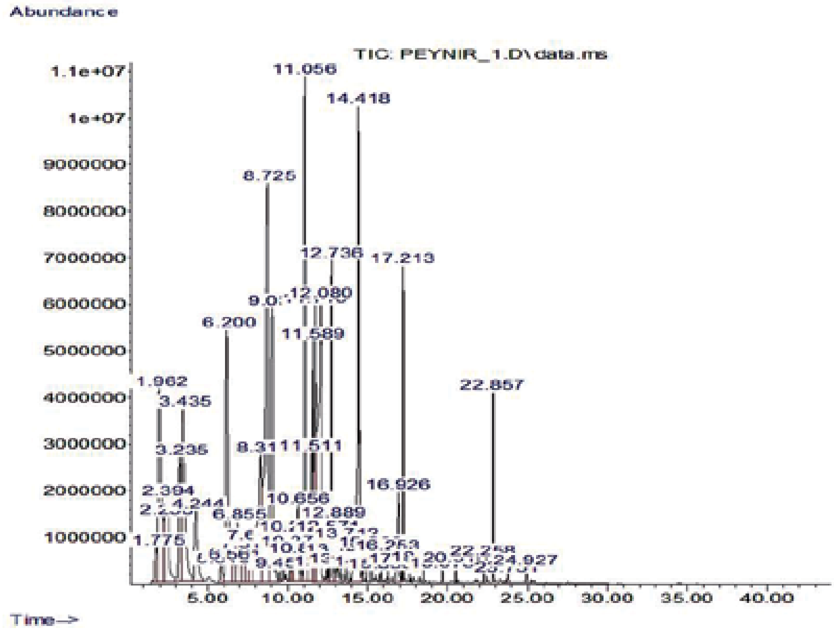

Figure 7.
GC-MS chromatogram of volatiles compounds identified form goat beaten cheese [21].

Kumanovo beaten cheese than other regions (**Figure 7**). Also 2-octanone, 8-nonen-2-one, and 2-nonanone were rarely found in cheeses from other regions.

Heptanol is determined in highest amount in the beaten cheese with goat milk from the northeast region and has been identified as a key aromatic flavor- component in gorgonzola and grana padano cheese [37]. Curioni and Bosset [38] reported a high concetration of heptanols as well as in semihard varieties of Spanish cheese from goat's milk.

4. Conclusions

The breeding of the goats in the Republic of Macedonia has a mark of tradition, namely, because of appropriate grazing conditions. This is very economical, because the entire diet is reduced to a grazing with less extra feed in the form of concentrate and minerals. Also Macedonia has real possibilities for transformation of many extensive goat farms into an organic farm. In addition, it creates additional opportunities for the outlay on the markets in the EU, for which the organic production year-by-year increases. Macedonian goat cheeses are being differentiated by their strong bounds with the territory of their origin, and so they represent a historical and cultural designation of the community which they are produced by. Production of these cheeses is in limited geographical areas with use of know-how techniques transferred from generation to generation and use of milk that has undergone no treatment after milking. Goat milk can be successfully used to produce various cheeses because cheese is characterized by a specific lactic acidic taste and aroma, a good degree of protein breakdown. Lactic acid processes and changes in moisture content take place more evenly during ripening than cow cheeses. From milking to the end of ripening process, this type of cheeses is passing through different surroundings where a variety of microorganisms have an opportunity to grow and develop. The research that has been conducted has shown that traditional made cheeses have unique benefits in terms of palatable pleasure, richness, and diversity as well as protection against pathogens. Undoubtedly their properties have been achieved due to the presence of unique indigenous microbiota especially because of the use of raw milk, combined with specific skills that give their general characteristic properties and quality. In order to understand the situation of traditional milk processing and utilization in this part of the state, one should recall that milk production has an obvious seasonality related to climatic conditions and most of these products are homemade following neither standardized conditions nor proper hygiene standards. Careful attention must be paid to hygiene in order to produce milk of high bacteriological quality. However, despite all precautions, it is impossible to completely exclude bacteria from milk. Therefore, good hygiene is particularly important in producing especially fresh ripened cheeses. So prevention of contamination of the milk and meticulous attention to good hygiene during cheese production and ripening will reduce the incidence of pathogens; therefore, good acid-produced cheese during proper ripening is also helpful.

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Section 4

Health

Chapter 8

Unique Pharmacokinetic and Pharmacodynamic Parameters of Antimicrobials in Goats

Saganuwan Alhaji Saganuwan

Abstract

Pharmacokinetics, the process that involves drug absorption, distribution, metabolism and excretion (ADME) of antimicrobials, determines pharmacodynamic response, that is, what drugs do to the body. Therefore, of all the pharmacokinetic parameters, elimination half-life ($T^1/_2\beta$), volume of distribution (Vd), maximum plasma concentration (Cmax) and maximum time reached (Tmax) are the most important parameters. Hence, the parameters are unique in determining pharmacokinetic and pharmacodynamic response of antimicrobials. However, it is elimination half-life and minimum inhibitory concentration (MIC) that determine the dosing interval of antimicrobials. The dose range of 2.5 mg/kg for gentamicin passing through 4 mg/kg (ciprofloxacin), 4.2 mg/kg (ampicillin L/A), 5 mg/kg (kanamycin, enrofloxacin, gatifloxacin and norfloxacin), 7 mg/kg (mequindox), 10 mg/kg (amikacin, enrofloxacin, lincomycin, pefloxacin, cefpirome, erythromycin and isoniazid), 20 mg/kg (oxytetracycline) and 30 mg/kg (metronidazole) have elimination half-life of 1.2–67.2 h, Cmax of 0.12–54.4 μg/ml, Tmax of 0.2–24 h, bioavailability of 16–99.8% and plasma protein binding of 0–>80% when administered intramuscularly, intravenously and orally. Human equivalent dose formula could be used to extrapolate human-goat therapeutic doses of antimicrobials. However, some antimicrobials such as sulfadimidine, tulathromycin, oxytetracycline and azithromycin may have high residues in the milk, kidneys, liver, intestines, brain and skeletal muscles and may portend high risk of antimicrobial resistance, hypersensitivity reaction, epidermal necrolysis, Stevens-Johnson syndrome and other adverse drug reactions.

Keywords: pharmacokinetics, pharmacodynamics, goat, tissue residue, human equivalent dose, resistance, receptor, agonism, antagonism

1. Introduction

Antimicrobials are either synthetic or natural products (antibiotics) that are used in killing (bactericidal) or controlling the growth (bacteriostatic) of pathogenic microbes. Sometimes, antimicrobial and antibiotic are interchangeably used. Goats belong to species (caprine) and serve as the source of meat and milk [1], and the money realized from sales meet financial obligations of small- and large-scale goat farmers [2]. There are up to 800 million goats in the world [3]. The economic species of goats spread across the globe are not limited to Teddy, Kilis, Ardi, West African Dwarf, Black Bengal, Indian native, Murciano-Granadina, Angora, Red Sokoto, Boer and Nubian goats [4–13]. However, the diseases of goats include colibacillosis, salmonellosis, staphylococcosis and streptococcosis, among others [14]. Age, sex, dosage formulation, route of administration and dose of antimicrobials affect pharmacokinetics and pharmacodynamics of antimicrobials in goats [13]. For example, female West African dwarf goats are more sensitive to sulfadimidine than male West African dwarf goats [15]. There are also intraspecies differences in pharmacokinetic and pharmacodynamic parameters of domestic goat (*Capra aegagrus hircus*) such as West African dwarf, Pakistan, Shiba, Netherland dwarf, Nubian, Red cross-breed, Angora, Boer, LaMancha, Oberhasli, Toggenburg as well as wild goats, *Capra aegagrus aegagrus* (bezoar ibex), *Capra aegagrus blythi* (Sindh ibex), *Oreamnos americanus* (mountain goat), *Capra aegagrus chialtanensis* (Chiltan ibex), *Capra aegagrus cretica* (kri-kri), *Capra aegagrus turcmenica* (Turkmen wild goat) and *Capra aegagrus pictus* [15–20]. However, *Capra aegagrus hircus* is the most popular domesticated from their wild progenitor, bezoar (*Capra aegagrus*) [21, 22]. Also, antimicrobials such as sulfonamides, trimethoprim-sulfamethoxazole, aminopenicillins, cephalosporins and quinolones could cause Stevens-Johnson syndrome in humans that eat goat meat which has the drugs residues [23] and tissue residues above threshold (2 ppm) could be found in the skeletal muscle, liver, kidney, milk, brain, intestine, heart and lung of goats which could portend threat to public health [13]. Although goats are domesticated 10,500 years ago, the genomic regions differentiating domestic goats from wild goats are associated to genes of the nervous system, immunity and productivity traits; 20 are common to *Capra* and *Ovis* [24] indicating the possible relevance of pharmacogenomics which is the study of how genes affect animal response to drugs. Because of unprecedented emergence of resistant bacteria, there is a fervent need to develop new veterinary drugs [25] using both in vitro and in vivo data that have been generated from basic, translational and clinical research. Solubility and permeability affect pharmacokinetics of oral formulations of antimicrobials in goats. The formulations are tablet, capsule, solution, suspension, etc.

2. Methodology

Intensive literature search was carried out with a view to identifying various chemical classes, dosage form, routes of administration, therapeutic doses, unique pharmacokinetic parameters such as elimination half-life, volume of distribution, bioavailability, concentration maximum, peak time, plasma concentration, minimum inhibitory concentration and spectrum of activities of various antimicrobials in various breeds of domestic and wild goats. Oral dose formulations of antimicrobials have been classified biopharmaceutically, and pharmacokinetic equations used for calculation of common pharmacokinetic parameters have been highlighted. Information on pharmacodynamic parameters, intraspecies and interspecies scaling, tissue residues, antimicrobial resistance, rehydration therapy and antimicrobial intoxication has been elucidated.

3. Results

Kinetic parameters of some antimicrobial drugs used in treatment of microbial infections in goats, goat-human extrapolated doses of some antimicrobials and half-life and tissue residues and withdrawal periods of some antimicrobials are presented in **Tables 1–3**, respectively.

Chemical class	Name	Route	Dose (mg/kg)	$T^1/_2\beta$ (h)	Bioavailability (%)	Cmax (μg/ml)	Tmax (h)	Breed	Spectrum of activity	References
Fluoroquinolone	Levofloxacin	Subcut	1.25	4.67	—	0.33	—	—	Gram-negative	[26]
Aminoglycoside	Kanamycin	i.v.	5	2.8 ± 0.02	—	33.6 ± 5.5	—	Teddy	Gram-negative bacilli	[7, 8]
	Amikacin	i.v.	10	1.94 ± 0.10	—	—	—	Indian native	Gram-negative bacilli	
Fluoroquinolone	Levofloxacin	i.v.	10	4.04 ± 024	—	15.51 ± 1.41	—	Bengal	*S. aureus*	[6, 9, 27, 28]
	Ofloxacin	i.v.	5	6.20 ± 0.23	32.5	0.81 ± 0.00	—	Angora	*S. aureus*	
	Enrofloxacin	i.v.	5	3.93 ± 0.46	—	15.53 ± 1.31	—	Egyptian native	Wide spectrum of activities	
Aminoglycoside	Gentamicin	i.v., i.m.	5	8.1 ± 1.6	94	—	-	Markhor	Gram-negative spp.	[29]
Fluoroquinolone	Ciprofloxacin	i.v.	4	1.63 ± 0.17	—	4.47 ± 0.33	—	Bengal	*Salmonella* spp.	[30–32]
	Norfloxacin	i.m.	5	5.24 ± 1.98	66	2.06 ± 0.42	0.77 ± 0.18	Pakistan native	Gram-negative spp.	
	Gatifloxacin	i.v.	5	2.47 ± 0.08	—	—	—		Anaerobes	
Glycopeptide	Lincomycin	i.v.	10	9.99 ± 2.83	—	46.0 ± 7.06	—	—	Bacteria	[33, 34]
		i.m.	10	6.19 ± 0.25	—	5.63 ± 2.5	0.2 ± 0.16		Bacteria	
Macrolide	Tulathromycin	Subcut	25	67.2	—	0.12 ± 0.02	24	—	Bacteria	[35]
Fluoroquinolone	Pefloxacin	i.v.	10	1.2 ± 021	—	—	—	—	*E. coli*	[36]
		Oral	20	2.91 ± 0.50	42	2.22 ± 0.48	2.3 ± 0.7		*E. coli*	
Cephalosporin	Cefpirome	i.v., i.m.	10	2.09 ± 0.08	75	10.97 ± 0.34	—	Surti	Gram-positive	[37]
Macrolide	Azithromycin	i.v., i.m.	20	45.2	92.2	—	—	—	Bacteria	[38, 39]
	Erythromycin	i.v., i.m.	10	1.41 ± 1.20	98.83	2.99 ± 1.53	—		Bacteria	
Penicillin	Ampicillin (L/A)	i.v.	4.2	1.71	—	0.26	0.04	Ardi	Gram-positive/Gram-negative microbes	[10]
Danoxaline	Mequindox	i.v., i.m.	7	1.8	99.8	11.01 ± 2.94	0.67 ± 0.13	—	Broad spectrum	[40]

Chemical class	Name	Route	Dose (mg/kg)	$T^1/_2\beta$ (h)	Bioavailability (%)	Cmax (μg/ml)	Tmax (h)	Breed	Spectrum of activity	References
Tetracycline	Oxytetracycline	i.v., i.m.	20	27.96 ± 11.66	83.2	13.57 ± 5.83	0.46 ± 0.09	Kilis	Broad spectrum	[11]
			10					West African dwarf		
	Isoniazid	Oral	10	2.05 ± 0.72	—	3.71 ± 0.40	3.14 ± 0.19	Teddy	Antituberculosis	[12]
Nitroimidazole	Metronidazole	i.m.	30	5.87	—	54.4	2.0	Nubian	Antiprotozoan; antibacterial	[4]
Cephalosporin	Ceftriaxone	i.m., i.v.	20	1.5–2.03	—	21.51	—	—	Gram-positive	[41]
Fluoroquinolone	Marbofloxacin	i.m.	2	7.2	—	1.9	—	—	Gram-negative	[42]

Key: —, non-available data.

Table 1.
Kinetic parameters of some antimicrobial drugs used in treatment of microbial infections in goats.

Antimicrobial	Route	Dose of drug (mg/kg)	Weight of goat (kg)	BSA of goat (m^2)	Goat Km (m/kg)	Weight of human (kg)	Height of human (m)	BSA of human (m^2)	Human Km (m/kg)	Translated human dose (mg/kg)
Tulathromycin	Subcut	2.5	20	0.76	0.04	78	1.9	1.96	0.025	4
Erythromycin	i.m., i.v.	10, 15	30	1.00	0.03	78	1.9	1.96	0.025	18
Tylosin	i.m.	15	22	0.81	0.04	72	1.85	1.85	0.026	23
Pefloxacin	i.v.	10	25	0.88	0.04	51.3	1.58	1.42	0.028	14.3
Ciprofloxacin	i.v.	10	30	1.00	0.03	48	1.48	1.32	0.028	10.7
Cefpirome	i.m., i.v.	10	32	1.04	0.03	46.5	1.59	1.36	0.029	10.3
Lincomycin	i.m.	10	50	1.40	0.03	44.8	1.55	1.31	0.029	10.3
Enrofloxacin	i.m.	5	20	0.76	0.04	44	1.63	1.34	0.030	6.7
Norfloxacin	i.m.	5	30	1.00	0.03	35.5	1.46	1.13	0.031	4.8
Gatifloxacin	i.v.	10	20	0.76	0.04	31.4	1.46	1.05	0.033	12.1
Azithromycin	i.v.	20	30	1.00	0.03	43	1.58	1.30	0.030	20
Mequindox	i.m., i.v.	7	30	1.00	0.03	48	1.53	1.35	0.028	7.5
Metronidazole	i.m.	30	33	1.07	0.03	49.3	1.60	1.40	0.028	32
Kanamycin	i.v.	5	30	1.00	0.03	20	1.58	0.87	0.043	3.5
Gentamicin	i.v.	2	20	0.76	0.04	60	1.60	1.56	0.026	3.0
Streptomycin	i.v.	10	30	1.00	0.03	51.3	1.58	1.42	0.028	10.7
Difloxacin	i.m., i.v.	5	50.2	1.41	0.03	55	1.70	1.54	0.028	5.4
Levofloxacin	i.v.	10	20	0.76	0.04	65	1.70	1.68	0.026	15.4
Ofloxacin	i.v.	5	20	0.76	0.04	70	1.50	1.63	0.023	8.7

Antimicrobial	Route	Dose of drug (mg/kg)	Weight of goat (kg)	BSA of goat (m^2)	Goat Km (m/kg)	Weight of human (kg)	Height of human (m)	BSA of human (m^2)	Human Km (m/kg)	Translated human dose (mg/kg)
Ampicillin	i.v.	4.2	55	1.50	0.03	45	1.40	1.25	0.028	4.5
Isoniazid	Oral	10	40	1.21	0.03	30	1.30	0.97	0.032	9.4
Oxytetracycline	i.m., i. v.	20	40	1.21	0.03	64	1.60	1.61	0.025	24
Amikacin	i.m.	10	25	0.88	0.03	56	1.30	1.35	0.024	12.5
Sulfadimidine	i.m.	33.3	10.4	0.49	0.05	60	1.20	0.75	0.0125	66.6

Table 2.
Goat-human extrapolated doses of some antimicrobials.

Antimicrobial	Route	Dose (mg/kg)	$T^1/_2\beta$ (h)	Quantity of residues (ppm)	Withdrawal period	Affected organ	Consequence(s)	References
Tulathromycin	Subcut	2.5	61.4 ± 141 days	2.09 ± 1.77	34 days	Kidney	Nephrosis	[5]
Erythromycin	i.v., i.m.	10, 15	—	2.06 ± 0.36	—	Milk	Resistance	[39]
Sulfadimidine	i.m.	100	26.3–41.9 days	1.24–5.68	>30 days	Kidney, liver, brain, skeletal muscle, intestine, heart	Steven-Johnson syndrome, nephrosis	[13]
Tylosin	i.m., i.v.	15	6.8 h	1.70 ± o.03	2 days	Milk	Possible resistance in kid	[43]
Gatifloxacin	i.v.	5	12 h	2.00	2 days	Milk	Resistance in kid	[32]
Delafloxacin	Subcut, i.m., i.v.	5	4.5–6.4 h	1.2–2.1	>1.5 days	Milk	Resistance in kid	[44]
Levofloxacin	i.v.	10	4.6–7.3 h	14.7–17.0	12.3–42.3 h	Milk	Resistance in kid	[9]
Ceftazidime	i.m., i.v.	10	4.7±1.1 h	2.4–18.3	4 days	Milk	Resistance in kid	[45]

Table 3.
Half-life, tissue residues and withdrawal period of some antimicrobials.

3.1 Biopharmaceutical classification of oral antimicrobials

This is a system of classifying antimicrobials based on aqueous solubility and intestinal permeability. The four major factors being considered in this classification system are dosage form, dissolution rate, solubility and permeability. Hence, antimicrobials are tested in vitro and classified into four classes:

Class 1: High solubility − high permeability
Class 2: Low solubility − high permeability
Class 3: High solubility − low permeability
Class 4: Low solubility − low permeability

All the classes of dissolution can occur in a pH range of 1–2, 4–5 and 6–8 [46]. Nevertheless, administration of highly toxic antimicrobials such as aminoglycosides (e.g. gentamicin) should be monitored since it damages the kidney.

$$\text{Such drugs are said to have narrow therapeutic range (NTR)} = \frac{\text{Minimum toxic concentration (MTC)}}{\text{Median effective concentration (MEC)}}$$

3.2 Pharmacokinetic equations of antimicrobials

Bioavailability, absorption half-life ($T^1/_2\alpha$), mean absorption time (MAT), mean residence time (MRT), apparent volume of distribution (Vd), volume of distribution, steady state (Vdss), area under curve (AUC), area under the first moment curve (AUMC), peak time (Tmax), elimination half-life ($T^1/_2\beta$) and systemic clearance (Cl) are the pharmacokinetic parameters commonly determined in all species of animals and humans [7, 9, 47–49]. The most important of all these parameters are elimination half-life, volume of distribution and plasma concentration of the antimicrobials.

The pharmacokinetic process of antimicrobials in goats obeys first-order kinetic (**Figures 1** and **2**) which could be mono-exponential or bi-exponential. The exponential equation commonly used for determination of pharmacokinetic parameters is $CP = A_e^{\alpha t} + B_e^{-\beta t}$. Other equations are:

$$T1/2\alpha = \frac{0.693 \times MAT}{ka} \tag{1}$$

$$MAT = 1/ka \tag{2}$$

$$MRT = \frac{AUMC}{AUC} \tag{3}$$

$$Vd = \frac{Clb}{\beta} \tag{4}$$

$$AUC = \frac{Dose}{Cl} \tag{5}$$

$$AUMC = MRT \times AUC \tag{6}$$

$$T1/2\beta = \frac{0.693}{\beta} \tag{7}$$

$$Clb = \frac{Dose}{AUC} \tag{8}$$

However, peak time (Tmax) and Cmax can be estimated from the pharmacokinetic graph [47].

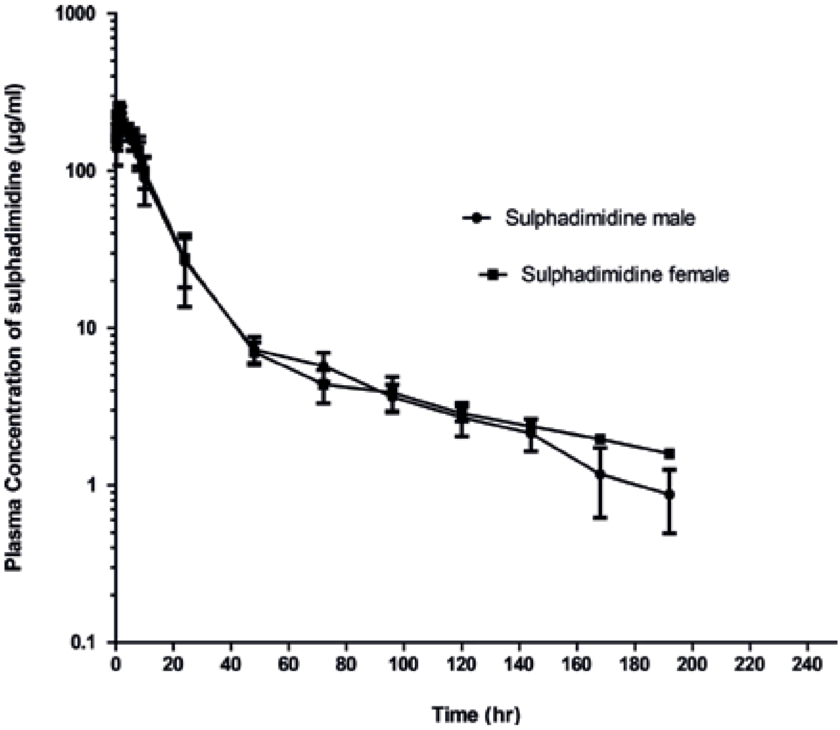

Figure 1.
Mean plasma concentration-time curves of sulfadimidine (100 mg/kg) in male and female WAD goats following intramuscular administration.

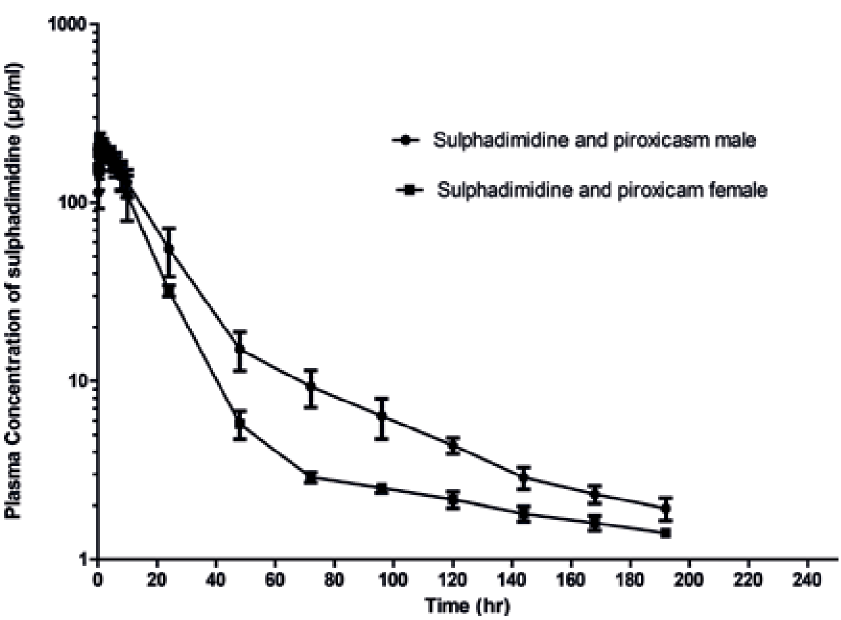

Figure 2.
Mean plasma concentration-time curves of sulfadimidine (100 mg/kg) when co-administered with piroxicam (5 mg/kg) to male and female WAD goats following intramuscular administration.

$$\text{Dosage rate (DR)} = \frac{\text{bioavailability (F)} \times \text{dose (D)}}{\text{dosage interval (DI)}} \tag{9}$$

$$\text{DR} = \frac{\text{plasma concentration (CP)}}{\text{body clearance (Clb)}} \tag{10}$$

$$\text{Infusion rate (Ro)} = \text{plasma concentration, steady state (Cpss)} \times \text{Clb} \tag{11}$$

$$\text{Accumulation index} = \frac{1}{\text{fraction lost per dosing interval}} \tag{12}$$

$$= \frac{1}{1 - \text{fraction left in the body}} \tag{13}$$

$$\text{Loading dose (LD)} = \frac{\text{target Cp} \times \text{Vss}}{\text{F}} \tag{14}$$

$$\text{LD} = \text{maintenance dose (MD)} \times \text{accumulation index (Al)} \tag{15}$$

$$\text{MD} = \frac{\text{DR} \times \text{DI}}{\text{F}} \tag{16}$$

$$\text{Rate of elimination (RE)} = \text{CL} \times \text{concentration} \tag{17}$$

$$\text{Bioavailability (F\%)} = \frac{\text{AUC Oral, Sc, Im} \times 100}{\text{AUCiv}} \tag{18}$$

4. Discussion

4.1 Comparative pharmacokinetics of antimicrobials in domestic goats

Species variations in response to antimicrobials are very important. Various antimicrobials from different chemical classes, their routes of administration, doses, elimination half-life, bioavailability, maximal concentration, peak time, breed and spectra of activity are presented in **Table 1**. The therapeutic doses of fluoroquinolones in goats are 1.2 mg/kg subcut for levofloxacin, 5 mg/kg i.v. (orfloxacin, enrofloxacin, norfloxacin and gatifloxacin) and 20 mg/kg oral (pefloxacin). The elimination half-life (2.8 ± 0.02 h) of kanamycin (5 mg/kg) and half-life (1.94 ± 0.1 h) of amikacin (10 mg/kg) in Teddy and Indian native goat, respectively, show that the disposition kinetics of aminoglycosides in goats is dependent on the dose of drugs. Also, disposition kinetics of antimicrobials in goats could be species dependent. For example, Cmax (236.3 ± 0.00 μg/ml) of sulfadimidine in West African dwarf (**Figure 1**) is higher than that of Pakistan female goat (6.0 ± 3.0 μg/ml) and Shiba goat (2.14 ± 1.05 μg/ml), respectively [16]. Tmax of West African dwarf (1.1 ± 0.3 h) is lower than that of Shiba (2.0 ± 1.2 h) and Netherland dwarf (2.0 ± 0.5 h), respectively [18, 19]. But Vd (3.9 ± 0.8 L/kg) in West African dwarf is higher than that of Nubian (0.32 ± 0.0 L/kg), Shiba (0.4 ± 0.2 L/kg) and cross-breed (0.3–0.5 L/kg), respectively [17, 19, 20], suggesting the difference in breed response to antimicrobials. However, half-life of kanamycin (5 mg/kg) was higher in buffaloes (4.35 ± 0.24 h), cow (6.0 ± 0.50 h) and sheep (3.4 ± 0.1 h) than that of goat (2.8 ± 0.2 h), respectively, indicating that goat is the species most sensitive to kanamycin among these species of herbivores. Also, difloxacin is effective at 5 mg/kg [8]. But normal milk reduces the activity of enrofloxacin against *E. coli* [50]. However, T1/2β (1.94 ± 0.1 h) of kanamycin for normal goat is lower than the T1/2β (3.17 ± 0.13 h) for febrile goat. Maintenance of therapeutic concentration (2 mg/ml) requires a priming dose of 14.73 mg/kg and maintenance dose of 13.95 mg/kg at an 8-h interval, respectively [8]. Plasma concentration of levofloxacin is higher in healthy goats (15.51 ± 1.41 μg/ml) than mastitis goats (12.48 ± 1.36 kg/ml). This plasma concentration does not affect levofloxacin elimination [9].

Since various brands of enrofloxacin have different pharmacokinetic parameters such as half-life (3.93 ± 0.46; 4.04 ± 0.53; 4.56 ± 1.24 h) and plasma concentrations (15.53 ± 1.31; 6.75 ± 0.56; 10.40 ± 2.65 μg/ml) [28], dosage formulations may have sufficient effects on pharmacokinetics and pharmacodynamics of aminoglycosides. Serum concentration of gentamicin (5 mg/kg) was maintained at 1.5–12 μg/ml for a period of 6 h. But gentamicin (2.5–3.0 mg/kg i.m.) every 8 h is therapeutically useful with less risk of nephrotoxicity [29], as daily intravenous administration of 4 mg/kg is effective for 36 h in the treatment of systemic and urinary tract infections caused by Gram-negative pathogens in goats [30]. Therefore, optimal dosage regimen, bioequivalence and kinetic parameters of antimicrobials are of clinical importance [31]. Elimination half-life, Cmax and Tmax of intramuscular enrofloxacin (2.5 mg/kg) are 5.39 ± 0.96 h, 1.14 ± 0.09 μg/ml and 0.83 ± 0.13 h, respectively [51]. Gatifloxacin (5 mg/kg) provided minimum inhibitory concentration (MIC) of 0.1–2 μg/ml for susceptible microorganisms between 6 and 12 h in healthy and febrile goats, respectively [32]. Elimination half-life (3.98 ± 0.18 h), Cmax (9.24 ± 1.2 μg/ml), MRT (4.13 ± 0.16 h), Vdss (1.22 ± 0.06 L/kg) and Clb (0.24 ± 0.01 l/h/kg) of enrofloxacin (5 mg/kg) have been reported [6]. The Vd (3.35 ± 0.45 L/kg), Clb (0.28 ± 0.03 l/h/kg) and $T^1/_2\beta$ (9.99 ± 2.83 h) suggest long persistence of lincomycin in goat as it can be repeated every 24 h with MIC (0.6 μg/ml) for treatment of febrile bacterial infections in goats [33]. But intramuscular lincomycin can be administered every 12 h [34].

Vancomycin was initially active against methicillin-resistant *Staphylococcus*, but presently vancomycin-resistant *Staphylococcus* has emerged, and vancomycin-resistant *Enterococcus* has also emerged due to its usage as feed additive. Hence, prophylactic use of antibiotics should be highly reduced [52]. Concentration of pefloxacin (0.25 μg/ml) was maintained in plasma for 6–10 h after oral or intravenous administration. Therefore, intravenous pefloxacin (20 mg/kg) every 6 h or thrice orally is effective against sensitive pathogenic microbes in goats [36]. But intravenous dose (10 mg/kg) of ciprofloxacin with $T^1/_2\beta$ (2.72 ± 1.04 h), MRT (3.33 ± 1.42 h), Vdss (3.37 ± 0.8 l/kg) and Clb (19.59 ± 9.05 ml/min/kg), respectively, should be administered every 12 h [53]. Cefpirome (10 mg/kg) every 12 h is *useful when administered intravenously in goats. It is 19.9% plasma protein bound* [37] and so may compete weakly with other plasma-binding drugs such as sulfadimidine, warfarin, non-steroidal anti-inflammatory drugs and barbiturates. The long half-life of azithromycin after intravenous (45.2 h) and intramuscular (32.5 h) administration and MRT of 40.1 h and 60.3 h and bioavailability of 92.2% [38] show that the drug could be administered every 2 and 3 days, respectively. But half-life (67.2 h) of tulathromycin (25 mg/kg) indicates that the withdrawal period of tulathromycin may be long and there may not be a need for repeated doses of the drug. But elimination of erythromycin is higher in lactating goats (3.18 ± 1.32 h) than non-lactating goats (1.41 ± 1.20 h) [39] signifying that erythromycin is quickly removed from the body of non-lactating goats. MIC of erythromycin against *Staphylococcus aureus* was 0.50 and 0.75 μg/ml [54], respectively. Tylosin (10–15 mg/kg) was administered to goats both intramuscularly and intravenously. The intramuscular bioavailability was 72.6%, and serum protein binding was 37.6%, Cmax (2.38 μg/ml), Vd (1.7 L/kg), $T^1/_2\beta$ (3.04 h), Tmax (4.19 h) and Clb (6.8 ml/kg/min), respectively. Hence, tylosin should be injected every 14 h [43]. Gentamicin (4 mg/kg), amikacin (10 mg/kg), tobramycin (5 mg/kg), kanamycin (10 mg/kg) and apramycin (20 mg/kg) may have synergistic or additive antibacterial activity [55]. Intramuscular metronidazole can be administered to goats at 10 mg/kg body weight every 12 h [4]. Oxytetracycline (10 mg/kg), ampicillin (20 mg/kg) and combination of trimethoprim (20 mg/kg), sulfamethazine (50 mg/kg) and sulphamethyl phenazine (50 mg/kg) are effective in treatment of ehrlichiosis [56]. But extensive and very wide use of antimicrobial agents in goats may portend very high risk of resistance [57]. Therefore, each antimicrobial must be studied on species basis for effective and safe use for animal well-being and public safety in terms of animal product consumption and human/animal drug resistance [3].

4.2 Pharmacokinetics of antimicrobials in wild goats

Although the information on pharmacokinetics of wild goats is rare, allometric scaling can be applied for extrapolation of some parameters including Vd and Cl except T1/2β [58]. Ceftazidime (10 mg/kg) administered to Creole goat showed high serum concentration, good penetration and high bioavailability of the drug [45]. But cephalexin (10 mg/kg) administered (subcut, i.m. and i.v.) to *Lama glama* showed high bioavailability of 72% (i.m.) and 89% (i.v.), respectively. The MIC90 values of cephalexin against coagulase-positive staphylococci and *E. coli* were 1.0 μg/ml and 8.0 μg/ml, respectively [59]. But MIC90 value (0.01–0.1 μg/ml) of ceftazidime against *E. coli*, *Salmonella* species, *Pasteurella haemolytica* and *P. multocida* [45] shows that ceftazidime is more active and efficacious than cephalexin, which can be administered 8 mg/kg i.m. or subcut every 12 or 24 h, respectively [59]. Other modes of administration such as ballistic implants and impregnated beads can be employed for some antimicrobials to avoid frequent administration as seen in cefovecin with very long half-life in dogs and cats, allowing a dosing interval of 14 days [60, 61]. This strategy may reduce the chance of resistance by microorganisms against antimicrobials. For example, an amoxicillin formulation with half-life of 130 h can be administered every 6 days, and ceftiofur with half-life of 37 h can be administered every 2 days in goats [62]. Orbifloxacin administered to Mehsana goat (2.5 mg/kg i.v.) with T1/2β (8.63 ± 0.13 h), Vdss (2.99 ± 0.04 l/kg), MRT (21.07 ± 0.8 h) and bioavailability (155.5%) showed antimicrobial activity against *E. faecalis*, *S. epidermidis*, *S. intermedius*, *S. aureus*, *S. pyogenes*, *E. coli*, *S. typhimurium*, *S. typhi*, *S. enterica*, *Shigella flexneri*, *K. pneumonia*, *E. aerogenes*, *P. aeruginosa*, *P. mirabilis*, *Pasteurella* species, *Mycoplasma* species and *Mannheimia haemolytica* [63].

4.3 Pharmacodynamics of antimicrobials

Pharmacokinetics determine maximal therapeutic effect that depends on plasma drug concentration, drug receptors, health status and co-administration of antimicrobial with another drug that shares same or different binding receptors. Slowly eliminated and accumulated antimicrobials are least compared by poor dosing interval [64]. The maximal effect of antimicrobials is dependent on molecule-receptor interaction and drug-affinity response. Therefore,

$$\text{Drugs (D)} + \text{receptor (R)} \rightleftarrows \frac{k_1 DR}{k_2} \tag{19}$$

$$\text{Affinity constant (Kaff)} = \frac{k_1}{k_2} \tag{20}$$

$$\text{Kaff} = \frac{1}{ED_{50}} \tag{21}$$

However, antimicrobial treatments can be monitored as follows:

$$\text{Dose(new)} = \frac{\text{Cpss(measured)}}{\text{Cpss (desired)}} \times \text{Dose(previous)} \tag{22}$$

But Cpss is achieved when antimicrobial is administered repeatedly at different time intervals.

$$\text{Therapeutic index (TI) is defined as a ratio of } \frac{\text{Lethal dose fifty (LD50)}}{\text{Effective dosefifty(ED50)}} \tag{23}$$

$$\text{Effective dose (ED)} = \frac{\text{CL} \times \text{effective concentration (EC)}}{\text{Bioavailability (F)}} \tag{24}$$

However, when the body weight of goat is reduced by diarrhea or intoxicated by antimicrobials, there may be a need for fluid infusion to maximize balanced pharmacokinetic/pharmacodynamic process of antimicrobials. Clinical correlates of weight loss as a measure of dehydration (>5–12%) must be considered.

$$\text{Drops/minute} = \frac{\text{volume of infusion (ml)}}{\text{time of infusion (min)}} \times \text{drop factor (drops/ml)} \tag{25}$$

$$\text{Infusion rate (IR)} = \text{drug dose} \times \frac{1}{\text{drug conc}} \times \text{drop factor} \tag{26}$$

Only half of calculated deficit should be administered in 1–2 h. Half replacement in 4–6 h is safer and should be completed in 2 days [65]. Isotonic solutions such as 5% dextrose and 0.9% normal saline can be administered via all routes. But hypotonic and hypertonic solutions should be administered intravenously to avoid tissue reaction.

Weighted AUC approach accounts for a more powerful PK/PD link and reveals uniqueness outcome of therapeutic indices and problems of antibiotic resistance [66]. A combination of ampicillin/sulbactam (20 mg/kg) in ratio 2:1 was administered to goat with elimination half-life of ampicillin (0.71 ± 0.12 h), and sulbactam (1.02 ± 0.36 h) shows that the preparation could be administered at the same dosing rate in both sheep and goats [67]. Also, intramuscular dose (2 mg/kg) of cefquinome (Cobactan 2.5%) daily yielded effective MICs against a variety of susceptible pathogenic microbes of goat including *Micrococcus luteus* [68]. Serum concentration and AUC integrated with MIC values can predict clinical success. The efficacy of macrolides, penicillins and tetracyclines is determined by the length of time, the serum concentration exceeds the MIC of a pathogenic microbe. But fluoroquinolones, aminoglycosides and metronidazole have concentration-dependent bactericidal activity [69]. The ratio of Cmax/MIC indicates potential of antibacterial activity. Amikacin has the lowest MIC90, whereas kanamycin has the highest [55]. Co-administration of two or more drugs could also affect pharmacokinetics and pharmacodynamics of a drug. For example, West African dwarf goats are more sensitive to sulfadimidine co-administered with piroxicam (**Figure 2**) [15].

4.4 Intraspecies and interspecies scaling of antimicrobials in goats

Variation is an important factor in development of antimicrobials for all species of animals including wild and domestic goats. The problems encountered are how to scale up the pharmacokinetic data from animals to human and how to extrapolate in vitro data to in vivo data for efficacy and safety [70]. There is no enough data on toxicological effects of antimicrobials in goats. Hence, several extrapolations are necessary in order to arrive at safe therapeutic and toxic doses [71]. The effective therapeutic doses of some antimicrobials translated from goats to human are given in **Table 2**.

The formulas used for calculation of extrapolated doses are as follows [13, 72, 73].

$$\text{Human equivalent dose (HED)} = \frac{\text{animal dose} \times \text{animal Km}}{\text{human Km}} \tag{27}$$

$$\text{Metabolism constant (Km)} = \frac{\text{body surface area}}{\text{body weight}} \tag{28}$$

$$\text{But human body surface area (BSA)} = H^{0.528} \times W^{0.528} \times K \tag{29}$$

whereas H = height, W = weight and K = constant.

But goat's BSA = $W^{O.67} \times 10^{-3}$ and dosimetric adjustment factor (DAF) is body weight of goat over body weight of humans and can be scaled up to 0.25, 0.33 and 0.58. However, body weight exponent of 0.67 and 10^{-3} safety factor should be applied to goat, and the exponent of 0.528 should be applied to human weight and height, respectively [72, 74].

4.5 Antimicrobial tissue residues in goats

Tissue residues of some antimicrobials above recommended thresholds are of public health importance. The presence of sulfadimidine residues (>0.1 ppm) in the liver, kidney, skeletal muscle, spleen, lung, brain and heart after administration of the drug (100 mg/kg) shows that the withdrawal period is longer than 30 days. Hence, sulfadimidine is not easily excreted in West African dwarf goats [13]. This may be due to the presence of desamino-sulfonamide, a sulfadimidine metabolite [75] which is eliminated slowly, thereby increasing the withdrawal time [76]. Lack of adequate water to dilute crystals of sulfadimidine in the kidney can lead to crystalluria that can consequently cause nephrosis in the affected animals [44], and consumptions of meats with high residues of sulfadimidine can cause Steven-Johnson syndrome in sensitive humans who may be slow or fast acetylators [13, 23]. Based on the tissue tolerance limit in cattle (5 ppm), the withdrawal period for tulathromycin is 19 days in cattle and 34 days in goat when administered subcutaneously [5]. The quantity of erythromycin residues (2.06 ± 0.36 μg) is above the recommended threshold and may portend risk to public health. The bioavailability of tylosin in goat is $72.6\pm 2.3\%$, and its withdrawal period (48 h) [43] shows that the higher the bioavailability, the lower may be the withdrawal period in milk. Residues of antimicrobials in various tissues are presented in **Table 3**. A kid that feeds on milk with residues of antimicrobials may be vulnerable to resistance of microorganisms against the antimicrobials.

4.6 Antimicrobial resistance

Goats are exposed to antimicrobials via prevention, treatment of diseases and growth promotion. This has caused the emergence of resistant *Salmonella*, *Campylobacter*, *Pasteurella*, *Actinobacillus*, *Enterococcus* and *Escherichia* species. The resistance is transferred by genes. But good and improved management practices and increased use of vaccines and probiotics could minimize emergence and spread of resistance genes [77].Off-label use of antimicrobials in goats could also contribute to emergence of resistance. Meanwhile, lack of official-generated data on consequences of extra-label use of drugs in goats cannot rule out its potential risks to goats and other species of animals [78]. However, T-phage, transposon and integrin are used for resistance gene transfer. Unfortunately, the worldwide consumption of antimicrobial drugs is increasing, and the manufacturing industries are not keeping pace. The worst of it at the moment is the emergence of superbugs and super drugs. Therefore, there is a need for green antibiotics to minimize the chance of resistance [79].

4.7 Determination of creatinine and glomerular filtration rate as indices of renal function in goats

Kidneys are responsible for water-electrolyte balance in the body, usually affected by activity-rest rhythm under hormonal influence. The diurnal changes are useful in chronobiology and chronopharmacology [80]. Many xenobiotics including antimicrobials are toxic to the kidney, and renal impairment can be assessed using creatinine clearance which is physiologically, pharmacologically and toxicologically related to body weight, clearance, volume of urine creatinine, plasma creatinine, serum creatinine, urine volume, glomerular filtration rate, creatinine clearance, creatinine half-life and depuration [81]. The plasma creatinine of Boer-Cross (0.60 mg/dl), Nubian (0.55 mg/dl) and Spanish (0.57 mg/dl) goat have been reported [82], whereas creatinine value (1.03–1.24 mg/dl) has been reported for healthy captive, Persian wild goat [83]. Area under curve could be used to determine creatinine clearance and plasma clearance as demonstrated in the equations given below [81].

$$\text{Dose (D)} = \text{AUC} \times [\text{CrCl} + 25] \tag{30}$$

$$\text{Pcl} = \text{CrCl} + 25 \tag{31}$$

$$\text{CrCl} = \text{Pcl–25} \tag{32}$$

$$\text{GFR} = \frac{14616.8}{\text{Crt1/2}} \tag{33}$$

$$\text{Depuration (Dep)} = \frac{\text{Ucr}}{\text{Pcr}} \tag{34}$$

$$\text{Serum creatinine(Scr)} = \frac{\text{Ucr}}{1440} \times 1000 \ (1000 \text{ ml} = 1 \text{ l}) \tag{35}$$

$$\text{Creatinine clearance (CrCl)} = \frac{\text{Ucr}}{\text{Pcr}} \times 144 \tag{36}$$

For example, paracetamol reduced glomerular filtration rate and induced less urinary excretion of isoniazid. Also, renal handling of isoniazid involved glomerular filtration, back diffusion and active tubular secretion [84]. Glomerular filtration rate which is a function of creatinine clearance can be affected by environmental and genetic factors as may be seen in native Pakistan goats administered ampicillin (20 mg/kg) with renal clearance of 0.08 ml/min/kg [85]. Hence, GFR is lower in Pakistan native than the foreign goats [86] unlike renal handling of marbofloxacin in Lohi sheep that involves both glomerular filtration and active tubular secretion [87] indicating that environment has physiological effects on various breeds of goats. This agrees with Bergmann's rule which states that light animals tend to live in hot regions of the world as opposed to fatty animals that tend to live in cold regions [88]. Since 8% of total body weight determines total blood volume, red cell volume and plasma volume could also be determined from hematocrit as indicated in the equation given below [89].

$$\text{Total blood volume} = \text{plasma} \times 100/100\text{–hematocrit} \quad (37)$$

Long-time administration of sulfadimidine over a period of 1 week may cause hemolysis leading to anemia [90]. Hence, the formula can be used to determine anemia and plasma deficit in goats, photos 1-46 [1, 2, 21, 22, 24].

1, Abergelle goat; 2, Afar goat; 3, African pygmy goat; 4, Altai mountain goat; 5, American Alpine doe; 6, Anglo Nubian goat; 7, Angora goat; 8, Ardi goats in the Arabian Peninsula; 9, Attappady black goat; 10, Babrbari-goat-breed; 11, Beetal-South Asia; 12, Black Bengal goat; 13, Black Oberhasli; 14, Bosque Valley Boer goats; 15, British primitive (Feral goat); 16, Dairy goat; 17, Dutch Toggenburger; 18, Eid-goat; 19, Indian Boer male goat; 20, Italian Adamello blond; 21, Kalahari-red-goat; 22, Marciano-Granadina; 23, Markhor wild goat; 24, Markhor-Pakistan; 25, Murciana goat; 26, Nederlandse Landgeit; 27, Nigeria West African dwarf goat; 28, Nubian blackgold goat; 29, Nubian-Ryan-Somma; 30, Oberhasli goats; 31, Osmanabadi goat; 32, Pakistan Bakra goat; 33, Paaltu Bakri-Nashik goat; 34, Shiba goat; 35, Pure-white-Tappra-teddy-male-goat; 36, Saanen-goat-in-Pakistan-Urdu; 37, Sangamneri-South Asia pro-poor; 38, Shatner goat; 39, Sirohi-male-kid-goat; 40, Sojat-goat; 41, Sokoto Red goat; 42, Teddy-tapra-bakra-goat; 43, Toggenburgerbok goat; 44, Toggenburg-Nigerian-dwarf-Oberhasli-goat; 45, Valachian goat; 46, White Barbari-goat.

5. Conclusion

Pharmacokinetic, pharmacodynamic, intraspecies and extraspecies scaling are some parameters that can affect physiological functions of antimicrobials in goats. Lack of judicious and extralabel use of antimicrobials in goats could cause high tissue residues and development of resistance by susceptible microorganisms against the antimicrobials in both goats and humans. Tissue residues of sulfadimidine may cause Stevens-Johnson syndrome in the vulnerable individuals. Dehydrated goats may be more susceptible to antimicrobial toxicity. GFR can be used to assess the level of kidney damage caused by antimicrobials, and rehydration therapy is useful in dissolution of antimicrobial crystals formed in the kidney. In case of fervent need for extralabel use of antimicrobials, the relevant formulas reported herein could be used to translate goat dose to human dose and vice versa.

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Chapter 9

Goat Immunity to Helminthes

Mohammad Mazhar Ayaz, Ahsan Sattar Sheikh, Mubashar Aziz and Muhammad Mudasser Nazir

Abstract

Goat hematology, especially, shares considerable attention since the last 1980s. Large number of discrepant normal hematologic values is reported. The discrepancies resulted came from the differences in age group, breed, and health standing of goats. This makes it further complex with variances in climate of the region, its environment, and size and methodology applied. With time, many inconsistencies, reasonably standardization in normal caprine kinetic hematologic values, are in place. Both goats and sheep are infested by the same key digestive tract helminthes (DTHs) diseases. Helminthes are exceedingly ubiquitous worm parasites that progressed to adopt with many erudite means to evade host immune system.

Keywords: goat, Helminthes, parasites

1. Introduction

Global estimates gathered over time show that goat population is getting bigger as in comparison to sheep numbers. It is estimated that approximately that both share a staggering number of 2.1 billion—over 1.7 billion (80%) resides within Africa and Asia continent [1, 2] and more than 90% of the goat population found in Asia and Africa (**Figure 1**). This increase in goat population is accomplished with its economic value as an efficient converters of low-quality feeds into high quality meat, dairy, and leather products [3, 4].

Goat hematology, especially, shares considerable attention since the last 1980s [5, 6]. Large number of discrepant normal hematologic values is reported. The discrepancies resulted came from differences in age group, breed, and health standing of goats [7]. This makes it further complex with variances in climate of the region, its environment and size and methodology applied. With time, many inconsistencies, reasonably standardization in normal caprine kinetics hematologic values are in place [8–10]. Talking of immune system, specific evidence on the goat immune system remains hard to get as compared to other animal species [11].

Both goats and sheep are infested by the same key digestive tract Helminthes (DTHs) diseases [12]. These parasites are enormously efficacious parasites that affect innate immune response globally around the world [13, 14]. Helminthes are exceedingly ubiquitous worm parasites that progressed to adopt with many erudite means to evade host immune system [15]. They incite pathological features resulting in huge economic losses. Till now most data on the host-parasite interactions are accumulated through ovine (sheep) studies [12, 16]. Helminthes in the abomasum and related area of host still remains as one of the major threats that is responsible for weight loss, anemia, reduced performance and production in goat [17, 18].

In contrast to cattle, many of Cestodes, Trematodes and Nematodes readily cause disease in goat as well as in sheep (**Figure 2**). Recently, some data also highlights differences in caprine and ovine species/strains, especially for nematodes [4, 19]. In goats, it is understood that they tend to accumulate parasites, which is assessed from constant monitoring of increasing number of eggs, keeping in view about seasonal differences in excretion [20]. Sheep acts in reverse [11]. In developed nations, the main magnitudes of these infections is reflected as spartan losses of production. Whereas in underdeveloped/developing countries it translates in more aggravate DTHs mortalities [11, 21].

After goat and sheep domestication, both independently settled down to different feeding habits. The sheep are grazers and prefer to take grass and broad-leafed plant. Goats, on the other hand, are classified as browsers or intermediate browsers. They can ingest substantial amounts of woody plants, vines and brush according to their liking [3]. These feeding habits could upshot to sources of DTHs infestation and with distinct strategies with major consequences to host-parasite relationships [4].

In the caprine evolutionary processes, adaptation to this high miscellany of plants, direct for three consequences to regulate parasitic populations. They include

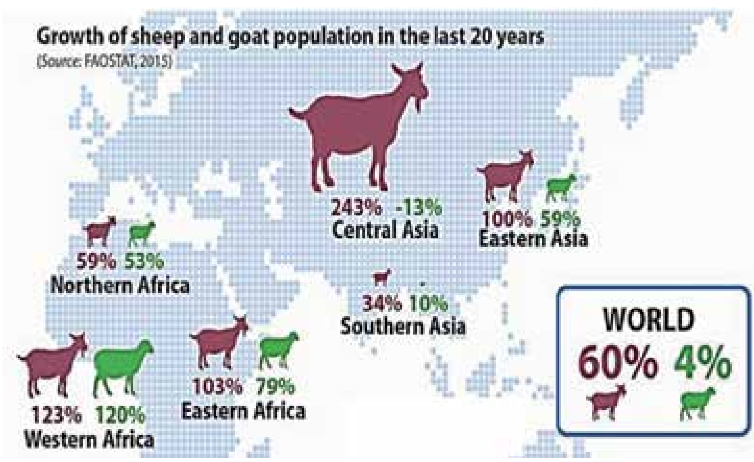


Figure 1.
Growth of sheep and goat population in the last 20 years.

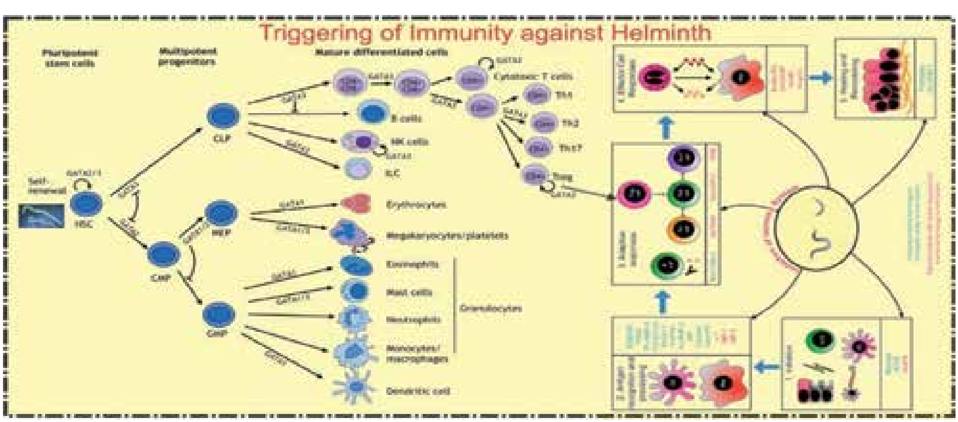


Figure 2.
Developmental stages of immune cells during Helminth infection.

(i) subdued immune response, (ii) increased metabolism of xenobiotics and (iii) self-medication [4]. Recent literature, and documentation show that sheep is studied more to greater depth than to goats. However, generally both species share high degree of genetic and physical similarities [6, 19]. Small differences, however, do exist between the two, such as, goats cannot harbor *Helicobacter pylori* in its gastric lumen. This is in contrary to wide range of animals including sheep and cattle.

2. Research methods and analysis

The method used in this chapter mostly focuses on literature already published or still in draft form. The thorough insight in to literature discussed put some light on the immune response in general and goat immune system in particular for the further areas to be addressed in future studies.

3. Discussion

In goats, full immune response expression, seems to be delayed by 6 months i.e. 12 months versus 6 months in goat to sheep [22]. Immune differences in expression between the two hosts are also been documented [4, 23]. It is also assumed that goats tends to accumulate parasites more than sheep. Because of goats weak recognition, and expulsion systems, larval reduction and expulsion of larval or/and adult worms are rarely observed [11, 24]. DTH infections under ordinary circumstances could be reduced as a result in changes to; (i) helminthes resistance by developing an immune response (ii) infective contact especially by avoidance feeding pattern of goats; and (iii) self-medication as results of alleviating worm challenges [4].

In this modern era, helminth's genomics and proteomics understanding tend to provide dependable evidences on presence of large number of immunomodulatory products. These are abridged in number of articles. We can group them in immunological phases;

3.1 Immunological phases

i. initiation,

ii. recognition of antigen and processing,

iii. adaptive immune response,

iv. cellular effector factor responses, and lastly,

v. coagulation, healing, or remodeling.

3.2 Parasite immune-modulators

In each phase, parasite immunomodulators acts specific phase [14, 25]. Immune responses, against most DTHs, are initiated by vulnerability signals generated by initial indicator molecule. The pivotal role of pathogen- or damage-associated molecules patterns (PAMPs and DAMPs respectively) are recognized through receptors on myeloid cells [14]. These chemical identities are acknowledged directly to the physical presence of helminthes in goats' gut [25]. The parasitic induction by DAMPs and PAMPs signals are presented in following figure [14].

Helminthes and some of its products, released by them, can damage the epithelial layer, resulting in the release of damage associated molecular patterns (DAMPs) and which ingresses in the intestine. DAMPs and pathogen associated molecular patterns (PAMPs) can be sensed by receptors that are present on dendritic cells (DCs) and macrophages (Mϕ) [14, 26]. The attachment signals are followed by activation, and antigen presentation to appropriate lymphoid cells [27, 28]. These extracytosolic signals, transmitted as cytokines, influence the central hub of innate lymphoid cells 2 (ILC 2) bundle that stimulates IL 25, IL 33, and thymic stromal lymphopoietin (TSLP)—protein that enhances the maturation of myeloid (CD 11c) dendritic cells. The release of ILC 2 consequential provide signals to type 2 cytokines that amplifies immune type 2 reaction. This aids in the initiation and amplification of the type 2 immune response [29].

4. Innate lymphoid cells (ILCs)

Since last a few years, new players have emerged in cell activation and sustaining an immune response to helminthes infection. The innate lymphoid cells (ILCs) bundles are collection of assorted population that are discovered recently. These collections does not initially express any specific antigen on receptors [30]. These lymphoid cells believed to orchestrate adaptive immune system, type-2 innate lymphoid cells (ILC 2), activities were able to demarcating ILC 2 functions, especially in helminth infection [31] (**Figure 3**).

This all came into the picture, after the discovery, within the T- and B-cell-deficient mice. Functional analysis of ILC 2 and TH 2 cells showed that they share common roles. To secrete rapidly cytokines and in large quantities, these two group of cells coordinate and interact with each other directly [14]. The cells release cytokines (type-2) after spur from Alarmin—IL 25 axis [32, 33]. On the topic, many study reports on origin, differentiation, mobility, functionality, plasticity, and communication skills of these cells within the immune system [33]. The ILC family includes ILC 1, ILC 2 and ILC 3 [30]. These clusters originate from common innate lymphoid progenitors (CILPs). CILPs cells transform into differentiate into ILC precursors (ILCPs) [34, 35]. The system polarize into three different innate lymphoid cell populations; ILC 1 via expression of Tbx 21/T-bet [36, 37] that predominantly express IFN-γ The ILC 2 bundle is acted upon by GATA 3 and RORα factors. The RORα is an absolute requirement for the development of ILC 2 bundle which expresses IL 5 and IL 13 [27, 31]. Literature citations show that development of ILC 2 is rather primitive.

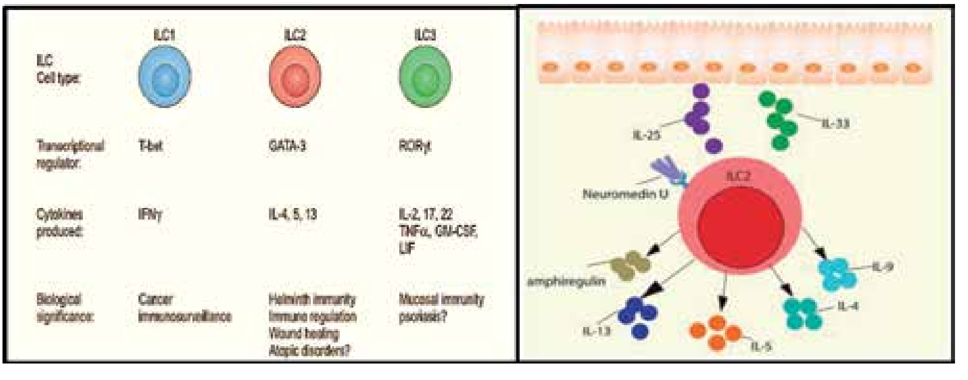


Figure 3.
Types of ILC and activation of ILC 2 and release of various interleukins [30, 31].

Transcriptional programs define molecular characteristics of innate lymphoid cell classes and subsets [38]. The last but not least, ILC 3 differentiate with RORγt expression that provide stimulus by cytokine signals through IL 22 and/or IL 17 [33].

ILC 2 is considered as tissue-resident in the gut. On infection with helminthes, expansion occurs at the location of mucosal place [39]. ILC 2 s were first discovered in gastrointestinal (GI) nematode infection models. These bundle of cells modulate immune system at tissue mucosal sites; i.e. lung, small intestine, colon, and MLN. These cells are also present in the bone marrow, spleen, liver, kidney, and adipocyte tissue [38]. When parasites drive the immune reaction to produce goblet cell hyperplasia, mucus production, smooth muscle hypercontractility and ultimately worm expulsion [31] (**Figure 4**).

ILC 2 group, important in helminth infection, is further categorized into (i) natural and inflammatory (ii) cytokines responsive groups [41]. This classification is recently challenged by Germain and colleagues [42]. This model is further refined

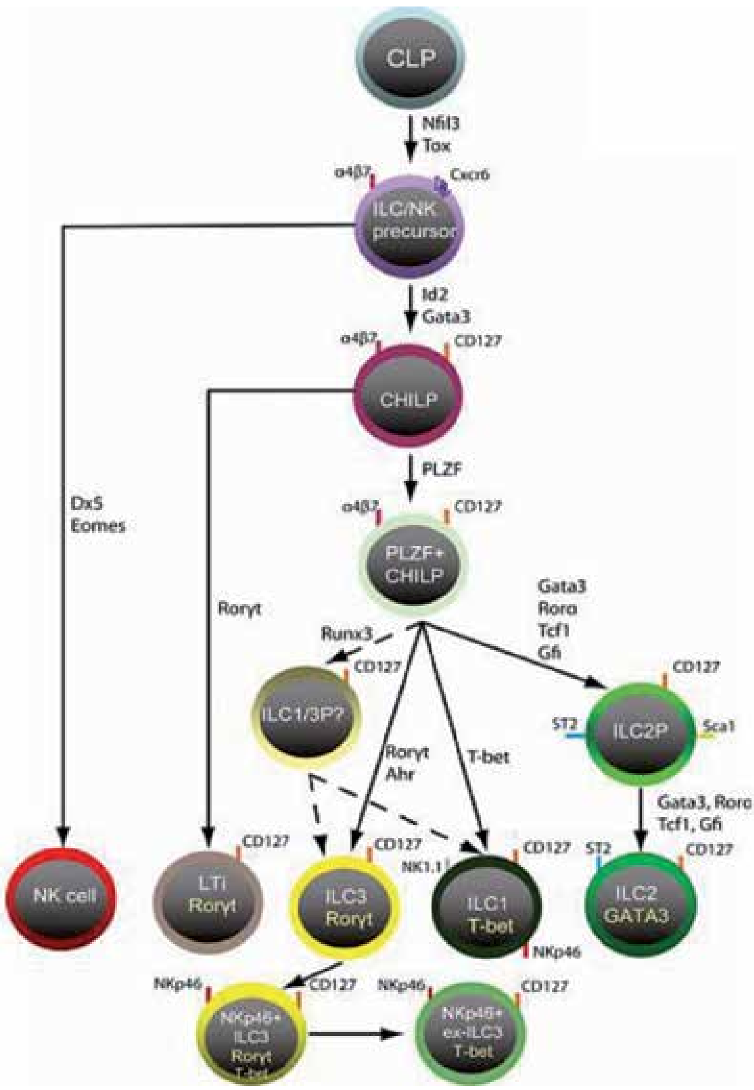


Figure 4.
Cell signalling of transformation of Immune cells [40].

with tissue-resident lymphocytes across innate and adaptive ancestries with migratory capabilities [43].

Unlike T cells, ILC 2 bank on the activation on cytokines. ILC 2 bundle are a critical innate source of type 2 cytokines. As discussed above, helminth infections excite type-2 adaptive responses which results in a SOS on the immune evasion strategy [44]. This circumvention quality was identified over decades ago. Helminthes evolved to modulate their host's immune responses also [43]. This down-regulation of immune response outcomes in asymptomatic animals that maintains the life cycle of the helminthes within them [45]. The transducer signals initiate secretion of moderate magnitudes of IL 5 and IL 13. In the second activation signal, IL 4, IL 9, granulocyte macrophage-colony stimulating factor (GM-CSF), and Amphiregulin (protein produced after stimulus by IL 33 on the tissue damage of intestine) are produced. These cytokines potently induce Mϕ migration inhibitory factor (MIF), rapid production of eosinophils [46]. ILC 2 clusters tend to be extremely receptive to Alarmins—host biomolecules that cause noninfectious inflammatory response [33, 46].

4.1 T_H 2 type immune responses

The T_H 2 type immune responses comprises with three independent modules; inflammation, wound repair, and resistance to helminthes [47]. The T_H type 2 specific immunity against helminthes are delimited by CD4 TH 2 cells that create signal transduction to produce interleukin (IL) 4, IL 5, IL 9, IL 10, IL 13, Immunoglobulin (Ig) E and chemokine ligand CCL 11 [48] (**Figure 5**).

Helminthes, especially nematodes, developed numerous workings that restrain host to act on them. This provoke instigation to innate and adaptive regulatory cells, inflammatory cytokines and inhibitory antibodies [50]. One of studied example, is the chronic infection of *H. polygyrus*, which showed that there is very little expansion of ILC 2 pool in nearby mesenteric lymph nodes [51, 52]. Probable enlightenment on the issue showed that such infections validate with the release of host derived IL 1β which take a check on for the production of IL 25. This IL 25 acts in return on the ILC 2 cluster [27, 53]. ILC 2 cluster are identified by their expression of IL 2, IL 25, IL 33 and IL 33 receptor (IL 33R) with activation of p38 MAPK that phosphorylates GATA 3 [54]. These factors in return reduce the Ig E, as well as IL 4 and IL 5. They recruit, migrate and infiltrate with these activated eosinophils, basophils and mast cells [33].

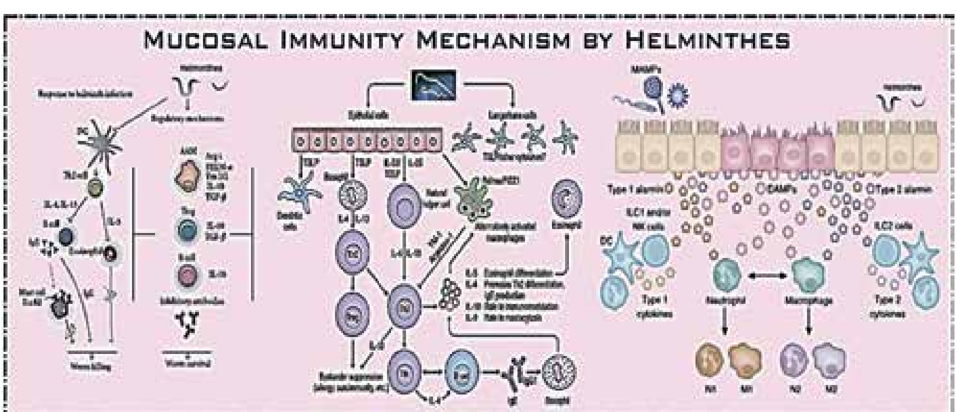


Figure 5.
Cell signaling of transformation of immune cells [49].

5. Dendritic cell and subsets

The dendritic cells (DCs) are a heterogeneous population of immune cells that have specialized functions. All types of DCs are principally regulated by well conserved, various transcriptional factors. These cells are divided into conventional or classical DC (cDC) and the plasmacytoid DC (pDC) [55]. The plasmacytoid DC acquired function to intuiting the nucleic acids and in response producing large quantities of type 1Interferon (IFN) [40, 56]. The other, cDCs, tend to be more active in specialized work of antigen presentation, and later activation of primary T cells. Today, we can further subdivide cDC into murine CD8a/CD103 and CD11b cells [57]. Transcriptomic studies represent a powerful tool to determine the phylogenetic relationship between different cell types of the immune system, including DC [58]. Analysis between goats/murine and human DC subsets differentiating into MF from DC and classifying DC subsets [59]. Dendritic cells (DCs), in animals, in immune competent system accredited to helminthes infection as extensively reconnoitered in past. These infections tend to incline and persuade T_H 2 type cells to respond effectively. However, this recognition of helminthes is not yet fully resolved or understood [60]. In the first set of cells are those which specializes in presentation of antigens to CD 8 T cells. These cells prompt to mucosal immunity through T_H 1 cells. Whereas the other, murine CD 11b cells, cooperate with both CD 4 and CD 8 cells for its subset activation. These cells provoke specialized T_H 17 cells through the stimulus of Interleukin (IL)—17 secretion [59]. The IL 17 activities setup all the framework for type-2 cytokines, and mesenteric lymphoid clusters activation [61]. These neo innate lymphocyte clusters, found confined to differing tissues, which is part and parcel of type 2 cytokines albeit to monikers as "nuocytes" or "natural helper cells" [62]. This stimulation geared up for the first response to the immune challenges caused by helminth infections [63].

5.1 Intestinal DCs and macrophage subsets

Dendritic cells (DCs) subsets, which differentiated from ILC bundle, perform compounded roles in final outcome in the immune responses. In the gut, DCs handshake many exogenous antigenic pathogen to prevent infections [64]. The intestine DCs and amended Mϕ appears to be indispensable in the instigation of active immunity and homeostasis in the gut. These cells have unique ability to rove through the goats mesenteric lymph nodes (MLNs) to perform key start of naïve T cells priming for adaptive immune response [65]. These intestinal DCs and Mϕs within the lamina propria perform vital steps in the initiation, development and regulation of specific intestinal immunity [66]. Most naïve T cells mature up in peripheral lymphoid organs. These cells get expression activation through gut-associated lymphoid tissues (GALTs). In goats, Peyer's patches and mesenteric lymph nodes (MLNs) act as hub of transformation of the CD 4 T and CD $8_{\alpha\beta}$ T cells which in turn prime the antigen-presenting cells (APCs) [67]. The lymphoid associated organs attain the ability to transfer to intestinal area with specific gut homing molecule, integrin α4β7, by its upregulation and others [68].

6. Helminthes and dendritic cells

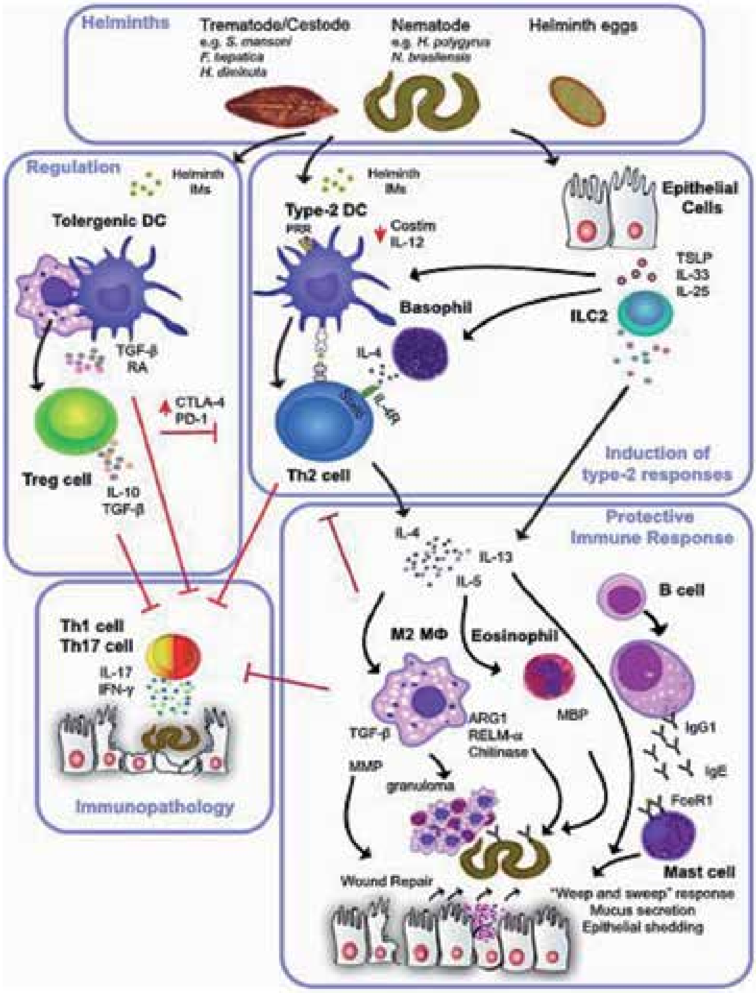
In the small intestine, Lamina propria harbor large number of DCs. All of these intestinal DC subsets are well studied and documented. Of these both highly expressed $CD11_c$ and Major Histocompatibility Complex (MHC) class II cells are of real importance [69]. Phagocytic group of cells in Lamina propria comes from different lineage and perform diverse functions [70]. Relocation of these DCs tend to be tightly regulated by one gene product, CCR7. Expression levels of this gene largely control non-migratory and migratory scenarios [43, 71]. In payer patches, CD103, $CD11_b$ expressing and non-expressing DCs are well studied that induces lymphocytes [72]. Many T cell receptor (TLR) expressing DCs also induce the production of Immunoglobulin (Ig) A. On the other hand, pDCs can incite IgA directly and repress inflammatory processes [73].

7. Extra-helminthes immune molecules

Research studies on helminthes immune modulation system is more engrossed to find cytokine activation, release and mechanisms of cytokine-mediated effector functions. This all rely on the first immune recognition, probably PAMPs and DAMPs, and message of early immune response activation or even suppression. Later this signal is converted to sustained and regulatory immune response [14]. It is observed that in the early phase, limited inflammation occurs in the invading tissues which is overlooked by immunoregulatory milieu to evade, and survive [74]. One of the tool these invading parasites is are; (i) apoptotic processes against immune cells [75], (ii) manipulation of Pattern Recognition Receptors (PRRs), (iii) lowering of T_H 1/T_H 2 cells and (iv) associated cytokines activation [76]. Recently many goat helminthes shown to ubiquitous cog with the release of endocytologic extracellular vesicles (EV) on to cytoplasmic membrane in the intestinal Lamina propria. EVs are vesicles slashed out by different categories of cells which plays role in modulation of immune response to helminthic pathogenesis [77]. Depending on their sizes and origin, these are classified into three types; Microvesicles, Exosomes, and Apoptotic bodies. The exosomes range in size from 30 to 100 nm in diameter that are released by the cells. Microvesicles, however, also called ectosomes—shed 100–1000 nm vesicles or microparticles. Lastly apoptotic bodies are just 2–4 μm in size that are released by dying cells [78].

7.1 Chemical analysis of EVs

The chemical analysis of EVs revealed that they contain soluble proteins, lipids, and carbohydrates with immunomodulatory action [79]. Helminthes counter with a palette of protein modulators, from protease inhibitors to receptor ligands that target these pathways [14]. The list of these immunomodulatory molecules are increasing over the last decade [80]. Many parasites release exosome and/or microvesicles. These vesicles play a cornerstone to the downstream communication into the immune system [81]. These vesicles actively induce IL 33 which binds to IL 33R that pledges an allergic reaction. These EVs or exosomes also inhibits activates ILC 2 and eosinophils [77]. Recent investigation on EVs of *H. polygyrus* showed that they suppress receptor for the Alarmin—cytokine IL-33 in ILC 2 [74]. The internalization of EVs causes down regulation of IL 33 and type 1 and type 2 immune cytokines; IL 6 and TNF, and Ym1 and RELMa [81]. Several documents demonstrate that exosomes promote TH 2 slanting towards the activation of DCs and T cells during infection and vaccine development (**Figure 6**) [82]. Recently, evidences are brought forward to the notion that EVs are secreted by both the parasite and the host [80]. Interestingly, it is suggested that there helminth plagiaristic EVs structures could also be used in the inflammation regulation, especially in allergic, autoimmune, and metabolic disorders regulated by miRNA [83, 84]. Helminth immune modulation has some beneficial effects as allergies, and inflammatory and autoimmune diseases which are less common in populations infected with helminthes. A large body of literature provide reasonable evidences on mechanism of immunomodulation that arise from the helminth infections [85].



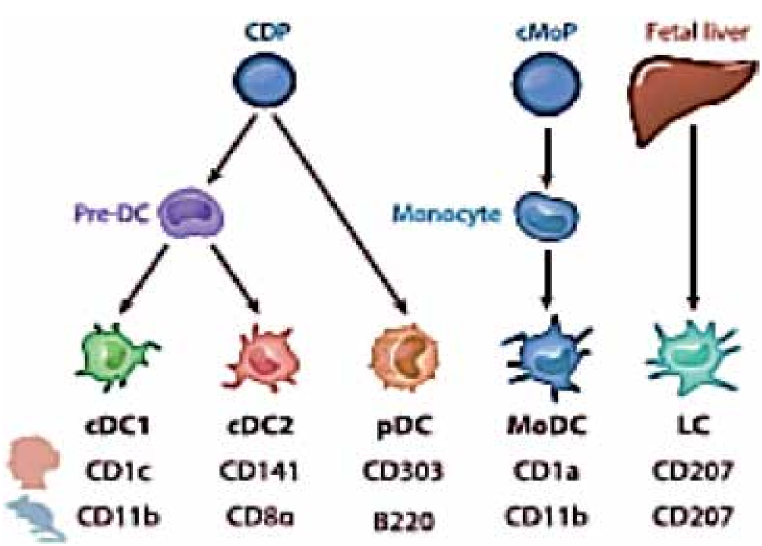


Figure 6.
Types of dendritic cells.

In goats, a definite systematic immune regulations is contemporaneous placed in various world breeds of goats [25]. In sheep, explorative investigates lead us to draw near perfect immune mechanisms followed after the helminth infections and vaccination [86]. It is to remember that helminthes when infect goats, they are not recognize merely whole organism, rather it is a combination of small amino acid sequence derived from PAMPs and DAMPs attached to the cellular peptide-MHC (pMHC) within the groove of MHC molecule [87]. The bound peptide (8–11 amino acids for MHC I and 13–22 amino acid for MHC II) is presented to antigen-presenting cells (APC) through groove—exposed motif (GEM) [45]. The induction of systemic immune responses following parenteral immunization occurs in similar ways in many species including mice, humans, and small ruminants [88].

7.2 Mucosal immunity

The development of effective mucosal immune responses by way of vaccination is considered important because mucosal immunity is able to prevent early establishment of the pathogen and hence could at least theoretically prevent infection at an earlier (less damaging) time point. Thus, vaccines targeting mucosal sites have been in development for a considerable amount of time [88]. The primary protective surface at mucosal sites is the secretion of mucus form gastrointestinal lining. Mucus is a dynamic multimolecular matrix built on polymeric, gel-forming glycoproteins (mucins), with different mucins dominating the barrier at different mucosal sites [89]. At mucosal sites, specialized epithelial cells such as goblet cells secrete gel forming mucins. Upon infection, these cells undergo hyperplasia and increase mucin production, which expands the secreted mucus barrier and provides protection against multiple pathogens [90, 91]. The formation of mucus layer also add on; (a) antimicrobial molecules (e.g., IgA, lysozyme, defensins), (b) immunomodulatory molecules (e.g., cytokines, secretoglobins), (c) repair molecules (e.g., trefoil proteins) [29]. In mice model, the mucin producing Muc 2 are major producer of gel like mucus formation that creates a barrier against contact to the lining in the gastrointestinal tract. This mechanism also provide in return helminthic worms modulating antigen and tolerance [92]. Off the subsets, Muc5ac cells are specifically upregulated after worm infection that also influences expulsion of worm [93, 94]. The sheep model in studying immune mechanisms, with special reference to mucosal immunity, by using nasal vaccines and delivery systems suggested specifically the distribution of the antigen with in the lymph nodes, processing, induction and drainage [88]. Innate lymphoid bundle cells (ILC 2) and T_H 2, as discussed above, share common feature of secretion of IL 13 with differential kinetics for each type [29] (**Figure 7**).

7.3 T cell subsets

T cells as well B cells tend to form two major components within the adaptive immune system. The initial T cell development starts in the bone marrow from hematopoietic stem cells (HSCs). The T cell predecessors pass through to the thymus, from where it gets acronym. The differentiation steps provide ultimately culminate into various mature T cell subsets. The whole process is summarized in **Figure 1** [95]. T-cell development/maturation is very much dependent on their presence within the thymus. In mice, absence/removal of it generates severely impaired T cell development [96]. The differentiations and developments of, especially, T cells produces T cells, B cells, natural killer (NK) cells, or dendritic cells (DCs). However, further stoppage within the thymus, further differentiate into these

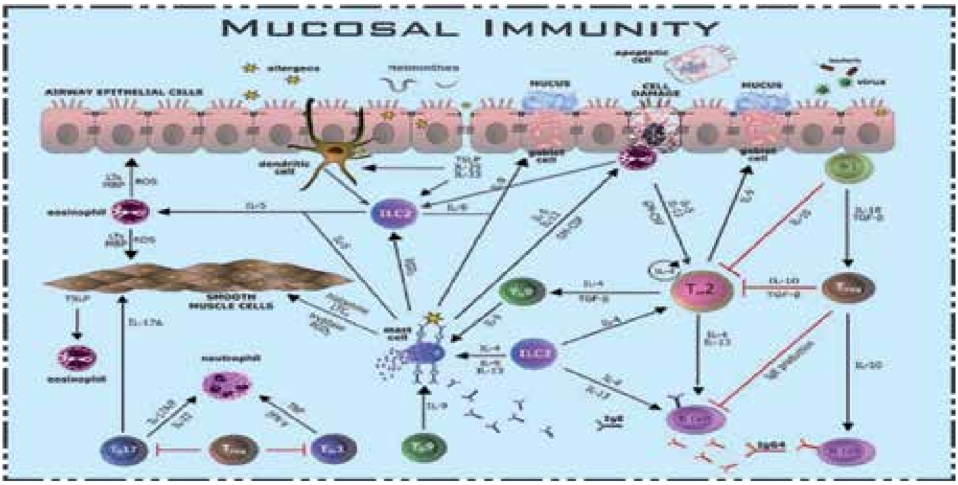


Figure 7.
Cell signaling network through mucosal immunity.

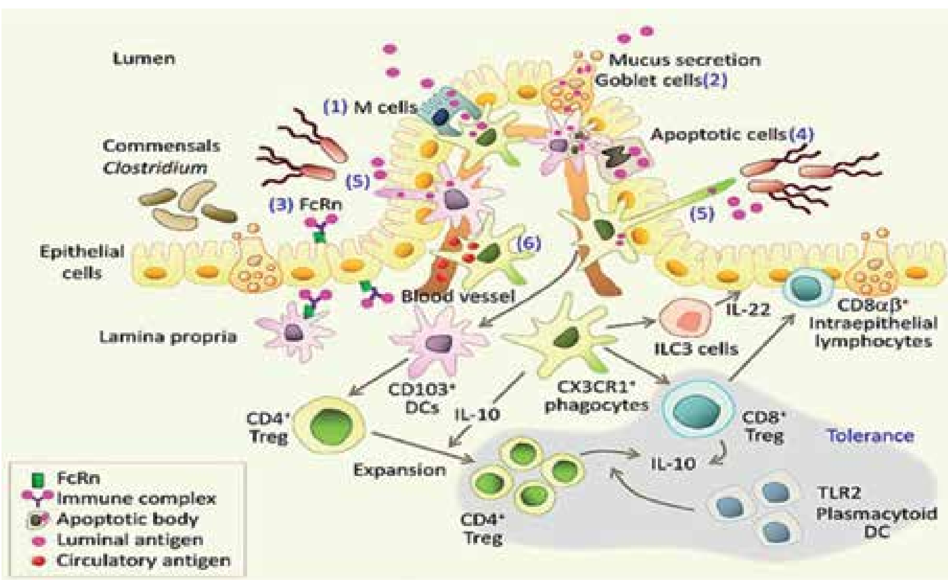


Figure 8.
Microenvironment in the Helminth infection.

subsets the maturation of these subsets i.e. B cell, NK cell, or DC differentiation occurs in bone marrow and fetal liver (Rich eBook).

7.4 Formulation of immune response

In the formulation of immune response, Treg cells a produce homeostasis and secondly the autoimmune suppression. A growing body of evidence suggests that the Treg cell repertoire contains organ-specific/tissue specific Treg cells. Treg cell share specificities in lymph nodes throughout the body, suggesting that the anatomical distribution of Treg cells is shaped by the presentation of regional organ-specific antigens [97]. On the other hand, the Macrophages (Mϕ) show profound differences with various profiles. Under the influence of an alternative phenotype (also labeled M2 cells) which occurred by the presence of helminth infection. This is driven by type 2 cytokines IL 4 and IL 13 cytokines (**Figure 3**). Ongoing research divided these Mϕ by gene expression, metabolism, and function differences into classically activated (M1) macrophages. However, M2 macrophages are required in the effective immunity to some parasites (including *H polygyrus*) [15]. The DCs are professional antigen-presenting cells (APCs) that play an essential role in presenting antigen to T cells to initiate immune responses. Although the role of DCs in inducing T_H 1, T_H 17, and Treg responses is well established. Often overshadowed by their T-cell counterparts, regulatory B (Breg) cells are also crucially important in control of the immune response during helminth infection [15] (**Figure 8**).

These DCs can also patrol among enterocytes while extending dendrites towards the lumen [16]. Treg cell population by producing IL-10 to harness immune tolerance [98]. CX3CR1+ phagocytic cells can capture Salmonella by extending dendrites across epithelium in a CX3CR1-dependent manner [99]. Antigens captured by CX3CR1+ phagocytic cells can be transferred through gap junctions to CD103+ DCs in the lamina propria to establish oral tolerance [100]. In addition to luminal antigen, lamina propria CX3CR1+ cells facilitate the surveillance of circulatory antigens from blood vessels [73].

8. Host-parasite interaction

Almost all animals get gastrointestinal infection (GI) by helminthes in their lifetime. Though all parasite (Helminthes) species share a very similar general morphology and they undergo into four molts reforms during their development period [101]. Each of the species shares dioeciously life spans that could be weeks to years. These worms are investigated because they threaten animal as well to the human health [102]. Nearly all helminthes invade tissues and install an immunomodulatory surrounding for their survival especially taking care of Treg cells [103]. Recently cites articles suggest that both, worms and host, evolved to get reciprocal immune related benefits during the disorders with some clinical outcomes. Numerous studies suggest that immune response appears to be imprisoned that is even extended to expansion of Treg cells [103]. As a consequent a melioration of type 2 immune response that resulted in chronicity [103]. Many findings, however, chronic helminth infection are still poorly understood. These parasites are also important as a model where they create constant, foremost challenge to host immune system [101]. Many of aspects, especially regulation of chronic GI infection, remain to be defined. It is believed that during the evolutionary processes they exclusive adapted to such avoidance to host defenses [104]. These masterful adaptations enable them to remodulate host immune response [105]. It may well be the evolutionary mechanisms that exclusively down regulates early expansion of ILC 2. This is seen in *Heligmosomoides polygyrus* system where IL 1β shows to down regulate early ILC 2 responses in mice [106]. However, this is not true for another parasitic *Trichuris muris* infection where IL 1β null mice [107]. This depression in the levels of IL 1β provokes type 2 protective immune responses, and leads to worm expulsion [53]. The helminthes in the GI tract interact with the mucus layer and many a times pass through into the epithelial layer and reproduce at the site [108]. One of the interaction of worms to intestinal mucosal barrier and hyperplasia, secretion large mucin forming a layer. The mucus layer is a highly hydrated gel mucins. These are largely high molecular weight glycosylated glycoproteins secreted by goblet cells (GCs). The initial also interact with antimicrobial compounds, commensal metabolites and finally antibodies. Like in mouse as well as in humans, MUC 2 cells produces to mucus layer as predominantly part first line of innate immune response [109].

Mucin production is synchronized by many immune type 2 cytokines. As discussed above, IL 4 and IL 13, plays key role in proliferation and differentiation of these GCs [101]. As the intestinal infection ensues it initiates worm expulsion seen for many helminthes [110]. This expulsion is influenced by the presence of CD 4 T_H 2 cells which are controlled by IL 13 secretion [27]. In the knock down mutant studies in mouse showed that MUC 2, regulated by IL 13, led to defective delay in worm expulsion [101]. The, above described, incitation of type 2 immunity releases IL 4, IL 5, IL 9 and IL 13. Several other immune and nonimmune cell activators also participates in the web of effector mechanisms that also sways to parasite expulsion [111]. The commencement of the immune response by TH 2 cell trails through ILC 2 and subsets of dendritic cells. The sensed and trigger signals, however, of PAMP and DAMP results in the activation of different subsets of ILC 2 bundle, dendritic cells, various types of T cell types, basophils and nonimmune intestinal epithelial cells (IEC) against intestinal helminthes. The heterogeneous intestinal epithelium contains seven different cells that can sense helminth invasion into the epithelial cells to initiate T_H 2 cell mediated immunity [103].

9. Secretory IgA and intestinal DCs

Total serum protein in goats is in the range 6.75–7.53 g/dL [112, 113]. In the group of proteins, fibrinogen levels in goats fall between 0.1 and 0.4 g/dL, which are less compared to cows. In some instances hyperfibrinogenemia occurs with neutrophilia after inflammatory responses. In goats, however, maximum plasma fibrinogen levels are 1.1 g/dL during inflammation [114]. In the protein gamma globulins share considerably. In goat, there are three main immunoglobulins; Ig G, Ig A, and Ig M. In caprine, like in cattle and sheep, there are further two distinct IgG subclasses, IgG_1 and IgG_2 [115]. At the birth, IgG_1 is present in the colostrum. Moreover, IgG_2 is preferentially transported to mammary glands from serum as IgG_1 share high affinity to IgG_1 for Fc receptors on mammary epithelial cells [116]. The goat IgG_1 is the subclass that is predominant circulating antibody

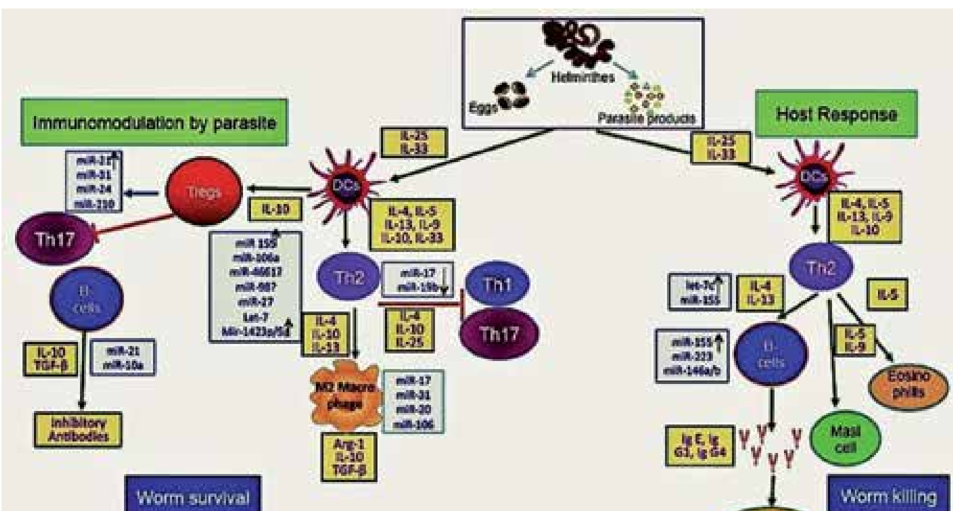


Figure 9.
miRNA regulation of immune response against Helminth infection.

which is produced in response to any infection which later isotopically switch to Ig E functions [117]. Locally generated IgG_1 is also detected after arthritis encephalitis (CAE) virus infection in the synovial fluid [118]. Very few work has been done for caprine IgM concentrations and activities. All the ruminant species observe little structural and functional differences [119]. Caprine IgA, on the other hand, is detectable from serum, colostrum, milk, saliva, and urine. IgA is the primary immunoglobulin present in mucosal surfaces. The secretory element to IgA could be found in either free-state or bound to IgA molecule. The serum very small amount of IgA is linked to secretory component [120]. Goat mucosal immune system produces sIgA by antibody producing cells differentiated from activated B cells. Immunoglobulin class switch do occur from IgA in gut-associated lymphoid (GAL) in Peyer's patches, MLNs, and ILFs within the lamina propria [28, 121]. The humoral immunoglobulin isotype switch occurs through intestinal pDCs, T cell-independent manner and B cell-activating factors (BAFFs) and A proliferation-inducing ligand (APRIL) proliferation inducing ligand [73]. Like in all ruminants, including goats, IgE typically associated to its biologic activities. Today IgE is accepted as useful marker in identifying different phases of parasites and parasite resistance. Nucleic acid sequencing in caprine IgE DNA is part of the overall effort [110, 122]. Goat's complement system is provided with limited concentrations [123]. Dynamic studies showed that in less than 6 month old young and adult indicate significant hemolytic, conglutinating, and bactericidal complement activities [124] (**Figure 9**).

10. miRNA regulation in goat immune system

Recent literature cites of the immune cells that are communicated through from one cell to other by transferring regulatory RNAs, microRNAs in particular. Many studies pin point that some sort of functional, regulatory extracellular RNAs plays a key role in cell-to-cell communication in various cellular processes [125]. MicroRNAs (miRNAs) are group of short RNA non coding sequences that are highly conserved between different eukaryotic species [126]. These are ~19–28 nucleotides long sequences that regulate(s) gene expression [127, 128]. miRNAs are particularly important in the cellular function that show time dependent responses [129]. miRNA literature show that they partake a mesmerizing role in both immune system and as an immune system [130]. These small RNAs lead to vertebrates transcriptional silences like a rheostat that act to fine tune (rather than complete shut-off) of translational products. The miRNA targeting could result in 3-fold decrease of mRNA transcripts [131]. In many studies, till now, more than 60% miRNA expression profiles are developed and tested in variety of tissues from livestock. These profiling post transcriptional regulate gene expression in several cellular processes such as differentiation, and transformation processes in cell cycle through signal transduction [127, 132]. miRNA molecules could broadly act as regulators on shorter time scale on protein transcriptional repressors that effect inflammation. They can also show quicker results without engaging translational or translocational machinery within the nucleus and controlling regulators. One example to this is the miR 155 regulation [129, 133]. Together with these options opens up many avenues that provide novel and exciting products in therapeutic as well as in clinical use, specifically for immunity and inflammation Today miRNA functionality can be dissected in leukocyte differentiation, innate signaling, and T_H cell biology [132]. *In-silico* studies using various tools on miRNAs on computation or experiments gathered about 35 Helminthes (11 Trematodes, 8 Cestodes, and 16 Nematodes, and two plant origin parasitic Nematodes). These analysis show that greater than 620 plus pre-miRNAs that are listed in miRBase of parasitic origin. Interestingly, the first miRNA was discovered in *C. elegans*, a nematode [133]. All known parasite miRNA database entries are analogous to miR database. The emerging, neglected disease of *Schistosoma*, a trematode, is one of the iRNA models in the whole family [134]. The miR database showed that there are 79 and 225 mature miRNAs associated to *S. japonicum* and *S. mansoni* respectively. These findings indicates that not only large number of variations do occur within the helminthes, but male and female worms also show differences. This also give insight to the role in morphogenesis, development and reproduction [135]. A similar picture arises from Next Generation Sequencing (NGS) and bioinformatic analysis and experimentation with stem-loop qRT-PCR identifies 13 species specific miRs in two species *Fasciola hepatica* and *F. gigantica* [134]. Studies on infection, more than 130 miRNA (analogy to other parasitic miRNA), are seen to flocculate in expression profile [135, 136]. It is shown at many instances that miR 155, miR 223, miR 146 are negative, suppressors of cytokine in a regulatory loop. In other studies, miR 155 is also interactive to transcriptional factor cMaf and tempers with TH 2 within the CD 4 group. In another analogy to a mouse model, same miRNA 34c, miR, miR199, miR 134, miR 223, and miR 214 are shown to effect 220 miRNA parasitic immune response silhouette [133, 137]. The powerful approaches of bioinformatics extrapolations along with stem-loop real-time PCR analysis on the *C. sinensis* showed that there are a total of 62,512 conserved miRNA sequences which includes six novel identified miRNA [138]. Pak and coworkers [135] demonstrated that there is an upregulation miR 16-2, miR 93, miR 95, miR 153, miR195, miR 199a-3p, and silences with miR let7a, let 7i, and miR 124a in the presence of EVs of *C. sinensis* [133, 139].

10.1 miRNA regulation of T cells

As a critical role of miRNA post transcriptional regulation in transformation within immune cells show that these tiny molecules can reduce the expression of various genes by 3 orders of magnitude during maturation [140]. Studies showed that different miRNAs are involved in the thymocytes development by Dicer or Drosha knockouts experiments. Obstruction in the process consequential drop of mature $T_{\alpha\beta}$ and natural killer T (NKT) cells [141]. In animals' helminthic studies, absence or presence of miR 155, showed that it can effect TH 2 differentiation involving apoptotic processes [131]. miRNA machinery knockout experiments demonstrate that some of the miRNA are of absolute requirement for Thymic development and peripheral function of nTreg cells. However, dicer knockout of Fox P3 cells consequences to nTreg cells without oppressive role. Treg cells can also transform into T follicular helper cells that resulted in loss of immunomodulation and B cell activation in this scenario miR 155 is a regulator of nTreg cells. It should be remembered that miR 155 is expressed in all adaptive immune cells [142]. The expression and formation of active miR 181a is found to be tightly regulated intra-thymic T cell development. The activities modulates the T cell antigen receptor (TCR) retort the down regulation through phosphatases which plays pivotal role in reducing TCR cell signaling. Thus the activities of miR 181a acts to modulates of TCR sensitivity towards T cell development in the lymphoid organ [131]. Blockage with antagomir (oligonucleotide) to miR 126 reduces the differentiation of TH 2 which are linked to helminthic pathogenesis during innate immune system activation. During this impasse, T_H 17 cells regulate another miR 326 within their reach by up regulation [143]. These cells are differentiated and regulated by cytokine IL 23 [144]. It is shown that miR 17 polarizes then T_H 2 cells, required in type 2 immune response to helminthes infection [141]. Mature T_H cells are further influenced by miR 182 in response to IL 2 cytokine synthesis. This regulation is post transcriptionally controlled with transcriptional factor Foxo 1 [145]. The ILC 2 bundle of cells are differentiated by GATA 3 factor, as discussed above. This transcriptional factor induces T_H 2 differentiation and produces larger quantities of IL 4, IL-5, and IL-10 *in vivo* and IL 13 [31, 141]. It is documented that miR 126 regulation effects TH 2 polarization. In mice, an activator of transcription is targeted through POU 2F3. Furthermore, PU-1 significantly inhibits specific binding GATA 3 factor. Another molecule of interest is miR 126 where *in vivo* studies proved that it reduces T_H 2 cells to specifically allergy promoting dust mite antigens [146]. miRNA machinery knockout experiments demonstrate that some of the miRNA are of absolute requirement for thymic development and peripheral function of nTreg cells. However, dicer knockout of Fox P3 cells consequence to nTreg cells but without oppressive role. Treg cells can also transform into T follicular helper cells that resulted in loss of immunomodulation and B cell activation in this scenario miR 155 is a regulator of nTreg cells. The suppressive part of miRNAs by the Treg cells can act on two points; (i) Treg regulating themselves, (ii) modified response of target cells on Treg cells [147].

10.2 miRNA regulation of B cells

Like T cell lineage, B cells also are tangled up with various miRNA classes that regulate their differentiation and development within the bone marrow. The miR 181 overexpression in hematopoietic bone marrow increase in the fraction of B cell subtypes. Similarly miR 150 effect the B cell development at pro- and pre-B cell transformation due the apoptosis. Knockdown miR 155 mice reveals skewed CD 4 T cell polarization in the T_H 2 subset [141]. B cell studies show that two miRNA, miR 155-5p and miR 155-3p, are expressed solely in these cells [148]. These miRNAs are positioned in Integration Cluster gene (BIC) area that positively prompt to various stimuli within the immune system [149]. Germline studies on miR-155 showed that its deletion induces reduction of B cell germinal centers [131, 150]. In mice, upregulation of miR 34a in the progenitor cells are acknowledged. Constitutively miR 34a expressed in B cell studies conclude that it block differentiation of pro-B to its next stage of pro-B cell and to mature B cell. The disparity occurs through Foxp 1 [148, 150]. Number of expression profile studies show that dysregulation is found for miR 182, miR 96, miR 183, miR 31 and miR 155 that effects B- and T-cells. Recent finding on miR 150, miR 127 and miR 379 also showed that there upregulation effects splenic maturation processes. The miR 150 levels are predominantly present in both B-cells and T-cells not on to their progenitors. On the other hand, miR 15 activities that it correlates to autoantibody production [150]. Another regulator The miR 17, encode several miRNAs from same transcript, also show that it negatively influences on pro- and pre-B transition through a blockage of BIM accumulation [131, 150]. Another protein, BMI 1—a ring finger structure, also promotes differentiation of TH 2 in a mouse model that in return stabilizes GATA 3 protein for transcription by protecting it from ubiquitination [141].

10.3 miRNA regulation of cell cycle

Numerous citations show that cell cycle of T cells are directly regulated by miRNAs profile. The regulation is associated cell cycle check points through Cyclin T1 levels in Mϕ. It is documented that miR 182, as shown above, functions on expression of generalized transcriptional regulator, FoxO 1. This control regulates CD 4 T cell expansion with Cdk inhibitor, $p27^{Kip1}$. Negative feedback on FoxO 1 is accomplish by miR 182. These signals activate IL 2. This induction results in T_H 1, T_H 2, T_H 17 and naïve CD 4 cells expansion. Studies *in vitro* and *in vivo* showed that in a feedback loop, down regulation of miR 182 results in stoppage of spreading out of CD 4 cells [127, 141]. The nearly all vertebrates, immune system evolved itself to a finely fine-tune, an extraordinarily flexible apparatus within the host defense [125]. Besides direct role of various miRNAs, indirect regulation is also well in place in immune system. This is seen for miR 19a, miR 19b in the miR 17 cluster. These two sequence encode deubiquitylation enzyme, CYC D, which blocks NF-κB activities. Its expression results in Cyclin and other growth factors. In a recent documentation that there is a universal reduction of CD 4 T cells which is one of the hallmark of helminthes infection [141, 151].

10.4 Helminth vaccines in focus

Global data on parasitic helminthes speaks loudly of the livestock diseases that affect many area of the world, including Europe. Their infections are related to huge economic losses in loss of fertility, production and body weight [152]. Cumulative responsible statistics show that more than 55% of livestock suffer from these infections outcome. It causes diseases in Europe and cause highly significant losses in productivity and welfare in animals and then in humans and welfare problems globally. Yearly estimates show that in liver fluke (*Fasciola hepatica*) infections up to US $3 billion per annum are lost [153]. Conservative estimates in the United Kingdom show that gastrointestinal (GI) helminthic infections to sheep industry shares losses of more than £84 million per annum [154]. These infections are traditionally controlled by administration of various anthelmintic drugs [155]. Naïve practice resulted in development of resistance to these medicines. Recent documentations for sheep farming, particularly in New Zealand, Australia and Brazil, showed that Multi Drug resistance (MDR) is much elaborative phenomenon worldwide and have upward trend [156]. Development of these vaccines started some 50 years ago. Most helminth component formulating and their administration showed that they effectively interrupt the dynamic morphological and antigenic changes during parasites life cycle of the worms and can be used as controlling tool [157]. Many helminthes share much sophisticated evasive immune mechanism that is discussed already in detail. This quality of worms make them very hard for scientists to move forward to develop efficient vaccine candidates [158]. Many efforts to develop anthelminthic vaccines in livestock started many years back with limited success [159]. As discussed in detail above, elusive behavior of worms does not provide adequate long-lasting protection at all stages of helminthic maturation [160]. Vaccines provide manifold benefits on improving animal health, welfare and control of animal infection. The use of vaccine also addresses resistance to acaricides, antibiotics and anthelminthic medicinal solutions [158].

At present, there tend to be two strategies to effectively develop vaccine; (i) attenuated and (ii) hidden antigen [159].

10.5 Attenuated vaccines

These vaccines are developed and used after irradiating L3 larval stage that prevents development of mature adult worms. This protection could reach up to 98% *in vitro* with two experimental doses. Attenuated larval *Dictyocaulus filaria* (sheep lungworm) name "DIFIL" for *Dictyocaulus filaria* larva is effectively used in India since 1981 [160]. A similar approaches are used to develop other vaccines.

10.6 Hidden antigens vaccines

Helminthic recombinant integral membrane proteins, part of worm gut, that whenever used provoke high degree of immune recognition and type 1 and type 2 immune responses [158]. In these vaccines enhanced innate and adaptive models suggests logical targeting of T_H 2 cells through type 2 arm of immune response. These types will be future vaccines against the helminthes infections [161].

10.7 Helminthes components as vaccines

The extracellular vesicles (EVs) of various helminthes are heterogeneous type of membrane vesicles that are on the loose by different types of infecting organism. The EVs, as described in detail above, contain complex mixture of transcriptomic messages [162] for proteins, lipids, galectins and glycans [163, 164]. EVs are of three categories divided on cell of origin, molecular contents, function, physical characteristics, specific protein markers, and isolation techniques [165]. The immunomodulatory effects of excretory secretory molecules and EVs influences both parasite worm as well as in the host [74]. Studies on these molecules show that this unresolved issue of the formation, packaging, cargo transportation, nature and mechanism of interaction, functional spectrum, docking of molecules and fusion [82, 166]. Efficacious helminth vaccines are developed seldomly with wide contrasting technologies [152]. Following early immunization experiments on sheep showed there is a wide variety of concoctions processes that releases various antigens that act as vaccine formulation [167]. These crude methods of administration provided induced partial protective immunity. One example of H11 protein of *Haemonchus contortus* antigenicity show differential activity of native and recombinant proteins [152]. New vision on the helminth control is formulated to bring new infusion of technology in the helminth research by 2030. The sustainable goals includes; (i) advancement in global diagnostic tools, (ii) innovative vaccine control and breeding methodologies, (iii) anthelmintic with new compounds, (iv) rationalization in integrated future control [168]. Today very few vaccines of helminthic worms are available in veterinary stores. These include nematodes vaccines for cattle lungworm (*Dictyocaulus viviparus*) vaccine (Bovilis® Huskvac, MSD Animal Health), vaccine against the barber's pole worm (*Haemonchus contortus*) in sheep (Barbervax®, Wormvax Australia Pty Ltd.). Scientists are working hard to develop (experimental phase) vaccines against several helminthes species including; *Teladorsagia circumcincta* in sheep, *Ostertagia ostertagi* and *Cooperia oncophora* in cattle, and *Fasciola hepatica* in ruminants. If these promising trials yield fruitful, wider range helminthes vaccines with be shelved in in the future [169]. In Cestodes, two recombinant vaccines are available for *Echinococcus granulosus* in ruminants (Providean HidatilEG95®, Tecnovax) and for *Taenia solium* in pigs (Cysvax®) are marketed. Rapid progress in the domain of proteomics and glycomics, it seems that in near future more and more synthetic vaccines will be solved by 2030.

10.8 Mucosal vaccine adjuvants

Presence of double edged sword with poor immunogenicity and evasion phenomenon produced by the worms. Large number of immunomodulatory supplemental molecules, known as Adjuvants, are tried to enhance antigenic processing, recognition, antigen presentation (APC) and immune cell activation through the PAMPs and DAMPs presence. These supplemental material scan be divided into two classes: (i) adjuvants that facilitates vaccine delivery through Liposomes, nanogels, oil-in-water emulsions and (ii) virosomes that stimulates the immune system that includes molecules binding to intracellular receptors including Toll-like receptors (TLRs), Nod-like receptors, and RIG-I–like receptors and to cytosolic DNA sensors [170].

10.9 Microbiome/microbial role

The proteins of the human microbiome, especially the gastrointestinal microbiome, the human proteome, and the immunoglobulin repertoire are also continually processed by APCs and presented to T cells [62, 63]. In examining the immunoglobulinome, it emerged that there is a frequency hierarchy of TCEM. This includes, at one extreme, common motifs found in most immunoglobulin variable regions. These are not limited to motifs encoded by the germline but also include motifs produced by somatic mutation. At the other extreme, very rare motifs are encountered only once in several million B-cell clones [171].

11. Conclusion

The various kinds of parasitic diseases (GIT or hemo-parasites) mean continuous threat for goats and goat keepers in all over the world for goat Industry. The helminthiasis in caprine is one the prime problem for goat breeders and sheep breeders in the goat and sheep rearing community and countries. These parasites not only pose a problem to goat(s) but a continuous threat for serious damage to their lives causing weakened immune response, less resistance and a great chance for various kinds of parasites not only to harbor in the body of host (goat) but also find a safe place to multiply and reproduce. In parallel to these immune responses in body there is ever increasing demand of using and developing various anthelmintics and vermifuges to curb the ever increasing list of parasites. So the animal immunity or production of resistance either in form of breeds development or discovery of innovative broad spectrum medication or production of vaccines has always been in focus since old and have got a big importance. The immunity in body of host (goat and sheep) plays a very decisive role regarding the selection process against the specific parasites prevalent in the area or on the animal health and on the use of medication. There are or could be several factors in the background of immunity in the body of goat which has been demonstrated by various figures present in the test to understand the mechanism(s) happening in the body in real time. We as authors tried best to demonstrate the up dated knowledge in the chapter for the better understanding of viewers or scientists working or intending to work on very sensitive issue of immunity in the body of animal or goat.

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Research and development in animal husbandry and products manufacturing are ongoing, and the results should be summarized from time to time and made available to the reader in order to increase their knowledge.The present publication seeks to present the results related to the goat species. The first part of the volume contains the cultural history of the goat as well as chapters on the breeds kept and bred in Spain, USA, and Nepal. The second part covers the chapters dealing with Cashmere and Pashmina wool. In the third part of the volume, you can read about the differences between the different goat cheeses. The first chapter of the fourth part compares the drugs that can be used in the treatment of goat diseases, while the second chapter describes the parasites of the gastrointestinal tract (GIT).

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