João Simões
Carlos Gutiérrez *Editors*

Sustainable Goat Production in Adverse Environments: Volume I

Welfare, Health and Breeding

Springer

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“Complicity and mutual affection”. Winning artistic photography of 2016 OIE Photo Competition and The Humanithy Photo Awards 2017 (UNESCO). ©Jorge Bacelar

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To promote a better world for animal and human populations.

Foreword

Since its domestication in the mountains of the Fertile Crescent about 11,000 years ago, the goat species has known a tremendous success. Goats were associated with the Neolithic revolution of agriculture and have accompanied the populations in the Near East, Europe, Africa, and Asia since millenaries. In the modern times, goat is now present over all continents and counts a little bit less than 1 billion heads, composed of more than 500 breeds and hundreds of systems of production. *Per se*, this success is the sign of the sustainability of goat livestock systems. These breeds are producing meat, fibers, skin, milk or cheese and contribute to provide manure for family agriculture.

The reasons for this very large success of goat in the World can be found in various characteristics of the species. The first one, associated with domestication and which seems to be among the most important ones, is the remarkable sociability of goats. Partly due to its small size, goats are described by their owners as very curious animals, always very reactive and imaginative individuals; these specific traits are probably important for the interest of farmers and their families toward the goat species. The second one is its adaptability to harsh conditions. Many goat keepers know that goats are able to find by themselves their subsistence in various conditions, from rangelands to cities. The third one is their ability to provide various products of high quality providing to the farmers good income from an animal of limited investment. For example, goat meat is able to reach high prices in India or Latin America, goat milk and cheese are of high value in Europe and the Mediterranean Basin, Cashmere fiber from China are among the most valuable fibers in the World.

One of the peculiarities of the very large majority of goat livestock systems is to be owned by poor families, which are able to use goat proteins for their own familiar consumption and/or for selling them to the market. This last characteristic of goat livestock systems is of specific importance for public policies because it allows developing a very efficient way to increase protein consumption of the poorest populations of the World.

Among the 500 breeds of goats existing in these systems, it exists a huge variability of phenotypes. Size, colors, horns, growth rate, seasonality, prolificacy, heat-stress resistance, milk production, carcass traits, disease resistance, etc. are extremely different from one breed to another and this represent an incredible treasury of biodiversity that we should preserve for the future generations of farmers.

All over the world, in the recent years, scientific knowledge has been produced to better know this goat species and try to propose improvements of the above breeds as well as their conditions of management, in order to increase productivity of flocks and, consequently, income of farmers. This knowledge should be largely spread among the community of goat scientists and goat technicians in charge of rural development, as well as among the policy makers. We should convince them, based on scientific evidence, that the goat species is a very interesting animal for a very large part of the rural populations, especially from the developing countries.

Tours, France

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Preface

Think Global, Act Local

Many archeological and genetic markers evidence that goats were the first herbivore animals domesticated about more than 10,000 years bp. approximately, and started during a long-term process in agriculture-based human civilization. One (*Capra aegagrus*) or more (C*apra prisca*, *Capra falconeri* and *Capra nubiana*) ancestral wild goats originated the actual domestic goat (*Capra hircus*). The geographical livestock migration, together or not with human population migrations, seems to be responsible for the worldwide goat dissemination at different times in the past, developing a special adaptation to harsh environments, i.e., semi-arid, arid and mountain regions of the world.

Historically, this species can survive browsing fruits, leaves and soft shoots, and reproducing local population according to the biomass found in their environment; and also can return to a semi-wild or wild status (Feral goats). These feeding and reproductive behaviors, as well as the easy obtention of milk, meat, wool, and other goat derivated products, and the relative low economical value of this small ruminant keep it as advantageous species to contribute mainly for the livelihood of rural populations, but not exclusively, in developing countries. In the XX century, some goat breeds, e.g., Saanen, Alpine and Boer, were genetically improved for milk or meat production. At the same time, mainly from the second half of the past century, nutritional and reproductive (as tool) managements intensified goat production in a similar way to that occured in high-producing dairy and beef cattle.

During last six decades, due to socioeconomic development in several human populations and the intensive world commerce, the duality of production between improved (high-producing) and non-improved (low-producing) goats, regarding the respective production systems, is more evident. Today, the total number of goats is near to one billion, worldwide disseminated with more than 500 breeds, many of them presenting distinct ecotypes according to their geographic isolation during centuries. The majority of these goats (and breeds) are low-producing animals, reared in extensive, e.g., pastoralism, production systems in lands with low level of biomass and small farming focused to the denominated "subsistence farming" *per se*. However, these circumstances have had a negative impact in many goat breeds around the world being close to extinction.

For all above, the present book was thought as an attempt to determine the current status of the goats worldwide, particularly in those less advantaged ecosystems in which other high-producing livestock cannot be reared. Thus, numerous researchers around the world that are involved in different scientific projects concerning local goat production and health toward the sustainability of this species in their distinct harsh environments have gently contributed to making this book a reality.

The number and extension of the different chapters have advised to divide this book into two volumes according to the several topics and for an easier reading.

In Volume I socioeconomic aspects of farming production are included (Part I) being the Mediterranean and Eastern Africa regions the geographical examples. An approach to the familiar involvement and system productions challenges and opportunities is also under reappraisal.

Part II considers reproductive strategies considering advanced (e.g., embryo transfer) and low-cost reproductive technologies, which can be complimentary. These, low-cost reproductive techniques, such as estrus synchronization regarding artificial insemination, are a crucial step to improve reproductive management and genetic resources of a local breed. Some of these techniques can be applied in a natural way, avoiding or at least reducing the use of hormonal protocols. Notwithstanding, the impact of crossbreeding with foreign goats is also approached.

Regarding the nutritional programs, the adequate use of shrub biomass in mountain regions, or the unconventional feedstuffs use in arid regions seem to be a promising approach (Part III). In fact, feeding and nutritional managements are crucial to prevent several metabolic and nutritional diseases in goats, considering some functional traits in this species. Moreover, nutrition is closely related with milk and meat organoleptic characteristic as well as their chemical composition, being favored when the animals are fed with local biomass.

Goat diseases and health management (Part IV) are focused to several diseases in semi-arid, arid and mountain regions, although those present in tropical and subtropical regions are also considered. Infectious, transboundary and zoonotic diseases are emphasized, and include particularities of the goat species. Many of these infectious agents, such as bacteria, can have a negative impact in milk quality and its derivate products. The health status is one of the factors responsive for animal welfare, although the environment plays a major role due to heat and water stress in several regions of the world (Part V). Nonetheless, the impact overall climate change will be a challenge for researchers in next decades. Interesting approaches of conservation priorities of goat populations based on genomics can also be found (Part VI). A distinct approach with the artificial breeding of six new goat breeds is reported in China.

The volume II addresses phenotypic and genetic characteristics of more than forty worldwide indigenous goat breeds belonging to different continents. They have been the livelihood for people living in marginalized areas for centuries;

however, currently many of them are endangered or, simply, near extinction. During the second half of the twentieth century, the general policy mainly in developing countries was to improve genetically animal performances, particularly milk production reaching high-producing goat breeds. In many worldwide regions these high-yielding foreign breeds, usually brought from France, were used for crossbreeding with local breeds. Nevertheless, some adaptive aspects were not fully considered such as the reproductive pattern, i.e., marked seasonality of reproduction, the resistance to local diseases like some gastrointestinal parasites or tsetse transmitted trypanosomes or also the better exploitation of local available feeds. Nowadays, the use of local genetic resources is considered as a key element to develop those ecosystems efficiently and sustainably.

The approach to sustainability of goat production needs to take into account the demographic census of animal and human populations was well as the Human Development Index. Approximately 600 million of goats, 60% of total goats in world, and more than 1/2 of human population are located in Asia continent. Africa sustain around 350 million of goats and incorporate a significant part of countries with low Human Development Index (United Nations). Europe and America incorporate to the global census less than 20 million and 40 million of heads, respectively.

Part I includes local goat breeds from Asia such as Osmanabadi and Barbari from India, some Chinese breeds or even Damani breed from Pakistan, including several strategies for their sustenance. Part II covers local breeds from Africa, including South African local meat breeds and probably the most commonly found in the continent, the West African dwarf goats and its Nigerian ecotype. Part III includes European goat breeds such as Turkish Hair and Honamli, the Italian Sarda, Girgentana, Garganica, Ionica or Maltese breeds or the Spanish Murciano-Granadina and the Canary Islands' goat breeds. The Portuguese Serrana goat is also represented in its reproductive aspects and the goat farming situation in Czech Republic show us the viewpoint of this livestock in Central Europe. Closing the Part, the status of some Brazilian breeds are exposed as an adapted livestock in arid and semi-arid environments.

Vila Real, Portugal João Simões
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To **Jorge Bacelar**, a veterinarian colleague working in rural zones, also dedicated as photographer, for his ceded artistic photos which illustrate this book. We also thanks to **Chinese Academy of Science** for granted contacts regarding its research institutes.

The initiative of publishing a new book on goat production systems in adverse environments is surely welcome. Most goats in the world are raised in arid and mountainous areas and generally in adverse environments. Goat breeders livelihoods are precarious, socioeconomic status is low, and the recruitment of new generations of herders is no more granted. Hence the considerable effort of editors to assemble these chapters together must be commended.

Serge-Yan Landau
Editor-in-Chief of Small Ruminant Research

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About the Editors

João Simões born in 1967 in Portugal as a son of small farmer, João Simões soon developed an affinity for agriculture and livestock that was to shape his professional life and career. From 1993, as a DVM he mainly worked in large animal clinics. Simultaneously, he joined the Portuguese academy as Professor at the School of Veterinary Sciences, University of Trás-os-Montes e Alto Douro. His academic research is focused on goat reproduction, and he obtained his Ph.D. in Veterinary Science in 2004. He has written numerous scientific and technical publications in collaboration with veterinary students, producers, and national agricultural associations. He lives with his wife and two small children in the mountain region of Northeast Portugal.

Carlos Gutiérrez DVM (Córdoba, 1986), Diplomate in Public Health (Madrid, 1988), DVM (Las Palmas, 1995), Master in Public Health (Las Palmas, 2003), University Expert in Biostatistics (Madrid, 2006), and Diplomate in European College Small Ruminant Health Management (-ECSRHM- Brussels, 2013), is currently Full Professor at Research Institute of Biomedical and Health Sciences/School of Veterinary Sciences, University of Las Palmas de Gran Canaria, Spain. He has about 100 international publications including books, book chapters, and papers in peer-reviewed journals listed in JCR. He has developed several projects, collaborations, and training periods in the Institute of Tropical Medicine (Antwerp, Belgium), Swiss Tropical and Public Health (Basel, Switzerland), or Vlaam Biotechnology Institute (Brussels, Belgium). He has a particular interest in animal tropical diseases (trypanosomosis in special), zoonosis as well as biomedical applications of nanobodies (VHH). Currently, he is an active member of different international committees like the *ad hoc* OIE group on non tse-tse transmitted animal trypanosomes (-NTTAT- Paris), Camel Section of the European Federation of Animal Science (-EAAP- Roma), or Teaching committee of the ECSRHM (Brussels) and belongs to several societies like the New York Academy of Sciences or the National Geographic Society.

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Abbreviations and Acronyms

2POC	Two-phases dried and destoned olive cake
AGID	Agar gel immunodiffusion
AI	Artificial insemination
AWIN	Animal welfare indicators
BCS	Body condition score
BHBA	β-hydroxybutyrate
BLUP	Best linear unbiased prediction
BT	Bluetongue
BTV	Bluetongue virus
BW	Body weight
BZD	Benzimidazoles
CC	Climate change
CCPP	Contagious caprine pleuropneumonia
CNS	Coagulase-negative staphylococci
CNV	Copy number variant
COC	Cumulus oocyte complexe
COWP	Copper oxide wire particles
CT	Condensed tannins
DM	Dry matter
DNA	Deoxyribonucleic acid
EA	Eastern Africa
eCG	Equine chorionic gonadotrophin
ELISA	Enzyme-linked immunosorbent assay
FA	Fatty acids
FAO	Food and Agriculture Organization
FMD	Foot-and-mouth disease
FMDV	Foot-and-mouth disease virus
FSH	Follicle stimulating hormone
FTAI	Fixed-time artificial insemination
GDP	Gross domestic product

GH	Growth hormone
GI	Gastrointestinal
GPV	Goat pox virus
GTPV	Goat pox virus
GWAS	Genome-wide selection
HS	Heat stress
HSP70	heat shock protein 70
IDR	Intradermal reaction
IFN-γ	Interferon-gamma
IMI	Intramammary infection
IQR	Interquartile range
IUCN	Conservation of Nature
IVF	*In vitro* fertilization
IVM	*In vitro* maturation
LA	Linoleic acid
LFMM	Latent factor mixed models
LH	Luteinizing hormone
LNA	Linolenic acid,
LOPU	Laparoscopic ovum pick-up
MAP	*Mycobacterium avium* subsp. *Paratuberculosis*
MAS	Marker assisted selection
ME	Metabolizable energy
MEKs	Marker-estimated kinships
MFB	Multinutrient feed blocks
ML	Macrocyclic lactones
mRNA	Messenger ribonucleic acid
NDF	Neutral Detergent Fibre
NEB	Negative energy balance
NEFA	Nonesterified fatty acids
OIE	World Organisation for Animal Health
OL	Olive leaves
PBMC	Peripheral blood mononuclear cell
PC	Partial contributions
PCR	Polymerase chain reaction
PEG	Polyethylenglicol
PGF2α	Prostaglandin F2alpha
PIC	Polymorphic information content
PME	Panola Mountain *Ehrlichia*
PMNL	Polymorphonuclear leucocytes
PNRT	Plaque reduction neutralization test
PPD	purified protein derivative
PPR GCES	PPR Global Control and Eradication Strategy
PPR	Peste des petits ruminant
PPRV	Peste des petits ruminant virus
PR	Pulse rate

PT	Pregnancy toxemia
PUFA	Polyunsaturated fatty acids
QBA	Qualitative behavior assessment
QTL	Quantitative trait locus
RFLP	Restriction fragment length polymorphism
RNA	Ribonucleic acid
RR	Respiratory rate
RT	Rectal temperature
RT-PCR	Reverse-transcription polymerase chain reaction
RVF	Rift Valley fever
RVFV	Rift Valley fever virus
SAT	Southern African Territories
SCC	Somatic cell count
SCCt	Somatic cell count in bulk tank
SNP	Single nucleotide polymorphism
SPGP	Sheep pox and goat pox
SPPV	Sheep pox virus
SRH	Somatotropin releasing hormone
STH	Somatotropic hormone
TBF	Tick-borne fever
THI	Temperature-humidity index
TLR	Toll-like receptor
WAD	West African Dwarf (goat breed)
WLM	Weighted log-linear model
WLMM	Weighted log-linear mixed model

Chapter 1
Introductory Chapter: Is There a Future for Goat Pastoral Systems?

Serge Yan Landau

Abstract Raising goats is associated with poverty and economical calculations show that intensification increases the profitability of goat pastoral systems in a wide array of ecological conditions. A goat pastoral system is analogous to a pearl necklace where one tries to replace several pearls without letting the remaining pearls fall around. Goat adaptation to harsh pastoral conditions is based on specific behaviors, including feeding behaviors, response to predators, and possibly self-medication behaviors transmitted from mothers to offspring that we term collectively "goat culture". Introduction of managerial changes should be designed in ways that will not disrupt goat culture. The new genomics technologies could be instrumental in identifying genes associated with anatomical and physiological adaptations to harsh environments. Pastoral systems are associated with an intimate knowledge of ethno-veterinary and medical practices and there is a risk that this knowledge is lost in the intensification process. Finally, evidence accumulates that goat pastoral systems, when well managed, provide a wide array of ecological services: fire prevention in brushland and woodland, landscape enhancement, and increased biodiversity. Simplistic economic evaluations have overlooked these societal contributions which should be quantified and paid for explicitly.

1.1 Introduction: Pastoral Systems of Goat-Keeping

Goat herders in adverse environments such as arid and mountainous areas operate extensive production systems. The level of extensiveness is defined by the levels of inputs into the system, be they buildings, feed, or labor. The most extensive system may well be one in which goats belong to nobody and the input in breeding them is nil: 2.6 million feral goats, which descend from goats introduced with the First Fleet in 1788, occur across 28% of Australia, mostly in sheep-breeding regions where

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wild dogs and dingo populations are well controlled. Under favorable conditions, they may be very productive and give birth to twins more than once a year. Their meat is harvested by hunting (Parks et al. 1999). Feral goats consume leaves, twigs, bark, flowers, fruit, and roots that are not a part of cattle of sheep diet. They are extremely well adapted to their environment (Canberra act 2601, accessed 24 August 2017). But is that a sustainable way of breeding goats? The answer is negative: they are considered as invasive species, they are incriminated of over-grazing, damaging soils—triggering erosion, and preventing regeneration. They disseminate weeds through seeds carried in their dung and serve as reservoir for a whole array of parasitic ailments (Canberra act 2601, accessed 24 August 2017). That goats can be destructive is not new: In ancient Israel, goats were banned from agricultural lands and goat-keeping was allowed only in woodlands and brushlands. In the second to fifth century A.D., an elaborated array of laws was even created to curb damages afflicted to crops by goats. Until the mid-twentieth century, goat grazing in Mediterranean forests was subjected to rigorous regulation in former Yugoslavia, Morocco, Greece, and Turkey (Bourbouze and Rubino 1992), among other countries. In other words, the management of land with goats must be "pastoral", in the sense that somebody—the pastor, or the shepherd—has to be responsible to society for the potential harmful effects of goat grazing. Recently, goat pastoral systems have been shown to generate services of societal interest, not only milk, meat, and fiber. A novel approach to the evaluation of these systems must encompass the definition and quantification, identification of consumers, and devising ways of compensation for those who deliver these services.

1.2 Alleviation of Poverty and the Intensification of Goat Pastoral Systems

Juan Capote in his introductory chapter to Volume 2 writes that "because low income food deficit countries form 27% of total countries and hold 61% of the goats on Earth, this closely links goats with poverty levels." In contrast, in a series of papers dedicated to reducing poverty in Africa, including the self-explanatory title "Goats—a pathway out of poverty", Peacock (2005) claims that goats can reduce poverty. How can this contradiction be resolved?

Peacock's strategy is focussed on poor farmers in Africa, in particular, women. Populations of traditional goat herders are not specially targeted. Goats are distributed in a community (a farmers' organization), including buck breeding service (with breed registration), veterinary services, cost-effective input supply, technical support, and the organization of product collection. This strategy does not consider land as a constraint, as goats will feed on communal pastures, crop residues, and fallow lands, but the authors themselves acknowledge that in modern Africa, the increasing human population pressure results in limiting free grazing and in tethering goats (Peacock 2005). In other words, the system might mainly rely on feed and fodder crops—where land is needed for food crops to Man—and require provision of a wide array of technical supplies given by governments or nongovernmental organizations. Using this approach, a thorough knowledge of the land, as featured by traditional herders, encompassing vegetation and its seasonality, toxic plants, and drugs, is not needed. Based on a questionnaire with 510 goat herders, Asante et al. (2017) also explained that veterinary services and increasing feed expenditures are the principal components needed to achieve greater output from goats in Ghana. It infers that systems that claim to bring people out of poverty promote intensification, in essence, they will depend on more feed, time-consuming care, and more input of veterinary services. However, there is no contradiction between Juan Capote who associates most goat production systems, still kept in rangelands under adverse environments with minimal inputs, with poverty, and Peacock (2005) who promotes intensification up to almost zero-grazing, encompassing feed, and veterinary services, as an out-of-poverty pathway, because they do not address the same populations of goat herders. Juan Capote addresses traditional populations of goat herders, while Peacock (2005) is about non-pastoral systems.

Even in more developed countries, such as Spain, dependence on the land is increasingly viewed as a constraint: Nahed et al. (2006) compared the productivity, stability, flexibility, equity, and self-management properties of three dairy goat production systems in the mountainous Sierra de Cadiz in Spain, including semi-extensive (100% local Payoya goat, 1.02 ha/goat), semi-intensive (85% Payoya breed, 0.49 ha/goat), and intensive (50% Payoya breed, 0.13 ha/goat). They reached the conclusion that even though intensification was inefficient in terms of energy use or net margin per liter milk, it promoted better adaptability and equity values. Most importantly, the net margin per family did not differ between the three production systems. In another study of goat farms in mountainous SW Spain, Gaspar et al. (2011) concluded that "the best management practices and productivity results were obtained by the farms furthest from the traditional systems."

So, why should a goat breeder opt for the extensive or semi-extensive options, including long walks under harsh and seldom predictable climatic conditions, increased risks of theft, and high probability of predation, if he/she can reach the same income from the more secure and adaptable intensive zero-grazing system? It is expected that whenever possible—if funds for investments and technical support are available—goat systems will intensify and systems encompassing traditional goat grazing on rangelands will be under siege.

1.3 The Pearl Necklace of Goat Pastoral Systems: Replacing One Pearl Without Losing All the Others

Pastoral systems of goat production are like a necklace of pearls: in order to replace one pearl, one has to open the necklace, but there is a risk that once the necklace is open, all the pearls fall and scatter. A widespread example would be crossbreeding goats to a more productive breed, which may appear to be less resilient to indigenous parasites, say a *Haemonchus* challenge: in a first step, anthelmintics will be used, until their efficacy decreases (see Paraud and Chartier in this volume). In a second step, traditional ways of grazing will be disrupted in order to avoid the *Haemonchus* challenge with valuable animals, until, step after step, the system loses the rationale of grazing altogether.

Research is, therefore, confronted with the question: if goat grazing systems have to be intensified, what should be kept unmodified, and what can be changed? In his much-cited review of the physiological basis of goat adaptation to harsh environments, Silanikove (2000) discusses adaptation to harsh environments, and in particular to pasture, with emphasis on their ability to browse and thrive in tannin-rich environments (Fig. 1.1). There is ample evidence that many feeding selectivity patterns of goats have been acquired largely after domestication (Landau and Molle 2009). A survey carried out in the Cazorla Natural Park of Spain (Garcia-Gonzalez and Cuartas 1989) showed that wild goats (*Capra pyrenaica*) consumed a diet consisting of only 41% browse and 59% herbaceous, where domestic goats (*Capra hircus*) selected a diet with 81% browse and 19% herbaceous. Why and when did that evolution happen? The location and quality of pasture allocated to grazing animals in ancient times was a function of their relative economic importance to the landowners. Cattle was used for ploughing and transport, and was the most important species. In the fourth millennium B.C., the wool mutation occurred in sheep and dramatically upgraded their economic importance (Sherratt 1983). In contrast, goat wool—mohair—appeared much later and, outside Turkey, significant flocks of Mohair-yielding Angora goats were rare until the end of the nineteenth century. In other words, cattle and sheep had much higher economic value than goats for most of the time since domestication and goats were allotted to the poorest and the most arid rangelands and had to implement sophisticated patterns of feeding behavior in order to procure enough nutrients without ingesting too much of the toxins that are ubiquitous to brush species or by finding ways to neutralize them (Landau and Molle 2009). There is accumulating evidence that "goat culture", i.e., the knowledge of what to eat and how to behave in a rangeland is passed from mothers to offspring (Biquand and Biquand-Guyot 1992), irrespective of mother and offspring genotype (Glasser et al. 2009) through milk taste or by imitation of feeding behavior (Arviv et al. 2016). In some goat breeds, this possibly even includes learning how to self-medicate against gastrointestinal nematodes (Amit et al. 2013). But goat culture is not everlasting: any procedure that disconnects mothers from offspring will threaten the continuation of goat culture: for example, artificial rearing of kids with milk replacer—a step taken by Spanish herders (Gaspar 2011) will have harmful effects, but crossbreeding may be sustainable if crossbred animals follow a "locally educated" doe that was itself following a "locally educated" goat.

Knowing what to eat is only one facet of adaptation to adverse environments outlined by Silanikove (2000). The outcomes of physiological or anatomical adaptations, such as the ability to reduce metabolism, increased nitrogen recycling, renal, and ruminal adaptations to watering have not been studied in crossbred goats

Fig. 1.1 Domestic goats are very well adapted for grazing and browsing in different topographies. **a** A Druze shepherd and his flock, Mount Carmel (provided courtesy of Ella Segal); **b** Feeding on thistles, Carmel Mountain (provided courtesy of Adi Arviv); **c** Mineral nutrition, the Judean Hills (provided courtesy of David Evlagon); **d** Monitoring grazing behavior (provided by S. Y. Landau); **e** browsing olive tree (provided courtesy of Dorit Kababya); and, **f** giving birth at pasture (provided courtesy of Dorit Kababya); Israel

and they are possibly lost in the crossbreeding process. The genetics of dwarfism, another adaptation of goats to scarcity, is not known. In their analysis of the resistance of goats to worm challenge, Chiejina and Behnke (2011) have claimed that crossbreeding West African Dwarf Goats decreases their resistance to worm challenge. Out of 97 papers published on goat genetics from August 2010 to August 2016 in the journal "Small Ruminant Research", most address genetic diversity of goat breeds and its use to improve productivity, generally measured under experimental farm conditions. Only three publications by Gama and Bressan (2011), Yakubu et al. (2016), and Adjmone-Marsan et al. (2014) address explicitly ways of exploiting new molecular genomic technologies to select goats according to targets specific of extensive goat production systems. Adjmone-Marsan et al. (2014) write "the comparison of patterns of diversity among the genomes in selected groups of animals (e.g., adapted to different environments) and the integration of genome-wide diversity with new GIScience-based methods are able to identify molecular markers associated with genomic regions of putative importance in adaptation and thus, pave the way for the identification of causative genes. Goat breeds adapted to different production systems in extreme and harsh environments will play an important role in this process." An interesting example was recently published (Yakubu et al. 2016) whereby, gene polymorphism in IL-2 (interleukin-2) gene was measured in Sahel, Red Sokoto, and West African Dwarf goats and was shown to be associated with the resistance to heat stress.

Therefore, intensification is probably economically unavoidable. When steps are taken in this direction, great care is required not to disrupt goat culture. A strategy of better exploiting the diversity of local breeds, identifying genes associated with adaptive characteristics, is feasible, but will scientists switch from the productivity-minded way of thinking and learn how to replace certain beads in the necklace of goat pastoral systems without losing them all?

1.4 The Cultural Contribution of Goat Pastoral Systems to Humankind

We are not always aware of the cultural contribution of pastoral societies to humankind: the most prominent actors in the Old Testament and the ancient Greek mythology literature were staged in pastoral societies where goats had major roles.

Pastoral societies have obviously contributed to humankind, a wide variety of products from goat milk (Fig. 1.2), fermented milk, cheeses, and diverse ways of meat conservation, hair rugs, and tents. Literature is full of examples of the outstanding health value of goat products sourcing from grazing goats: a recent study reported that goat milk produced on a diet of Mediterranean brushland was richer in protein, omega-3 fatty acids, improved ratio of omega-3 to omega-6, higher content of mid-length fatty acids, than milk produced by the same goats when fed alfalfa hay, with no difference in milk yield (Hadaya et al. 2017).

An untold contribution of pastoral culture to humankind is pharmacognosy whereby shepherds, and particularly goat shepherds, have learnt to identify the medical—veterinary—effects of grazed plants. For example, in a study by Gradé et al. (2009) entitled "four footed pharmacists", 24 traditional healers and 123 pastoralists in Uganda were asked to narrate observations of: (1) animals having an obvious ailment that pastoralists could visually diagnose; (2) these animals displaying behavior that is rare when healthy, such as grazing an unpalatable plant; (3) improvement of the animal's symptoms; (4) animals ceasing the said behavior

Fig. 1.2 Bedouin woman making butter, Negev Desert (2004), Israel (provided by S. Y. Landau)

after they recovered; and, (5) the plant species being part of the local human pharmacopeia. The authors used a number of statistical estimates in order to ensure that the data were dependable. Eight plant species fulfilled all of these conditions and results provided support for the hypothesis that goats graze specific plants when ill and suggest that people have developed some of their knowledge through animal observation. A variety of herbal and human procedures identified with goat herders in the Middle East corroborates this hypothesis (Landau et al. 2014).

Even though pastoral ethno-veterinary and herbal medicine knowledge are increasingly replaced by Western medicine, better understanding of some aspects of pastoral culture among urban populations is achieved by agrotourism: walking with goats is popular in the UK (http://www.buttercups.org.uk/goat-walking.htm, accessed on September 5, 2017); a 420 km long walk along ancient transhumance pathways allows tourists to taste pastoral life and products between France and Italy (http://chevre.reussir.fr/actualites/la-routo-marche-avec-les-chevres:IADS993Q.html, accessed on September 5, 2017), and an effort is made in Spain to renovate and re-exploit transhumance pathways (Amat-Montesinos 2017). A wide program of "walking with the goats" was implemented in 2007 in Israel (Fig. 1.3), encompassing exposure of urban population to extensive goat herding, goat products, brushland botany, and Bedouin life (Kababya and Adar 2008) whereby economic implications for herders were analyzed.

Fig. 1.3 The “walking with the goats” project (Israel) (provided courtesy of Dorit Kababya)

1.5 Who Benefits from Goat Pastoral Systems?

In all the studies presented above, the only source of income was products: milk, meat, fiber, and possibly dung. But pastoral systems create a wide array of societal benefits: goats prevent brush encroachment; they are used as a tool to modify landscapes (Levin et al. 2013) (Fig. 1.4); they decrease the accumulation of flammable materials in Mediterranean fire-prone areas (Leytón and Vicente 2012); and, if correctly managed, they promote biodiversity (García et al. 2012).

In the first part of this quick survey, it was claimed that goat pastoral systems are bound to be intensified. However, if goat herders were compensated for these societal contributions, their economic situation could be upgraded and the extent of intensification could be reduced. It will be the role of scientists to quantify these societal services and make their economic value explicit to decision makers.

Fig. 1.4 Goats foraging on (young) pine trees can contribute to prevent the next fire, Carmel Mountain (2016), Israel (provided by S. Y. Landau)

1.6 Concluding Remarks

Goat pastoral systems are associated with poverty. The way out of poverty is by increasing productivity, generally achieved by replacing or crossbreeding local goats with more productive genotypes. This could be avoided if the societal services provided by goat herders were recognized as preventing brush encroachment and fire hazard, enhancing landscapes and promoting biodiversity have an economic value. However, if the system is bound to intensify but still exploit rangelands, scientists must be instrumental in preventing the disruption of goat grazing culture and in harnessing novel genomic technologies to conserve local goat adaptations to harsh environments.

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Part I
Sustainability and Socio-economic Aspects in Goat Production

The Humanity Photo Awards 2015 (UNESCO). © Jorge Bacelar

Chapter 2
Sustainability of Local Goat Genetic Resources in the Mediterranean Region

Dehouegnon Jerry Agossou and Nazan Koluman (Darcan)

Abstract The Mediterranean region comprises a great diversity of indigenous goat breeds that are well adapted to the local environments. Indigenous goats play a significant economic, social, and environmental role providing income and ensuring food for the local population. Despite their relevant importance, indigenous goats are subjected to a variety of factors causing their progressive decline. The wide intensification of goat production with the goal to meet the increasing demands for animal products and to contribute to improving livelihoods is the major threats to goat genetic diversity. Also, in the absence of measures to ensure that the use of exotic genetic material is well planned, the impact on local breeds can be serious. To ensure a sustainability of indigenous goat genetic resource, some conservation methods grouping in situ, ex situ in vivo and in vitro (ex situ) conservation could be implemented. The successful implementation of these strategies requires an active involvement of farmers, researchers, governments, and nongovernmental and international institutions by developing and supporting various policy issues. This chapter highlights briefly the present situation of indigenous goat genetic resource and some policies implanted to ensure the sustainable conservation of these genetic resources in the Mediterranean region.

2.1 Introduction

According to archeozoological and genetic data, goats were domesticated some 10,000 years ago in the geographical region that spans from Eastern Anatolia to the Zagros Mountains in northern Iran. They play important economic, cultural, and religious roles in many human cultures (Nicoloso et al. 2015). According to Food and Agriculture Organization (FAO) the global population is expected to grow from 7.4 billion in 2016, to more than 9 billion in 2050 (FAOSTAT 2017a). The demand

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for livestock products would double in the first two decennia of the twenty-first century because of the growth of the human population, urbanization, economic progress, and changing consumer preferences (Udo et al. 2011). By 2050, this expanded world population is expected to consume two-thirds more animal protein than it does today. Total consumption of meat is projected to increase by 73% and that of dairy products by 58% (Dijkstra et al. 2013). To meet the increasing demands for livestock products (milk, meat, wool, etc.) and to contribute to improving the livelihoods notably in rural households, intensification of livestock production has been widely advocated (Udo et al. 2011).

According to Marie (2017), the sustainability concept can be defined as a development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs. It refers to the long-term success of a system. In order to keep sustainable animal systems, changes must be implemented to allow animal production to continue in an efficient and environmentally conscious manner (Peralta et al. 2014). Breeding, nutrition, environment and production systems, animal and human health, animal welfare, and new assisted reproduction technologies all contribute to sustainable agriculture, which can help to adapt to the new challenges.

Goats providing tangible benefits such as cash income from animal sales, meat, and milk for home consumption, manure, skins, and fiber play an important role in resource-poor communities. They are also a source of intangible benefits, e.g., savings, insurance, and for sociocultural purposes (Byaruhanga et al. 2015).

This chapter highlights briefly the present situation of indigenous goat genetic resource and some policies implanted to ensure the sustainable conservation of these genetic resources in the Mediterranean region.

2.2 Presentation of the Mediterranean Region

The Mediterranean region also known under the denomination of Mediterranean Basin or sometimes Mediterranean, is the region at the crossroads of three continents: Europe, Africa and Asia (Reguant-Aleix 2012). Around the Mediterranean Sea, it stretches c. 3800 km east to west from the tip of Portugal to the shores of Lebanon and c. 1000 km north to south from Italy to Morocco and Libya (Atalay et al. 2008; Sundseth 2009).

The Mediterranean region comprises 12 European countries (Albania, Bosnia-Herzegovina, Croatia, France, Gibraltar (UK), Greece, Italy, Malta, Monaco, Montenegro, Slovenia, and Spain), five Northern African countries (Algeria, Egypt, Libya, Morocco, and Tunisia), and six Western Asian countries (Cyprus, Israel, Lebanon, Palestine, Syria, and Turkey).

The climate is characterized by hot-humid summers and humid-cool winters but it can also be notoriously capricious with sudden torrential downpours or bouts of high winds (e.g., the Sirocco and the Mistral) occurring at various times of the year.

These climatic conditions have a profound influence on the vegetation and wildlife of the region (Sundseth 2009).

Moreover, the Mediterranean region offers an ever-changing landscape of high mountains, rocky shores, impenetrable scrub, semiarid steppes, coastal wetlands, sandy beaches, and a myriad islands of various shapes and sizes dotted amidst the clear blue sea (Sundseth 2009). Although much of the hotspot was once covered by a dense cover of forests, the basin has experienced intensive human pressure which has impacted on its ecosystems for at least 8000 years, significantly longer than any other hotspot. The greatest impacts have been deforestation, habitat fragmentation, intensive grazing, and fires, and infrastructure development, especially on the coast, which have distinctly altered the landscape. The agricultural lands, evergreen woodlands, and maquis habitats dominating the basin are the results of these disturbances over several millennia (Atalay et al. 2008).

In mountainous of Mediterranean part of Turkey, goat farming is the most important animal production of people who don't have any other alternative for their subsistence. In addition, meat and milk products from goats are very important for population (Darcan et al. 2005).

2.3 Goat Breeds Around the World and the Mediterranean Areas

The Mediterranean's goat population is over than 43 million heads (excepted Gibraltar where data are not available), accounting for 4.3% of World's goat population estimated at over than 1 billion heads. In 2014, among all Mediterranean countries, the largest number of goats were observed in Turkey followed by Morocco, representing about 23.8 and 14.2%, respectively. Malta has the lowest goat population (4627 heads) accounting for 0.01% out of the regional total number (FAOSTAT 2017a). According to FAO, the World's goat population comprises more than 1153 goat breeds, each having specific characteristics resulting from its evolution in the environment and selection (Zjalic et al. 2005; Gurung and Solaiman 2010). Nevertheless, Gurung and Solaiman (2010) reporting the World Dictionary of Livestock Breeds (Mason 1996) found that among 565 goat breeds plus 76 varieties (sub-breeds), only 68 herdbooks and/or established breed societies exist.

They also stated that in developing countries, efforts to establish the purity of breeds or to improve existing breeds are still insufficient. Therefore, the majority of goat breeds listed in the FAO database found in the developing countries are only recognized in their countries of origin (Gurung and Solaiman 2010). This is the case of Morocco, where despite the National Association for Sheep and Goats the latter are less known (Berkat and Tazi 2006). However, recent studies have demonstrated the separation between the local Draa, Barcha, and Atlas goat breeds, although genetic characterization using genetic markers is needed to confirm that separation (Ibnelbachyr et al. 2015; Boujenane et al. 2016).

Boer is the most popular meat breed, while Angora and Cashmere are the main fiber-producing breeds. A few dairy breeds, such as Saanen, Toggenburg, Alpine, and Anglo-Nubian, are widespread and are frequently found in commercial herds throughout the world. However, dairy breeds require higher levels of care. The Saanen, Alpine, and Toggenburg breeds were originally from the Swiss and French Alps, while Anglo-Nubians were developed in the United Kingdom by crossing British goats with bucks of African and Indian origin (Capote 2014). In addition, established selection and breeding programs mainly in developed countries have been carried out by research institutions, with participation of the farmers. Those crossbreeding programs established in different countries allowed obtaining suitable and improved genotypes (see Chap. 7). For instance, in Egypt local goats are classified into several breeds according to color, size, and other morphological features, such as Zaraibi, Baladi, Sinawi or Bedouin, Barki, and Saidi (Hassanane et al. 2010). Egyptian goat genetic improvement schemes involving crossbreeding trials with Damascus goats and the development of local breeds, namely the Zaraibi breed, has been a recent target of joint work with the FAO (Agha et al. 2008). Zaraibi (also called Egyptian Nubian, Nuba, or Theban) goat is known to be a progenitor of the standard Anglo-Nubian and one of the better known native breeds. In 1990, sires of the present herds were selected based on their dam milk yield. Since 2000, selection indices were applied on both males and females including body weights and milk yield of their dams at 1st parity. Although the population size is small (2% of the total goat population in Egypt), the breed has a good reputation in Egypt and the Near East region, because of its high prolificacy and milk production (Galal 2007; Shaat et al. 2007; Aboul-Naga et al. 2012).

Additionally, in Turkey, the Saanen breed was used as an improver and crossed with Turkish local Kilis goat in 1961. The crossing was terminated after obtaining first backcrosses (3/4 Saanen, 1/4 Kilis) and backcrosses were bred within themselves. The resulting cross became the most popular improved dairy goat in the country (Yener 1989).

The population of Hair goats increases along with the altitude of the land because of the vegetation. In forests and bushy areas, where the extension of cultivated land is limited, the number of goats increases. Those regions are quite suitable for fulfilling the demands of goat products while, at the same time, the feedstuff available in those areas can be utilized only by goats. People living in such regions keep goats mostly for self-consumption, while some territories are occupied with small-scale arable farming as well. On the other hand, Angora goats are basically raised in central Anatolia, especially in the province of Ankara and surroundings. Apart from these two main breeds, there is another native breed which is called Kilis and kept especially in the southeast region. Honamlı goat, another local breed, is located in the Tarsus Mountains in the Mediterranean region, Antalya, Isparta and Konya regions. Norduz goat, a Turkish breed, is located in Gürpınar in Van province and Norduz locality. A limited number of Malta, Saanen, and crossbred dairy goats are also present especially in the Aegean and Marmara regions (Daskiran and Koluman 2014).

The Damascus breed is a popular goat genotype generally used for milk production. It is mainly raised in Cyprus, Lebanon, Syria, and Southern part of Turkey. The breed is also known by some other names such as Aleppo, Baladi, Chami, Damascene, Halep, or Shami. The Damascus goat is a native breed of the Middle East, and it has been raised in big herds throughout the region. These goats were imported by British people at some time in the nineteenth Century. They were taken to Cyprus where they were then bred and raised in large numbers. It was during this time that the breed picked up the name "Damascus". The Damascus goat has been mentioned in many classics of Arabic literature. In fact, the breed appears in the religions and folklore of the region as well. Because of being noble and having striking characteristics, the Damascus goat was used for creating many other goat breeds. And there has been interest in the breeding and genetics of this goat (Schilt 2017).

2.4 Goat Production Systems

The main features of the different goat production systems are related to the way in which animals are raised. There are various production systems which are categorized according to adopted criteria, notably, the use of feed resources and the nature of flock movement during the annual cycle (Nefzaoui et al. 2011). The traditional dairy system classified from the land utilization implies three different breeding systems: sedentary, transhumance and nomadic (Bocquier et al. 2006). There are also semisedentary system, oasis system, and peri-urban system (Nefzaoui et al. 2011).

Nomadic and Transhumant system: In the past, the nomadic and transhumant production systems were dominant. In summer and autumn, the flocks move to the cultivated areas to graze cereal stubble and the residues of irrigated crops. During the last decades, transhumance is being gradually abandoned. The majority of transhumant flocks were turned into sedentary flocks (Nefzaoui et al. 2011). In the nomadic system, pastoralists move annually at the end of spring from the drier lowland to the higher mountain grasslands and forests. It is the common system used for small ruminants in the driest areas of North Africa and Near East countries (Guessous et al. 1989; Nefzaoui et al. 2011). Sheep and goats raised by pastoralists are generally low-producers in terms of milk and offspring but are well adapted to the climatic conditions and are relatively tolerant of local diseases (Degen 2007).

Semisedentary system: In this system, animals are fed on cultivated fields as well as natural pasture. Indeed, during the winter season, the animal are driven to cultivated fields where they are fed on the harvest residues. However, in February they move to grazing areas in the steppe to avoid crops' damage. Animals are moved back into cultivated areas immediately after crop harvest to graze cereal stubbles. By the end of summer, the flocks are moved back to their villages (Nefzaoui et al. 2011).

Sedentary system: In this system, sheep and goat flocks are kept at or close to the village or farm all the year round. The sedentary herding system is dominant among the sheep and goat farming systems. During the day, they are grazing either on the common village range or on privately owned or hired grazing areas; they also have access to stubbles and fallow fields. For the night they return to their sheds in the village or on the farm (Yalçin 1986; Laga et al. 2005). These fenced systems of managed fodder area or of seminatural grazing lands can easily be found in Turkey, Greece, Italian regions of Sardinia, Tuscany, Lazio, and Sicily, but especially in western Spain. Also, animals receive some hand-fed supplements in almost all seasons (Yalçin 1986; Directorate-General for Agriculture and Rural Development 2006; Nefzaoui et al. 2011).

Oasis system: The oasis system can allow rearing of improved goats thanks to the possibility of producing enough fodder and by-products to feed the animals (Djemali and Bedhiaf 2005).

Peri-urban system: This system is more common in the peri-urban areas, where some producers keep small herds making use of accessible adjacent markets. Milk is the main product from such herds where the young are sold for fattening. Animals are confined in a yard or barn for fattening. Traditionally barley is the main diet's ingredient. Despite the relative economic importance of this system, there exists very little information about it (Galal 2007; Nefzaoui et al. 2011).

Sheep and Goat Mixed Systems: Particularly, Turkey has approximately 3 million livestock farms, of which 95% are sheep and goat farms. Mixed farms are localized in the central region. Those crossbreeding programs established in different countries allowed obtaining suitable and improved genotypes, especially in east and southeast Anatolia. Sheep farmers using extensive system prefer easily controlled and managed goats while sheep graze. In addition, farmers keep goats to provide their family requirements including meat and milk products or their commercial value (Daskıran and Koluman 2014).

2.5 Meat and Milk Production from Indigenous Goats in the Mediterranean Region

In 2013, Mediterranean's meat produced from indigenous goat and whole fresh milk from goats were, respectively, 5.2 and 14.6% of the world's production (FAOSTAT 2017b). Milk of sheep and goats is produced in all Mediterranean countries. In some of them (Greece: 59.4%, Libya: 36.8% and Syria: 35.7%) (FAOSTAT 2017b), small ruminant milk yield represents from 20 to 60% of the countries' total milk production. Cheese is the principal dairy product traditionally prepared in all Mediterranean countries. The milk of the Mediterranean indigenous goat has almost the same gross composition as cow's milk, with the fat content being a little higher (Mantis 2001).

The main indigenous meat and milk producer countries in the region are shown in Table 2.1. Thus, countries like France, Turkey, Spain, Greece, and Algeria produce more than 82% of the whole production. Regarding indigenous meat, it is mainly produced in Turkey, Egypt, Greece, Morocco and Algeria, with 68.8% of the regional production.

2.6 Challenge of Sustainability of Local Goat Genetic Resources

Genetic diversity in goats is under constant threat of erosion. Various factors including natural causes, man-made disasters, and loss of habitat, negligence and abandonment of the well-adapted indigenous landraces, breeds, and populations constitute potential threats for genetic diversity. The effects may be felt in a different manner: undermining the production systems of which animal genetic resource form a part; physically destroying livestock populations; or provoking responses that are in themselves a threat (Rischkowsky and Pilling 2007; Shrestha and Galal 2010).

2.6.1 Socio-economic Factors Contributing to Genetic Erosion of Local Goat Breeds

According to FAO (2000), 27% of the goat breeds have been deemed at risk of extinction in the world (Shrestha and Galal 2010). Taberlet et al. (2008) stated that global economic and agricultural practices changes constitute the major threats to livestock genetic diversity. Indeed, the growth of the world human population associated with the increased demand for livestock products lead to widespread substitution of local breeds by a narrow range of high-yielding breeds in order to increase output (Rischkowsky and Pilling 2007; Thornton 2010). In addition, intensification of animal production due to the progress achieved on animal reproduction, animal breeding and flock management systems such as artificial

Table 2.1 Main indigenous meat and milk Mediterranean producer countries

Country	Meat indigenous goat (ton)	Country	Whole fresh goat milk (ton)
Turkey	56,483	France	601,400
Egypt	55,495	Spain	457,031
Greece	37,100	Turkey	415,743
Morocco	25,990	Greece	350,871
Algeria	18,494	Algeria	303,823

Source FAOSTAT (2017b)

insemination and embryo transfer, data recording and processing, have led to a gradual disappearance of the local genetic resources (Hoffmann 2010; Thornton 2010). Also, the wider availability of vaccines and chemotherapeutics against endemic diseases promotes the use of higher production and less well-adapted genotypes (Zjalic et al. 2005; Taberlet et al. 2008).

The progressive abandonment of agricultural activities in less favored areas notably rural, the successful industrialization of animal breeding combined with all prior facts have driven farmers to partially or completely abandon a number of autochthonous breeds (Kume and Papa 2005; Taberlet et al. 2008). Apart from food supply (meat, milk) and wool production, indigenous breeds have an important economic value which is not really estimated because of the application of inadequate or the lack of suitable methods. This fact is also partially responsible for this trend. Consequently, a great reduction of many locally adapted animal populations has been noticed, causing the new problems of genetic drift and inbreeding to their ranchers (Taberlet et al. 2008). In Mediterranean areas the population of many indigenous breeds has declined and those breeds are classified as at risk extinction. For example, of Italian goat population where 41.7% of breeds are classified as at risk, 11% are endangered, i.e., the mean number of heads per breed is less than 1200 with a declining trend (Nicoloso et al. 2015). The status of native breeds in some Mediterranean countries is shown in Table 2.2 (also see Chap. 29).

2.6.2 *Environmental Pressure's Role in Goat Genetic Resources Extinction*

The current urban encroachment observed is a pressure on most traditional breed populations and landraces that have remained in their habitats for centuries (Shrestha and Galal 2010). The survival of many breeds is threatened by the negative impact of the environmental issues related to the destruction of their natural habitats. This situation is more critical in the nomadic pastoralist systems due to predators, overgrazing, loss of grazing rights in the mountain and forest pastures, and abandonment of the traditional profession (Shrestha and Galal 2010).

Table 2.2 Number of local goats at different status of extinction risk in some Mediterranean countries

Countries	Number of natives	Critical	Endangered	Extinct	References
Turkey	6	–	3	No	Karagöz (2006), Yilmaz and Wilson (2012)
Greece	2	–	1	–	Georgoudis et al. (2010)
Spain	22	–	15	1	Capote (2014)
Italy	54	13	11	1	Bittante (2011), Nicoloso et al. (2015)

For instance, in the Mediterranean basin, due to high temperature and lack of rainfall pasture growth is limited in summer causing significant declines of grazing capacity of mountainous grassland during autumn (Nardone et al. 2004). Apart from these climate change impacts reducing water and pasture availability, high ambient temperatures compromise reproductive efficiency in both female and male animals. Indeed, environmental stresses affect the oestrus behavior, embryo production, birth weights, placental size, and function and fetal growth rate. It can lead to abnormal gametogenesis (spermatogenesis and folliculogenesis) and ovulation, a delayed onset of puberty, large anoestrus periods, change in sexual behavior, increased embryo and pregnancy losses, low fertility and prolificacy, and increased perinatal morbidity and mortality (Sejian 2012; Prasad et al. 2015).

In worldwide, the majority of goat breeds in danger of extinction rely on a very small number of fertile male and female for their propagation, minimizing the effective population size (Shrestha and Galal 2010; Gerber and White 2014). As a consequence, there are recurrent losses of genetic variation and erosion of genetic diversity (Shrestha and Galal 2010). These adaptive characteristics for harsh environmental conditions contribute to a growing interest in indigenous species for conservation and breeding programs (Salles et al. 2011).

2.6.3 Health Challenges Due to Diseases Pressure

Biotic stress factors, in particular, gastrointestinal nematodes (helminths), are a major disease crisis in small ruminants. Recent studies demonstrated a very significant effect of short-term weather and climate on free-living larval stages on pasture and respiratory diseases development in small ruminants. They also revealed that gastrointestinal parasites are responsible for important production losses, and increased susceptibility to other diseases and/or pests, and even death (van Dijk et al. 2009; Sotiraki et al. 2013; Rahal et al. 2014).

Furthermore, Sejian (2013) reported that changes in temperature associated with an irregularity of rainfall may cause a spread of disease and pathogens and, consequently, a higher incidence of diseases and mortality with concomitant decrease small ruminant's productivity. More seasonal rates in diagnosing parasitic gastroenteritis suggest that, in line with increases in temperature, fewer larvae of some parasites like *Teladorsagia* and *Trichostrongylus* species survive the winter and spring at pasture, while the routes of transmission of these species, and of *Haemonchus contortus* as well, have extended into the autumn. For all specie categories significant differences in rates of diagnosis, and in the seasonality of disease, were identified among regions (van Dijk et al. 2008).

2.6.4 Influence of Policies on Indigenous Genetic Resources

Inappropriate government policies can directly or indirectly have severe consequences for indigenous genetic diversity. Two policy developments have significantly affected gene resources:

First, the demands from breeders and livestock keepers for high-performing animals stimulate the importation of exotic breeds. The desire to achieve rapid progress means that the use of genetic material from high producing exotic breeds is often favored (Hoffmann 2010). In addition, some policy-makers adopt policies promoting the use of artificial insemination to increase the rate with which exotic germplasm can be disseminated (Hiemstra et al. 2006). An exacerbating factor can be the promotion of exotic germplasm by breeding companies from developed countries; in some cases, this is supported by development agencies seeking to promote the use of their national products. In the absence of measures to ensure that the use of exotic genetic material is well planned, the impacts on local breeds can be serious (Hiemstra et al. 2006).

Second, the implementation of employment strategy and particularly in livestock sector prioritizes the promotion of short-cycle livestock-keeping activities, such as poultry and pigs (Rischkowsky and Pilling 2007; Scherf and Pilling 2015).

2.7 Importance of Local Goat Genetic Resources Conservation

The importance of animal genetic resources diversity lies not only in underpinning the provision of a wide range of products and services, but also in enabling these services to be provided in a wide range of circumstances. Harsh production environments characterized by extreme temperatures, lack of good-quality feed, rough terrain or severe disease pressures, can only be utilized effectively by breeds that have particular characteristics that enable them to cope with these challenges (Scherf and Pilling 2015).

Native goat breeds represent important genetic resources for conservation and breeding programs because of their good adaptation ability to harsh local environmental conditions (Blasco 2008). In many countries, indigenous goats are among the most important species of livestock (Salles et al. 2011) and still play an important role. They provide food for on-farm consumption as well as for local market, thus representing a basis for food security at family level and good nutritional habits (Zjalic et al. 2005).

The genetic diversity of animal species within a farm constitutes a considerable resource to realize required changes in the phenotypic characteristics of a defined population (Oldenbroek 2007). These characteristics can roughly be categorized in production traits (quantity and quality) and fitness traits (adaptation, conformation, fertility, and disease resistance). Genetic variation in production traits is the base for artificial selection applied in breeding programs to realize genetic improvement in forthcoming populations. Genetic variation in fitness traits may be affected by artificial selection in breeding programs: for example, selection for milk production has a negative effect on fertility of dairy cows (Oldenbroek 2007; Oltenacu and Broom 2010). The genetic variation is the base for natural selection that facilitates the adaptation of a population to its (changing) environment and the base for artificial selection in commercial populations. Besides being sources of genetic variation, breeds can bear other values. Following these considerations, objectives for conservation are distinguished in the following subsections. The first four aims to maintain opportunities for the future, while the last three aims at present and future utilization (Oldenbroek 2007).

2.8 Conservation and Genetic Improvement of Local Goat Genetic Resources

Rischkowsky and Pilling (2007) defined conservation of animal genetic resources as all human activities (including strategies, plans, policies and actions) undertaken in order to ensure that the diversity of animal genetic resources is being maintained to contribute to food and agricultural production and productivity, or to maintain other values of these resources (ecological and cultural) now and in the future. Conservation breeding strategies for domestic goats under threat of extinction or endangerment can benefit from the following: (a) historical evidence that indicates the unique status of goat populations; (b) existing scientific knowledge of application of quantitative genetic principles; (c) advances in husbandry and disease control measures; and, (d) cryoconservation (Shrestha and Galal 2010).

In general, conservation methods are grouped into in vivo (including both in situ and ex situ) and in vitro (ex situ) conservation and the successful implementation of these strategies require governmental and nongovernmental institution support by developing various policy issues (Rischkowsky and Pilling 2007).

In situ conservation

In situ conservation refers to preservation of livestock in reared and natural populations. The livestock keepers are responsible for the production system in which the livestock is reared, or where they are normally found and bred (Rischkowsky and Pilling 2007; Scherf and Pilling 2015). They are the best options, where the resources are available and chances of strengthening the resources are high. Many genetic improvement schemes worldwide also involve in situ conservation as a major objective.

In situ measures facilitate continued co-evolution in diverse environments and avoid stagnation of the genetic stock. In situ conservation measures are best based on agroecosystem approaches and ideally should be established through economically viable and socially beneficial sustainable use (Commission on Genetic Resources for Food and Agriculture, and Food Agriculture and Organization of the United Nations 2007).

Data collected from some Mediterranean states (France, Spain, Italy, Greece, and Portugal) showed that 80% of local goat breeds are under in vivo in situ conservation programs (Zjalic et al. 2012). For instance, in 1996 the Turkish government initiated the in situ and ex situ conservation of three native goat breeds (Angora, Kilis, and Honamli) considered to be endangered (Yilmaz and Wilson 2012).

Ex situ in vivo conservation

Ex situ in vivo conservation refers to the maintenance of live animal populations outside of their normal or traditional management conditions (e.g., zoological parks and in some cases governmental farms) and/or outside of the area in which they evolved or are now normally found (Hiemstra et al. 2006; Rischkowsky and Pilling 2007). A clear differentiation between in situ and ex situ in vivo conservation is not defined and careful description of conservation objectives and suitable nature of conservation must be taken in each case (Rischkowsky and Pilling 2007).

Many gaps and inefficiencies have been noticed in most countries practicing these conservation methods. This fact is due to an insufficient financial support and human resource base for in situ conservation, ex situ conservation, and the better utilization of animal genetic resources for food and agriculture (Commission on Genetic Resources for Food and Agriculture, and Food Agriculture and Organization of the United Nations 2007).

Ex situ in vitro conservation

Ex situ in vitro conservation refers to the use of biotechnological tools such as inter alia, the cryoconservation of embryos, semen, oocytes, and somatic cells or tissues having the potential to reconstitute live animals at a later date (including animals for gene introgression and synthetic breeds) to preserve the living animal in an artificial environment under cryogenic conditions (Rischkowsky and Pilling 2007).

2.9 Concluding Remarks

The Mediterranean region is characterized by hot and humid summers and, humid and cool winters. The region comprises a great diversity of indigenous goat breeds that are well adapted to the local environment. Despite their low productivity, they remain an important source to provide food and food security, income generation and by the way ensure the development of communities living in mountainous and marginal regions. However, they are threatened by extinction risk due to several factors, notably global economic forces and changing agricultural practices, mismanagement, environmental, diseases challenges, poor control breeding, and unfavorable policies. Because of a number of reasons including their well-adaptation abilities to harsh local environmental conditions, diversity in native goat breeds should be conserved. Thus, conservation methods grouping into in vivo (including both in situ and ex situ in vivo) and in vitro (ex situ) conservation could be used to reach this target. Many countries have made progress in the establishment of the policies, programs and institutional frameworks needed. However, many weaknesses still need to be addressed, to promote the sustainable management of livestock diversity.

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Chapter 3
Goat Production in Eastern Africa: Practices, Breed Characteristics, and Opportunities for Their Sustainability

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Abstract It is estimated that 14% of the livestock in Eastern Africa are comprised of 146 million goats. The goats are in varying agroecological zones under farming systems ranging from small-scale mixed crop–livestock systems with a few animals raised on limited land resources, to extensive pastoral systems where large numbers of animals are raised on large tracts of land. The goats are raised primarily for meat, with milk treated as a secondary trait. Use of goat products at rural household levels in the region is not well documented. The goat populations have been developed over time through selection processes resulting in diverse goat breeds, with some adapted to harsh environmental conditions. In recent years, a strong drive to increase the productivity of goats has resulted in changes in breeding and management strategies and practices, including introduction of foreign breeds, mainly from temperate environments for use in crossbreeding programs, and a narrowing of the range and diversity of indigenous breed types. This, in addition to a lack of detailed information on the characteristics of the indigenous breeds, threatens the existing diversity of goat populations. This chapter presents an overview of the present-day indigenous goat breeds and the production systems under which they are raised in Eastern Africa. The chapter also highlights key constraints to improving goat productivity and outlines opportunities and changes to mitigate threats within the farming systems. The growing populations of goats and their potential for improving the livelihood of different communities call for innovative strategies to reduce their environmental footprint in the existing ecosystems.

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3.1 Introduction

The African countries of Burundi, Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, South Sudan, Uganda, and Tanzania make up Eastern Africa (EA). Within these countries, goats are found across different agroecological zones and play a key role in the livelihood of the different communities. They are an integral part of households, providing nutrition and disposable incomes. The goats are raised in farming systems that range from small-scale, where a few animals are raised on limited land resources, to extensive pastoral systems, where large numbers of animals are raised on large tracts of land. Goats provide both tangible benefits (e.g., meat and milk for home consumption, cash income from animal and milk sales, manure used as crop fertilizer and fuel, fiber and skins) and intangible benefits (e.g., savings, an insurance against emergencies, cultural, and ceremonial services) (Kosgey and Okeyo 2007; Semakula et al. 2010; Fantahun et al. 2016).

Goats are often found in mixed herds alongside sheep and cattle, and in some instances with camels. Their small body size, flexible feeding habits, and short generation intervals give goats several advantages over other livestock species (Peacock 2005a). The goats complement other livestock in the utilization of available feed resources and provide one of the practical means of using vast areas of natural grassland in areas where crop production is impractical (Rege 1994).

The productivity and adaptation of indigenous goat breeds to the production conditions are, however, confounded by low management standards. This has generally resulted in an assumption that indigenous tropical goats have a low genetic potential for meat and milk production. Breeding plans to help change goat productivity are thus implemented to either replace indigenous breeds with foreign breeds or to cross them with foreign germplasm (Kosgey 2004). Their implementation over time has, however, been unsystematic, resulting in a mosaic of genotypes.

This chapter presents an overview of the present-day indigenous goat breeds, the production systems under which they are raised, key constraints to their productivity and some opportunities for change that could positively impact the livelihoods of communities rearing goats in EA.

3.2 An Overview of Goat Production on Eastern Africa

3.2.1 Goat Population and Distribution

The EA countries have approximately 997 million livestock, comprising cattle (163,664,570), chicken (537,290,000), goats (145,829,697), pigs (3,889,841), sheep (129,340,766), and camels (17,049,695) (FAOSTATS 2014), with a human population in the region of 360 million (World Bank 2017). The total number of goats in the region comprises 14% of the livestock population. The number of goats in the region has greatly increased since 1961, when the region was estimated to have a population of 45 million heads (FAOSTATS 2014).

The number and distribution of goat populations in the EA region by country are illustrated in Fig. 3.1. Sudan and Ethiopia have the largest number of indigenous goats, with 31 and 29 million goats, respectively, followed by Kenya with approximately 25 million goats. The country with the lowest number of goats in the region is Comoros, with only 122,000 animals.

3.2.2 Main Products

In most of the EA countries, goats are raised primarily for meat production with milk as a secondary product (Olivier et al. 2005). The use of goat products at rural household levels in the region is generally not fully documented; it is however well noted that goat product sales and consumption enhance household food and nutritional security and income stability within the different communities. A large number of goat products flow through the informal markets (Lebbie 2004).

Out of the total 373 million tons of meat and 2.0 billion tons of fresh milk produced in EA in 2013, 40 million tons of meat (9.5% of the total meat

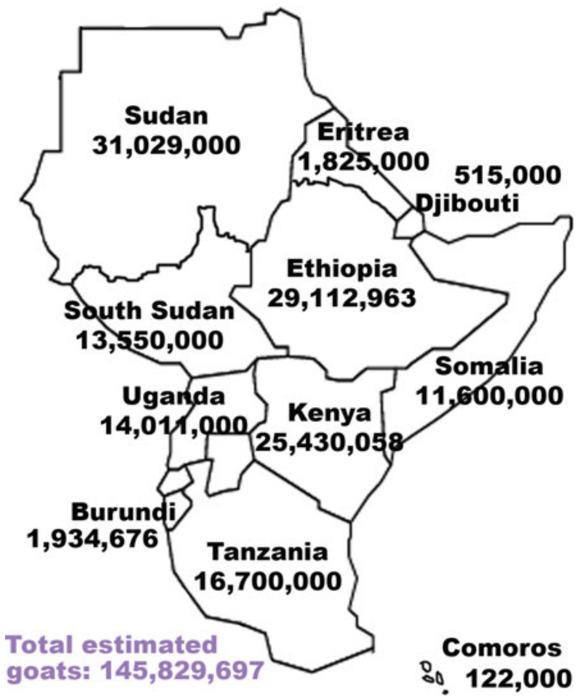

Fig. 3.1 Number and distribution of goats by country in Eastern Africa according to FAOSTATS (2014) data

Table 3.1 Total goat meat, milk, and skins in tons produced from indigenous goats of Eastern Africa in 2013

Country	Goat meat	Milk	Fresh skins
Burundi	39,000	ND	9800
Djibouti	2452	ND	48,800
Eritrea	612,000	920,000	72,000
Ethiopia	74,000	5,900,000	ND
Kenya	5,792,800	26,854,300	1,225,000
Rwanda	1,695,300	3,000,000	165,500
South Sudan	4,500,000	46,500,000	ND
Sudan	11,500,000	110,500,000	ND
Uganda	3,750,000	ND	800,000
Tanzania	3,780,000	11,060,000	787,500
Total	39,598,100	206,522,300	31,795

ND No data
Source FAOSTATS (2014) accessed January 2017

production) and 207 million tons of milk (10% of the total Eastern African milk production) were, respectively, produced by goats, Table 3.1 (FAOSTATS 2014).

In the growing urban areas of EA, there has been a notable increase in the consumption of goat meat over time (Lebbie 2004). Goat meat is lean and low in saturated fat (Banskalieva et al. 2000), making it attractive to the higher income health-conscious consumers. In pastoral communities, meat from animals slaughtered for household consumption that is not consumed immediately is salted and dried to prolong its shelf life.

Goat milk, because it contains smaller fat globules and has a lower lactic acid and total solids content (Jandal 1996) is more readily digestible by infants, immune-compromised, and elderly people. Goat milk and milk products are used either to produce gourmet items in specialty stores, or for subsistence living (Degen 2007). In most farming systems of EA, milk produced by goats is consumed at the household and community level.

3.3 The Origin of Present-Day Goat Genetic Resources of Eastern Africa and Threats to Their Continued Existence

Present-day domestic African goat breeds, *Capra hircus*, are descendants of the wild bezoar goat, *Capra aegagrus*, believed to have been domesticated in the Fertile Crescent in the Near East approximately 10,000–11,000 years ago (Zeuner 1963; Mason 1984; Davis 1993; Zeder and Hesse 2000; Luikart et al. 2001). The domestication and subsequent dispersal of goats into Africa are well documented (Pereira et al. 2008; Gifford-Gonzalez and Hanotte 2011; Zeder 2011). Goats first appeared in the eastern Sahara and Red Sea Hills approximately 7000 BP (Newman

1995; Hassan 2000). These goats were then rapidly dispersed reaching northern Africa between 7000 and 6000 BP, central Sahara and the Ethiopian highlands by 6500 and 5000 BP, respectively (Newman 1995; Clutton-Brock 2000), and following later migrations, they reached southern Africa (Smith 1992).

Subsequent to domestication, migration, and dispersal of livestock in Africa, the livestock keepers in the different regions of the continent have selected and bred animals to meet their particular needs (Gifford-Gonzalez and Hanotte 2011). This process has resulted in breed types with a diverse gene combination and characteristics that have enabled the animals to cope with and survive in a wide range of environments under different management systems (Chenyambuga et al. 2004; Tesfaye 2004). A strong drive to increase the productivity of livestock populations across the EA region, however, has led to several changes in management practices of goats in different environments. These changes influence the use of breeds across systems, in many cases, narrowing the range of indigenous breeds used. The failure to have characterized and determined the merits of different indigenous breeds may threaten their longer term survival in the region.

From the 1980s, programs involving the use of goats have been undertaken in EA to address the challenges of food insecurity, rural poverty, and under-nutrition within farming communities (Kosgey 2004). Most programs, however, used crossbreeding of the indigenous flocks with introduced foreign breeds. Results from several goat improvement projects such as the integrated small ruminant livestock project (ISLP) supported by German Agency for Technical Cooperation (GTZ) and the FARM-Africa Dairy goat project in Kenya, Tanzania, and Uganda (Peacock 2008), and the Kenya Dual Purpose Goat (Mugambi et al. 2007) illustrate benefits accruable through targeted crossbreeding and selection. The small scale of the projects however restricted the expanded use of improved animals across the region. As the projects ended, the practice of crossbreeding to change productivity was retained. The crossing of different breed combinations of animals has been practiced in an unplanned and uncontrolled manner (FAO 2007; Semakula et al. 2010).

Unplanned crossbreeding, often aimed at upgrading existing animals toward more productive foreign breed types has yielded mixed results across the production systems. In the extensive pastoral production systems, upgraded animals only thrive when environmental conditions are favorable, and are the first to die when environments deteriorate. The upgraded animals are generally less resilient and are unable to cope with the limited water and feed supply, hence soon dwindle in numbers. In the smallholder mixed crop–livestock systems, improved bucks are normally very few within a community. Since the animal's graze in the same communal areas, and the bucks are retained over long periods of time (up to 4 years) (Semakula et al. 2010), inbreeding is bound to have set in the populations. Lack of performance and pedigree records, and monitoring of the systems hinders the analysis and documentation of trends in practices and threats to the different populations.

Changing climatic conditions across the globe have greatly affected the availability of livestock feed resources, prevalence of diseases and parasites, and the ecosystems under which animals are raised. Adaptive links between breeds and the production environments are rapidly changing (FAO 2015). The vulnerability of different goat breeds within EA to climate change is not well understood; hence, adaptive measures are not in place. Statistics on the actual changes in herd structure and the dynamics of these changes among the production systems are not available. The prolonged and more frequent severe droughts and disease outbreaks, however, result in the loss of a large number of livestock in the vast arid areas of EA, often without a ready source of replacement animals. Where the systems host diverse goat breed types, conservation measures are required to retain the diversity of the breeds that best match the environmental conditions.

Conservation of diverse indigenous goat breeds is also important for the livelihoods of the communities who keep and are identified with them (Mwai et al. 2015). Communities which are the custodians of these breeds must be facilitated to effectively participate in their conservation and improvement efforts for such programs to be sustainable. Indigenous knowledge, innovations, and practices that enhance the management of the ecosystems under which the goats are reared while improving the livelihoods of the livestock keepers also need to be conserved. Unfortunately, indigenous knowledge systems, largely due to the fast-changing socioeconomic practices, values, and lifestyles, are being lost much faster than the indigenous genetic resources themselves.

3.4 Goat Production Systems in Eastern Africa

Goats are raised under a variety of production systems in the region (Table 3.2). These include smallholder mixed crop–livestock systems, smallholder intensive systems, extensive pastoral and transhumance systems, and large-scale ranching systems. Key differences between the systems and in the management practices adopted are outlined below.

3.4.1 Smallholder Mixed Crop–Livestock Systems

These production systems are often found in areas of medium to high potential for arable agricultural production. Sizes of land owned are normally small (less than five acres), and the human population densities are high. These systems provide food and nutritional security for low-income households, providing up to 80% of the household food requirements.

The farmers raise a small number of goats alongside other livestock species which include poultry, pigs, and cattle, while growing crops. Husbandry conditions for managing goats are minimal with low inputs, and decisions on management differ depending on the communities (Kosgey and Okeyo 2007; Kebede et al. 2012).

Table 3.2 Distribution, main characteristics, and management of the main goat types of Eastern Africa

Breed (local names where available are indicated in brackets)		Country	Distribution within Eastern Africa	Main characteristics and products (in order of importance)	Production system	References
1. Short-eared small-horned						
1.1 Small East African						
1. Western Highland (Agew) Photo: ILRI		Somali Ethiopia Eritrea	Western Ethiopian Highlands	A tall bearded white or fawn colored goat with long hair, concave facial profile, and straight backward facing horns. Mainly used for milk, meat, and skins	Smallholder mixed crop farming systems	ESGPIP (2009) FARM-Africa (1996)
2. Western Lowland (Gumez, Shankela) Photo: ILRI		Ethiopia Sudan	Western Ethiopian Highlands	A short bearded, white or fawn colored goat with a straight facial profile, short smooth coat, and straight backward facing horns Mainly used for milk, meat, and skins	Kept by pastoral and agropastoral communities	ESGPIP (2009) FARM-Africa (1996)
3. Central highland (Brown goat, Kaye, Maefur) Photo: ILRI		Ethiopia Eritrea	Central Ethiopia Highlands Southern Eritrea	A tall bearded red-brown goat with a straight facial profile, backward-pointing horns and a short and smooth coat. Mainly used for milk and skins	Kept by smallholder farmers. Animals freely graze; seasonal confinement during crop production	ESGPIP (2009) FARM-Africa (1996)

(continued)

Table 3.2 (continued)

Breed (local names where available are indicated in brackets)		Country	Distribution within Eastern Africa	Main characteristics and products (in order of importance)	Production system	References
4. Keffa Photo: ILRI		Ethiopia	Most parts of Ethiopia	A short bearded brown or black goat with a straight profile, straight backward facing horns, short pricked ears, and coarse or hairy coat. Mainly used for milk, meat, blood and skins	Maintained in small flocks	ESGPIP (2009) FARM-Africa (1996)
5. Sudanese hill goat (Southern Sudanese, Nuba Mountain, Ingessana, Latuka-Bari, Nilotic, Yei, Toposa, and Dinka) Photo: provided courtesy of Y. A. Hassan		Sudan South Sudan	Northeastern, Central, and South Sudan	A small goat with a straight or concave profile, a small head, twisted horns, medium length pendulous ears, and a slender body. Mainly used for meat	Maintained in arid and semiarid environments; management system is pastoral and agropastoral	ESGPIP (2009) FARM-Africa (1996) Wilson (1991)
6. Small East African (East African Dwarf, Sebei Karamoja, and Tanzania) Photo: ILRI		Kenya Uganda Tanzania	Found in a wide range of arid and semiarid environments	A small-horned goat with short fine hair and variable coat color. Some males have a short mane that extends down the back and flanks. Mainly used for meat and skins	Maintained in agropastoral environments. Animals graze freely except during the cropping seasons when they are tethered	Epstein (1971) Wilson and Murayi (1989) FARM-Africa (1996) Wilson (1991) Chenyambuga et al. (2012)

(continued)

Table 3.2 (continued)

Breed (local names where available are indicated in brackets)		Country	Distribution within Eastern Africa	Main characteristics and products (in order of importance)	Production system	References
7. Mubende Photo: provided courtesy of D. Kugonza		Uganda	Semi-humid highland regions of Uganda	A black-bearded goat with short fine hair, short horns and short to medium pricked ears. Mainly used for meat	Maintained in agropastoral environments. Animals graze freely except during the cropping seasons when they are tethered	Sacker and Trail (1966) Wilson (1991)
8. Rwanda–Burundi (Chèvre Commune, Chèvre Locale, Long-hair, and Short-hair)		Rwanda Burundi Uganda Tanzania	Rwanda, Burundi, southern Uganda, and extreme west Tanzania	A small bearded goat with long horns, short to medium ears, rounded chest, variable coat color, and well-proportioned legs. Males have a topknot and a mane that extends down the length of the back. Mainly used for meat	Maintained in small flocks within pastoral and agropastoral systems	FARM-Africa (1996) Wilson (1991)
9. Kigezi Photo: ILRI		Rwanda Uganda	Southwest Uganda and Rwanda	A small gray or black horned goat with long shiny hair and a convex facial profile. The ears are pricked and are short to medium in length. Mainly used for meat	Maintained in small flocks within pastoral systems	Wilson (1991)

(continued)

Table 3.2 (continued)

Breed (local names where available are indicated in brackets)		Country	Distribution within Eastern Africa	Main characteristics and products (in order of importance)	Production system	References
1.2. Somali						
10. Short-eared Somali (Denghier, Deghiyer, Ogaden, Modugh, Mudugh, and Gala)		Somali Ethiopia Eritrea Sudan Kenya	Ogaden in Somalia Ethiopia	A small white and bearded goat with straight and upward pointing horns. Mainly used for milk, meat, and skins	Maintained in large mixed herds of cattle, sheep and goats. Management is mainly grazing with seasonal migration in search of pasture	FARM-Africa (1996) Muigai et al. (2016)
11. Long-eared Somali (large-white, Degheir, Galla, Digodi, Melebo, and Boran)		Somalia Ethiopia Kenya Eritrea	Somalia, northern Kenya, Ethiopia Eritrea	A large bearded white goat with a straight facial profile and curved backward-pointing horns and horizontal semi-pendulous ears. Mainly used for milk, meat, and skins	Maintained in large mixed herds of cattle, sheep, and goats. Management is mainly grazing with seasonal migration in search of pasture	FARM-Africa (1996) Muigai et al. (2016)
12. Somali Arab goat (Ogaden, Galla, Modugh, and Mudugh) Photo: ILRI/S. MacMillan		Somalia Djibouti Kenya	Ogaden in Somalia, Djibouti Northern Kenya	A white colored bearded goat with short hair, straight upward pointing horns, and a straight facial profile. Mainly used for meat and skins	Owned by pastoralists and agropastoralists. Management system is mainly grazing with seasonal migration in search of pasture	FARM-Africa (1996) Muigai et al. (2016)

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Table 3.2 (continued)

Breed (local names where available are indicated in brackets)		Country	Distribution within Eastern Africa	Main characteristics and products (in order of importance)	Production system	References
1.3 Ethiopian Rift Valley family						
13. Arsi-Bale (Arsi, Gishe, Sidama, Manta, and Awarch)		Ethiopa Eritrea Djibouti	Distributed in the Arsi and Bale provinces of Ethiopia	A tall bearded white, black, or brown colored goat with long and semi-pendulous ears, a medium to large body, and backward-pointing straight or curved horns. Mainly used for milk, meat, and skins	Kept in small flocks in mixed or agropastoral farming systems	Wilson and Murayi (1989) FARM-Africa (1996) Banerjee et al. (2000)
14. Afar (Adal, Assaorta, Denakil, and Abyssinian short-eared) Photo: ILRI		Ethiopia Eritrea Djibouti	Ethiopia Eritrea Djibouti	A multicolored goat with short fine hair, medium length ears, and long (45 cm) straight horns that point straight or backward in males or scimitar-shaped in females. Males are bearded. Mainly used for milk, meat, and skins	Maintained in semiarid and arid environments; management system is nomadic and transhumant pastoral	Wilson and Murayi (1989) FARM-Africa (1996) Banerjee et al. (2000)
15. Woyto-Guji (Woyto, Guji, and Konso)		Ethiopia	Around the River Omo Southern Ethiopia	A horned, brown, black, or red colored goat with a shiny smooth coat and black or brown stripes on the back-line, underside or frontline of the legs	Maintained in pastoralist environments	Wilson and Murayi (1989) FARM-Africa (1996) Banerjee et al. (2000)

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Table 3.2 (continued)

Breed (local names where available are indicated in brackets)		Country	Distribution within Eastern Africa	Main characteristics and products (in order of importance)	Production system	References
				and a small concave or convex head. Males are bearded. Mainly used for milk, meat, and skins		
16. Abergelle Photo: ILRI		Ethiopia	Northern Ethiopian province of Tigray	A medium sized goat with a concave or convex facial profile with patchy or spotted coat, spiral or straight horns that point backward. The males are bearded. Mainly used for milk and skins	Maintained in mixed farming and agropastoral systems	Wilson and Murayi (1989) FARM-Africa (1996) Banerjee et al. (2000)
17. Worre (Tseada, Arab, Melege, Bilena, Boggos, Hamasen, and Asaorta) Photo: ILRI		Ethiopia Eritrea	Northern, central, eastern, and northern Eritrea	A small goat with short legs, a concave facial profile, straight or curved backward-pointing horns and beards in males. The coat has short smooth hair that is pied or white and brown in color. Mainly used for milk and skins	Maintained in a pastoral and transhumance system	Wilson and Murayi (1989) FARM-Africa (1996) Banerjee et al. (2000)

(continued)

Table 3.2 (continued)

Breed (local names where available are indicated in brackets)		Country	Distribution within Eastern Africa	Main characteristics and products (in order of importance)	Production system	References
2. Short-eared twisted horn						
2.1 West African twisted horn						
18. Sahelian (Sahel, West African, long-legged, Desert, and Sudan)		Sudan	Northern parts of Sudan around Darfur and western Kordofan	A large-bearded goat with long horns, a fine head, straight profile, a flat forehead, short neck, and short, thin straight back legs. The withers are prominent and coat color is varied (white to black) and the males have long manes that extend down the back. Mainly used for meat	Maintained in the arid northern Sudan regions in pastoralist and transhumance environments	FARM-Africa (1996) Wilson (1991)
3. Lop-eared goats						
3.1 Nubian						
19. Nubian (Sudanese Nubian, Shukria, Sciucria, Langae, Hassen, Beladi, and Bledi) Photo: provided courtesy of Y. A. Hassan		South Sudan	Northern Sudan, western Eritrea, and northwestern Ethiopia	A horned, bearded goat with a distinctly convex head and a black hairy coat. Mainly used for milk and skins	Maintained in very dry regions of northern Sudan in pastoral production systems and the agropastoral and agricultural production systems along the River Nile	Wilson (1991)

(continued)

Table 3.2 (continued)

Breed (local names where available are indicated in brackets)		Country	Distribution within Eastern Africa	Main characteristics and products (in order of importance)	Production system	References
20. Barka (Bellenay, Beni-Amer) Photo: ILRI		Eritrea	Southwestern Eritrea Northern Ethiopia	A bearded and horned white goat with a straight facial profile, and long pendulous ears. Mainly used for milk and skins	Maintained in pastoral production systems	FARM-Africa (1996) Wilson (1991)
21. Zaghawa		Sudan	North and northwestern Darfur Chad Eritrea	These are large animals with a flat facial profile. Both sexes bear long twisted horns. The ears are pendulous and are very long. Beards are present in both sexes, with the beards in the males being exceptionally bushy. The coat color is white, black, or gray. Mainly used for meat	They are raised as part of a mixed flock containing Zaghawa sheep	Wilson (1991)

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Table 3.2 (continued)

Breed (local names where available are indicated in brackets)		Country	Distribution within Eastern Africa	Main characteristics and products (in order of importance)	Production system	References
3.2 North African lop-eared						
22. Sudan Desert (Sudanese Desert) Photo: provided courtesy of Y. A. Hassan		Sudan	Northern regions of Sudan (Darfur) Eritrea	A large gray horned and bearded goat with a straight head profile, long drooping ears and a black stripe extending down the back. The neck and back are short, withers prominent, coat short and fine, and legs are long and bony. Males have manes that extend down the back. Mainly used for milk and skins	Maintained by pastoralists in nomadic and transhumance systems	Mason and Maule (1960) Wilson (1991)
3.3 East African lop-eared						
23. Benadir (Bimal, Cherre, and Tuni)		Somalia Ethiop	Southern Somalia Eastern Ethiopia	A white goat with short smooth hair, a large head with a straight profile and small, and backward-pointing horns. They have long legs. Mainly used for milk and meat	The goat is maintained in pastoral and agropastoral environments	Mason and Maule (1960)

The goats reared in these systems comprise a mixture of indigenous breed types and some crosses with exotic breeds (Kosgey 2004). Goats are often left to scavenge for feed resources on the periphery of crop enterprises and along public roadsides. During the non-cropping seasons, the goats graze freely on land owned by households and consume the crop residues left while dropping manure which fertilizes the soil. While during the cropping season, the goats are herded around the crops fields or in extreme situations tethered, with occasional supplemental forages provided.

3.4.2 Smallholder Intensive Systems

The rapid expansion of cities and towns coupled with the increase in demand for livestock products have resulted in an increase in the keeping of livestock, including goats, close to and within urban settlements on very small land sizes (less than a quarter of an acre). In these systems, goats are confined in stalls and grasses are cut and carried to them for feed. They are fed on natural pastures, some planted fodders, and crop residues from other farmers, and in some cases, commercial feeds are provided as feed supplements.

The goats reared in these systems are kept more for production of milk and meat for sale, hence their owners attach a higher value to their productive attributes. The goat breeds may be foreign/imported, indigenous or crossbreds between foreign and indigenous breeds, depending on the location. This type of production system is emerging and may be unique to various parts of EA.

3.4.3 Extensive Pastoral and Transhumance Systems

Extensive pastoral and transhumance systems are mainly found in the arid and semiarid areas of EA. These areas are generally of low potential for arable agricultural production and livestock are the main source of livelihood for the communities who live in these areas. These systems occupy up to 50% of the total land in EA (Kosgey et al. 2008). In both pastoral and transhumance systems, goats are reared in large numbers usually as part of a mixed herd that also comprises cattle, sheep, and camels. The livestock keepers use their traditional knowledge to optimally manage their herds and migrate with their herds in response to changes in the weather, vegetation and water resources. Animals are grazed on communally owned land and are moved from one area to another in search of pastures.

In the transhumance systems, pastoral livestock keepers are more sedentary and coexist with crop farmers using a management system that allows them to graze their animals in the fields of crop farmers after crops have been harvested. Manure from the animals is beneficial for crop production in the next cropping season.

Goat flocks are generally comprised of indigenous breeds, with a high number of female animals relative to male animals. Some communities regularly castrate young male animals that are not earmarked for breeding (Fantahun et al. 2016). However, in some pastoral communities castration of male animals is not carried out because the livestock keepers make selection decisions depending on the phenotypic characteristics of mature animals. The pastoralists also claim that entire male animals grow faster and cope with extreme conditions better than those that are castrated. These practices contribute to large variations in the characteristics of animals within flocks because the male animals, when mature, randomly mate with females in the flocks (Kosgey 2004; Semakula et al. 2010; Fantahun et al. 2016). Random and uncontrolled mating results in kids being born throughout the year with variable survival rates depending on the season of birth.

Goat productivity and offtake rates from pastoral and transhumance systems are low because animal growth rates are slow, taking up to 3 years to reach maturity. Inadequate nutrition, diseases, parasites, and challenging climatic conditions with frequent and prolonged droughts negatively influence enhanced productivity (Lebbie and Manzini 1989; Lebbie 2004; Fantahun et al. 2016).

3.4.4 Large-Scale Ranching Systems

The large-scale ranching systems comprise a small, but very important, segment of the goat production in EA. These systems are characterized by large pieces of land, owned by government, individuals, or private organizations on which different species of animals are reared on both natural and planted pastures.

Locally adopted foreign breeds of goats such as Toggenberg, German Alpine, Anglo-Nubian, and Saanen, indigenous goat breeds and crossbreds of imported X indigenous breeds of goats are kept for milk, meat, and skin production. The animals are kept in open sheds and are allowed to graze freely; however, reproduction is carefully monitored and mating is carried out in a planned manner. The systems provide a source of replacement animals for the small-scale intensive systems.

3.5 Crossbreeding Goats for Dairy Production

The raising of crossbred goats for dairy production has been practiced in Burundi, Ethiopia, Kenya, Uganda, and Tanzania through both government and private sector-led programs from the early 1980s. These programs were conceived initially as a way of reducing poverty and improving the nutrition and health of women and children and later as a mechanism for improving the dairy productivity of select indigenous goat breeds such as the Galla, Somali, and Small East African, using imported breeds such as Toggenberg, German Alpine, Anglo-Nubian, and Saanen breeds.

The various crossbreeding programs implemented have resulted in a mosaic of crossbred goats with varying levels of imported genes (Bradford 1981; Ruvuna et al. 1992; Das et al. 1996). In Tanzania, for example, a “blended” goat was developed for milk and meat production through crossing indigenous breeds with the Galla from Kenya, and the Boer from South Africa (Shirima 2005); in Ethiopia, a dairy goat was developed from crossing the Anglo-Nubian with indigenous breeds (Ayalew et al. 2003); while in Kenya, several dairy goats breeds have been developed including the Kenya Dual Purpose goat which was developed by crossing Toggenburg, Anglo-Nubian, Small East African, and Galla breeds in equal proportions (Bett et al. 2007; Mugambi et al. 2007).

The crossbred dairy goats offer an attractive investment because on average they produce higher quantities of milk than the indigenous goats, thus providing smallholder farmers with an important source of cash income (Omore et al. 2004; Shirima 2005; Bett et al. 2009). Milk production followed by sale of breeding stock encourage smallholder livestock keepers to raise dairy goats (Jaitner et al. 2001; Krause 2005; Bett et al. 2007, 2009). Goats for milk production are also important for women in the communities. In EA, women do not exercise control over large animals such as cattle and camels, but are able to own and manage of small animals including goats, sheep, and chicken in smallholder systems (Sinn et al. 1999; Ojango et al. 2016). The women generate income through the sale of goat milk and breeding animals; hence, they are able to meet their household food security needs, educate their children, and pay for any health needs of their household members (Peacock 2005a; FAO 2011).

3.6 Present-Day Goat Breeds of Eastern Africa

The indigenous goats of EA are mainly classified into three main groups: the short-eared small-horned, short-eared twisted horn, and lop-eared goats.

3.6.1 Short-Eared Small-Horned Goat

The short-eared small-horned goats comprise the Small East African family, Somali family, and Ethiopian Rift Valley family. The Small East African family of goats comprises nine indigenous breeds namely, Western Highland, Western Lowland, Central highland, Keffa, Sudanese Hill Goat, Small East African, Mubende, Rwanda–Burundi, and Kigezi. These goats are believed to have descended from the Somali Arab goats found in Somalia (FARM-Africa 1996). This breed is among the most widely distributed and is found inhabiting a wide range of environments in Eritrea, Ethiopia, South Sudan, Kenya, Uganda, Rwanda, Burundi, and Tanzania.

3.6.2 The Somali Goat Family

The Somali goats are divided into three subgroups, namely, the short-eared Somali, the long-eared Somali, and the Somali Arab (FARM-Africa 1996). The main products from the Somali family of goats are meat, milk, skins, and live animal exports. The Somali goats are widely milked by the pastoralists. The milk is either consumed fresh, made into butter or ghee for food and medicinal purposes. Some communities prefer to keep the Somali long-eared goat over the Somali short-eared goat because it produces more milk (Muigai et al. 2016). The Somali family of goats play an important role in the cultural lives of these ethnic communities (FARM-Africa 1996; Muigai et al. 2016).

Livestock is the main export earner for Somalia accounting for 40% of the country's gross domestic product (FAOSTATS 2015). In 2014, Somalia exported a record five million live cattle, sheep, and goats, with sheep and goats accounting for 92% (4.6 million) of total exports (FAOSTATS 2015). The estimated value of the export of sheep and goats from Somalia in 2011 was estimated to be over USD 200 million per annum (Somaliland Chamber of Commerce 2013). The sheep and goats are mainly exported out of the port of Berbera and Bossaso, with the Kingdom of Saudi Arabia taking up 70% of the exports (ADB 2010).

In addition to export, the critical role played by trading of small ruminants within domestic markets in providing employment of the local population, especially of women involved in selling of milk and meat has been documented (Marshall et al. 2014; Wanyoike et al. 2014; Muigai et al. 2016). The sheep and goats are trekked or trucked to various livestock markets located throughout Somalia. Traders involved in the export trade converge at these markets to select animals for export. These traders physically select animals bearing specific body condition and character traits. This selection process over a long time has resulted in the improvement and development of the Somali goat and market demands and trends have led to the breeding of animals that have very uniform body characteristics (FAOSTATS 2015).

3.6.3 Ethiopian Rift Valley Goat family

The Ethiopian Rift Valley family comprises several breeds of goats namely Arsi-Bale, Afar, Woyto-Guji, Abergelle, and Worre (FARM-Africa 1996). They are believed to be from the Rift Valley goat that is thought to have entered Ethiopia from Yemen and Saudi Arabia (FARM-Africa 1996). These goats are owned and kept by indigenous peoples of the Horn of Africa who maintain them in their regions. Milk is one of the main products that are produced by these goats. The goats are usually milked once a day for two to four months during the lactation period. The milk is sold to neighbors, and any extra is consumed by the households. The milk is consumed fresh or made into other products such as sour milk, butter, ghee or yogurt. The milk products are also considered to have medicinal value. Sour milk mixed with garlic, for example, is used as a traditional treatment for measles and butter is used to treat eye infections and as massage oil among the ethnic tribes located in the Horn of Africa.

3.6.4 Short-Eared Twisted Horn Goat

The West African twisted horn goat comprises several breed types; however in EA, only the Sahelian breed is found. The West African twisted horn goats are thought to have originated from the Middle East and migrated southward into the Sudan region *via* Egypt. The Sahelian, also known as Sahel West African long-legged Desert Sudan goat, is found in the dry northern parts of Sudan around Darfur and western Kordofan. It is also found in parts of Eritrea (Wilson 1991).

3.6.5 Lop-Eared Goats

These goats comprise the Nubian, Barka, and Zaghawa breeds. They are thought to have originated in the Middle East and migrated southward into EA *via* Egypt. They are found in the northern Sudan, western Eritrea, and northwestern Ethiopia, and are owned mainly by the Hedareb and Nara ethnic groups who are mainly pastoralists (Wilson 1991).

3.6.6 East African Lop-Eared Goat

This goat breed is thought to have originated in the Middle East and migrated southward into EA *via* Egypt. They are found in the northern Sudan, western Eritrea, northwestern Ethiopia. The main characteristic of these animals are the long pendulous ears that average 16 cm in length with pointed tips. These goats are mainly kept for milk and are the main milk producing breed in Somalia. Live goats and skins from these animals are main export commodities for Somalia.

3.7 Key Constraints and Opportunities to Improving Goat Productivity in Eastern Africa

3.7.1 Constraints

Key constraints to improving goat productivity within the farming systems of EA that are reported in the literature are outlined as follows.

Management practices: Livestock keepers in rural communities tend to adopt low-input agricultural practices due to low household incomes. Investments in goat production tend to be limited and the animals are generally left to the forces of nature to determine their performance levels. In many areas, overgrazing of communal lands, environmental degradation, overstocking, and exploitation of the fragile ecosystems is evident. The net result is poor animal management, poor feeding, inappropriate breeding practices, and inadequate adoption of proper animal health practices. The practice of free-range grazing with no supplementation in times of scarcity leads to slow growth rates.

Recording of performance of goats within the farming systems is limited. The livestock keepers use subjective criteria to select animals to retain depending on their breeding goals. In pastoral and smallholder farming systems, a high emphasis is placed on morphological characteristics when selecting bucks to be used for breeding. However, as the animals are herded in communal areas, mating is random, resulting in high rates of inbreeding in the goat populations.

Long-term negative selection practices are also observed whereby faster-growing animals are taken to the markets for sale at an earlier age.

Choice of genotypes to rear in different production systems: Information on the diversity of breed types available, and the expected performance level within the different environments found across the EA region is variably available. Goat producers seeking to improve the productivity of their flocks rely on information generated from animals reared on government research stations, or from information on animals introduced through development projects. Often such information may be misleading because of the observed genotype by environment interaction effects (Mwacharo et al. 2009). Availability of new breeds and desired breeding stock is often a challenge (Ahuya et al. 2005; Peacock 2005a). Crossbreeding is used to introduce and multiply improved breeds, however, the level of foreign breeds to which the indigenous breeds need to be upgraded to so as to achieve optimum production (both milk and meat) and adaptability in the herds remains elusive as this fluctuates randomly depending on the breeding acumen of the individual farmer.

Weak support services for goat production: Veterinary care and extension services for goat production are limited in many countries. Investments in services and technologies to support goat production in EA are inhibited by the low financial capacity of those who rear goats. Investments are not seen to yield rapid capital gains as the largest proportion of the goat population is found on the arid lands where livestock production practices are strongly tied to cultures, which restrict external inputs. Facilities for handling goats and goat products for sale are also inadequate as they are often adapted from cattle handling facilities.

Inadequate policies and market infrastructure: Supporting and enabling policies for sustainable management of goat genetic resources, and the marketing of goat products through fair commodity pricing from the producer level to the final consumer are generally nonexistent. Where policies exist, their implementation is often limited. In most arid areas, marketing of goats is highly influenced by middle-level actors that restrict direct access of livestock keepers to markets where they could receive better prices for their products. There are no grading systems that would provide incentive for quality goat products. A lack of infrastructure development in the arid areas further exacerbates the challenge as animals need to be available in reasonably large numbers in order to make it economical for buyers to transport animals.

Strong market chains for goat and goat products are yet to be developed in EA: Due to policy constraints, it is only since the 1990s that goat milk and its products have been recognized as wholesome saleable dairy products and marketed in more formal outlets in the various countries of EA (Peacock 2005b; Ahuya et al. 2005). Most milk produced for sale in formal markets is from the smallholder farming systems. However, for the smallholder farmers to reap the full benefits of dairy goat farming, value addition needs to be a component of the production system.

Limited capacity development: Research and development of technologies for goat production has limited the growth of sustainable models for goat breed production and development. Except for Ethiopia and Kenya, appropriately designed goat improvement and marketing programs are lacking. In Somalia, while there exists an organized export market system, programs to support long-term improvement at herd and community levels are lacking.

Socioeconomic factors in communities: In many of the farming systems, particularly in the arid areas, those who look after the animals on a daily basis are not the owners or the key decision-makers when it comes to purchase, sale, or management of the goats (Verbeek et al. 2007). Women in many pastoral communities do not have a strong voice in influencing decisions on selective mating in the goat flocks. They also do not have much control of incomes received from the sale of goats and their products. With a better understanding of the implications of the mating decisions on the quality of animals in the flocks, and the effects of inbreeding on the goat population, it could be possible to implement selective breeding within pastoral flocks. Under the more intensive smallholder farming systems, women play a key role in decision-making, often as a legacy of the projects that introduced improved goats to the communities.

3.7.2 Opportunities

Characterization studies on the current goat populations in the EA region as advocated through the two reports on the State of the World Animal Genetic Resources (FAO 2007, 2015) can be undertaken using new and evolving genomic technologies. Both indigenous and improved lines of goats raised in the different production systems of EA need to be evaluated in relation to their socioeconomic value, fiscal constraints, responsiveness to indigenous knowledge, and improved management within the given environment. Information generated will guide the development of innovative breeding strategies for goat production in different farming systems of EA.

The absence of precise estimates of genetic parameters and response to selection that would be possible through the use of large datasets greatly hinders goat breeding in EA countries. Quantitative methodologies as a guide to developing more productive and resilient composite goat breeds for low-input production systems remain unexploited. Advances in information technology and emerging genomic technologies and platforms now exist which if innovatively and jointly applied would significantly fast-track goat improvement and marketing. This would allow goat producers and traders to extract sustainable and profitable gains from goat production. Current and emerging information systems can support the generation of data on goat production from the different systems in paperless formats for use in breeding and monitoring programs. Researchers and innovators in the goat production sector of countries in EA need to develop and adapt relevant data capture, analysis, and feedback information tools to facilitate this.

Using genomic technologies, more precise crossbreeding programs can now be designed and implemented in a way that can optimize the combined genetic attributes of the indigenous and the foreign breeds without threatening the former, by developing stable composite breeds over much shorter time period than before (Rege et al. 2011). Also, gains through genomic aided selective breeding can achieve much higher gains over shorter periods than in the past thus offering new opportunities (Shrestha and Fahmy 2007). Smallholders need to continuously adopt breeding animals with sufficient genetic merit to improve the efficiency of their target product.

Organized group actions and community based breeding programs need to be supported to change the *status quo* (Mueller 2006; Haile et al. 2011; Mueller et al. 2015). Through groups, livestock keepers can organize breeding services for their animals, bulking of products to achieve better market prices, improved input supplies, and can seek technical support and training on ways of improving the productive efficiency of their flocks (Peacock 2005a).

Rearing goats also provide a source of employment for rural women, men, and youth in different communities. The marketing and sale of goat products also provide them with employment and a source of income.

In sedentary farming systems, goats contribute to the cycling of nutrients through their feeding, whereby they utilize crop residues and other farm by-products such as spoiled grains, vegetable, and root crops and transform them into high-value commodities. The manure produced by the goats is used as an organic fertilizer for maintaining and improving agricultural crop production. This is an important contribution since these farmers have low access to fertilizers and those who do find the cost prohibitive. Goats are thus a beneficial asset for smallholder farming communities.

3.8 Concluding Remarks

The rapid growth in numbers of goats in the EA region illustrates their ability to adapt and multiply within the harsh environmental conditions. There is, however, need for careful monitoring of the growing goat population in view of potential negative impacts of large animal numbers on limited areas of fragile land. Breeding strategies need to be developed and implemented for goat populations raised under the diverse production systems of EA in order to enhance the livelihoods of communities raising goats and reduce the environmental footprint of goats in fragile ecosystems.

Facilities for handling and adding value to goat products would make a significant difference in the marketing and pricing of goats and goat products from arid areas of EA.

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Chapter 4
Socio-Economic Aspects of Goat Farming in Arid Environments. The Example of Turkey

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Abstract Livestock is important in supporting the livelihoods of farmers, consumers, traders and laborers in developed but particularly in developing world. Recently, the international community recognizes the importance of livestock in terms of poverty reduction and economic opportunities. Despite its potential importance to sustainable economic growth and poverty reduction, livestock sector development has received limited attention from the international organizations and national governments in recent decades. On the other hand, some research have showed that goat production plays a crucial role in the lives of large number of people in the Mediterranean region. Thus, goat rearing is an essential element of their farming system. In some countries like Turkey, rural women carry out a primary role in goat production. However, women's productive work has been ignored and underestimated. Goat production can play an important role in improving rural livelihoods. Commercialization, another important aspect related to goat productions, should be improved to achieve a higher profitability of smallholder production systems. In this chapter, the social and economic aspects as well as gender issues involved in the goat production in Turkey, as an example of a typical arid environments, are described.

4.1 Introduction

A general conception is that the main objective of animal science research and technology development must be directed towards competitiveness and sustainable productivity. This would mean that economically efficient production systems must be consistent with the optimum use of resources, particularly in sensitive environments with complex ecological balances. In fact, animal science and technology

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must be linked more directly to the society's benefits increasing its competitive position in an increasingly globalized food-market and shrinking research funding availability. In this context, it is imperative that public institutions be aware that the ultimate beneficiary of research is the consumer. The maintenance of a competitive market-oriented and highly technological and commercial agricultural sector is, thus, thought to be of vital importance to ensure a sustained food supply for a rapidly expanding population. This does not minimize the importance of the traditional and small holder sector of the industry; on the contrary, it is really of great interest in the Mediterranean region and worwilde. Benefit of these farmers and food-safe products are assured because they receive the correct incentives, training and support to improve the sustainability and efficiency of their operations. Thus, they will not be a burden in the next future for the regional economy (Boyazoglu 2002).

Regarding animal production, it is well known that goats are considered as "the animal of the poor" or, by comparison with cattle, the "cow of the poor". Many projects have been implemented in all continents; besides, we have observed that goat has been the most growing livestock for more than 20 years (FAO 2011).

Indigenous goats have important socio-economic roles in the livelihood strategies of the poor farmers, especially those in rural and hard-to-reach areas of arid environments, such as Turkey, and many areas in Africa, Asia and Latin America. Those roles include their use as savings, insurance, security, accumulation and diversification of assets, and social and cultural functions as well. They are also valued for their productive performance, adaptation and disease resistance. Other attributes that make them favorable to pastoral production include the small body size, therefore requiring lower nutrient levels for survival than other livestock animals. They are also suitable for subsistence systems because they produce meat and other products in small readily usable quantities (Indetie et al. 1998).

Households are often forced to enter sharecropping agreements and face consumption and income shocks (Abiassi 2002). In addition, the rural families do not have the financial support to participate under the present "savings before credit" conditions to access to money credits. This scenario leads to low investment in agricultural activities, low productivity, low income, and consequently a vicious cycle of poverty and environmental degradation (Igue et al. 2000; Manyong and Houndekon 2000). In these situations, where formal financial and insurance institutions are absent, small ruminants are "easy to cash" assets. Small ruminants are also important in a diversification strategy that aims to reduce market and climatic risks and optimize the use of available resources (Valdivia and Nolan 1996).

Women usually make essential contributions to the agricultural and rural economies in developing countries. Their roles vary considerably between and within regions and are changing rapidly in many parts of the world, where economic and social forces are transforming the agricultural sector. Rural women often manage complex households and pursue multiple livelihood strategies. Their activities typically include producing agricultural crops, tending animals, processing and preparing food, working for wages in agricultural or other rural enterprises, collecting fuel and water, engaging in trade and marketing, caring for family members and maintaining their homes. Many of these activities are not defined as "economically active employment" in national accounts but they are essential to the wellbeing of rural households (FAO 2011).

In addition, in rural areas of developing countries, livestock is the backbone of the agriculture sector and animal husbandry is in general considered as a job of women (Ahmad 2014). Animal keeping is an integral part of rural life and is considered a pathway for women empowerment. Rural women play a key role in livestock management. However, it is often argued that their contribution is undermined, underestimated and their decision making power are highly limited (Malik et al. 2015).

4.2 Goat Farming Systems in Turkey

The goat production systems are very diverse. In Turkey, a large majority of goats is still managed under pastoral systems with local breeds well adapted to local conditions. These herds are generally very traditional, out of organized markets. They often face the rural decline of the mountainous areas but these production systems have generally been resilient and have contributed significantly to the survival and food safety of marginal poor populations without many other sources of income. These production systems have often enabled local typical products such as cheeses, fermented milks or meats. Meanwhile since 50 years, controlled production systems and breeds have been improved mainly for milk production with a high performance. Although the size of this sector is very small, their performances have reached the same levels than for the dairy cow sector but also with the same negative externalities (Dubeuf 2014).

Goats are often related with cereal production (grazing of fallow) and lands suitable for cultivation of shrub (macchia), bush land and forest areas. Goat management is linked to systems of natural resources. These natural or artificial feed resources are not equally distributed in the region. Because of the geomorphological and climatic conditions of the region the animals are exploited mainly under extensive management systems. In these extensive systems, the aim is to obtaining limited production at the lowest possible cost by using well adapted native goats, which can optimize the limited environmental conditions. Thus, the aim is not to provide maximum production, but to exploit rearing animals in unsuitable areas for cultivation, shrub, bushland and forest areas. These aspects are also related with socio-economic contribution to poor farmers rearing goats, outstanding in different productive traits such as milk, meat, hair, leather, etc. (Güney et al. 2007).

Nomadic and transhumance systems are very popular in the Mediterranean and east Anatolian regions of Turkey. However, the increasing adoption of modern production systems has resulted in declines in the nomadic system, while transhumance is also being replaced by sedentary systems. These two systems are very traditional, with each family member having an active role in goat and sheep management. Animal health and feeding systems are very primitive, and the economic and social status of these farmers are usually very poor. They process milk into cheeses using traditional methods and selling the cheese directly at local markets or to local traders. Traditional cultural heritage is important in both systems, and farmers try to maintain ancient immigration routes and cultural values (Daskiran and Koluman 2014).

Generally, extensive goat husbandry is either at a fixed location or linked to the migratory movements of these herders. In this region transhumance system is mostly used, which implies the seasonal movements suited for grazing between lowlands and upper lands (mountains). Flocks of goats move from mountains (summer) to transition area or plains for grazing in autumn and winter. Transhumance is practiced in these areas where the quality of the pasturage varies during different seasons of the year. Nevertheless, in many parts of the Mediterranean region farmers are moving to sedentary production system. Migration patterns in the region partly depend on available natural resources, tribal politics of several indigenous groups deciding the different ecosystems to be exploited and the time for their use. Migration routes and the composition of herds may vary depending on the vegetation and farmers' policies. Goat products provide self-sufficiency for the keepers' families, when the land is of poor quality and crop cultivation is often difficult and constrained by several environmental factors such as rainfall, very high temperature and poor soil fertility. Diversification in farming is a difficult task to attain; however, integration of goat production to the system would make significant contribution to poor farmers and the stability of small farm systems. It is evident that goat husbandry/pastoralism will continue to be important for the food producing system in the 21st century throughout the world (Güney et al. 2007).

4.3 Socio-Economic Aspects of Goat Farming

Goat production has been unique source of family livelihood especially in mountainous area. They do not have any other alternatives because of land structure, infrastructure and economic conditions. Main income of families is based on goat and sheep production. Additionally, they sell live animals in order to obtain cash. Goats are removed from the farms only when it is necessary to meet family needs, especially in case of emergencies.

In the field, goats spend the days in higher zones between Spring and Winter (nomadic system). According to Darcan (2006), almost 81% (162/200) of flocks are housed in winter time. Most of the farms are managed by the owners' families; particularly women and daughters are responsible of the flock. Male teenager helps their mothers, holding goats in milking time, among other activities. Few males (12%; 24/200) take part in goat production. Thus, the common business type in the region is the family one.

4.3.1 The Role of Rural Women

Women have heavy responsibilities in agricultural activities from production to consumption. In the United States, like in Canada, women make unspecialized works like to elaborate butter, cheese, in charge of dairying or vegetable gardens, and were generally self-sufficient (Shortall 2000). Thus, this latter author as well as Pinchbeck (1981) have detailed the different works that women carried out in England in the 18th century: from field work to harvesting and husbandry to dairying, describing the different roles and different social classes identifying dairying as most important and productive branch of women's work in agriculture at that time. It was such responsible work that on all but the largest farms, the mistress supervised dairy maids through every stage of the business and performed most of operations herself. The dairy woman was not only concerned with the actual making of butter and cheese. The farmer depended on the advice of the dairy women on the sales and purchases of stock. In addition, the rearing, feeding and sales of calves were entrusted to her (Shortall 2000).

The attitude of young women attending farm animals, the prospect of living in a farming household, or their attitude to the new roles were examined by Gidarakou (1999) in Greece. The findings indicate that the girls' attitude to farm employment remains extremely negative. Their attitude in relation to work and place of residence are characterized by strong inclinations to move to urban or semi-urban areas. Their attitude to the prospect of having a farmer as a husband is more flexible, but only on certain conditions. The participation of women in the agricultural sector is perceived as low income occupations, which can be seen only as a temporary expedient, acceptable as an answer to the employment problem (Gidarakou 1999).

4.3.2 The Turkish Women in the Goat Sector

Women were main component/element/carrier in goat production as well as in rural life in Mediterranean region of Turkey (Fig. 4.1). They have been seen as helper most of the time. Actually, they perform productive, familiar and community roles without interruption. Women are not aware of their fundamental status in rural lives and they define their job as a housewife while they are main component in productive activities. They accept every situation as it is, even currently. Main reason to explain this is the low educational status and patriarchal structure that subordinate women.

In a study reported by Davran et al. (2007), in Turkish mountain area, women worked an average 12.6 h a day (except crop production activities and seasonal working) when their productive, familiar and community roles were considered. This study remarked how long a normal working day is for many women, which is also observed in the developing world. Division of labors is usually unfavorable for women, having secondary status in the society. Beside it, in the worst conditions

Fig. 4.1 Farming activities carried out by rural women in small goat farms, Turkey. Photographs provided by N. Koluman (Darcan)

women do not have access to technology, education or other basic standards in the poorest rural places. In these conditions, illiterate women rate in total illiterate people is about 66%. However, labor constrains differ not only from one country to another but also from region to region. This is due to household size, socio-economic situation, ecology or religious, among other factors.

According to Sinn et al. (1999), many women in the developing world, work an average of 12–16 h a day. Nevertheless, they own less than 1% of the world's land despite the fact than in some developing countries more than half the households are headed by woman. There are still many women who manage the same resources and do not have control over the income. Even men and women farm side by side throughout the day, planting and harvesting crops, but the small ruminants are typically the primary responsibility of women and children.

According the survey reported by Darcan (2006), the Turkish woman and elder daughters are responsible of goat management in the majority of farms (90%). Sometimes, either elder boys or men help women only at milking time, holding the animal. The common distribution of daily labor of women in Turkey and their families is summarized in Table 4.1. According to obtained data, 42% of women are uneducated, while 14% are graduated from primary school. Only 12.5% of women (ages range between 20 and 25 years old) hold an University degree. About 85.5% (171/200) of the women attending goats in their farms participate in other agricultural activities in the farms.

Daily milking periods depend mainly on the flock size and milk yields of the goats, which are milked twice a day by adult and young women. Average milking periods are reported as 3.2 h a day. The grazing periods are the most time consuming daily activity of the women and their daughters. Sometimes girls and boys in a joint activity move the herds for grazing in areas normally close to their villages. The goat farming is forbidden in forest area in Turkey. Some farmers and their wives take the grass from the field for feeding their animals at stable. This activity is usually carried out by women and children as well.

Milk processing is commonly responsibility of women and elder daughter in the farms. Different kinds of cheese (white, tulum, lor and çökelek), yoghurt, butter, or cream are the main products derived from goat milk in the country. Farmers' families consume an average of 25% of the whole milk. The rest of the milk (75%) is sold preferibly as traditional-made cheese, by which they obtain more profit. After milking procedures, they ferment the fresh milk (without boiling) for cheese production. They use rather commercial yeast, and seldom traditional home-made

Table 4.1 Labor distribution of turkish women and their families (Darcan 2006)

Annual labor distribution (%)	Woman	Man	Man and woman	Daughters	Boys	Shepherd
Milking	56.3	12.4	5.7	22.7	2.9	–
Grazed to animals	16.9	28.2	14.1	15.9	–	24.9
Cleaning ruminant barn	52.0	17.0	–	19.0	12.0	–

Daily labor distribution	Frequency (%)	Labor distribution	Average (hours/day)
Crop production and animal husbandry	57.5	Milking to goats	3.2
Crop production (exclusive)	18.1	Cleaning to barn	1.5
Animal husbandry (exclusive)	21.6	Grazed their animals	4.5
Others (tailor, worker in the fabric and weaver of carpets)	2.8	Carrying fodder	1.5
		Others	2.0

Table 4.2 Zoonotic and work-related diseases in Turkish women

Type of illness	Frequency (%)
Pain in body	52.5
Parasitic diseases	41.2
Abortions	11.3
Brucella melitensis infection	22.5

More than one disease can affect to the same woman (Darcan 2006)

yeast. Some women who live in especially mountainous area, obtain their own yeast at home. Only, in a few regions, cheese fermentation is still done by traditional methods (e.g., into a skin or bury into ground).

As seen in Table 4.1, women and elder daughters are responsible of all business related to livestock, although men or boys can cooperate in some business. Some families hire a shepherd especially in summertime to attend the animals in highlands (36.3%). The mean wage of the shepherds ranges between 12 and 15 USD daily.

However, work-related diseases can appear in women, which are not commonly studied. Prevalence of these diseases in Turkey is summarized in Table 4.2. The most common zoonotic diseases are internal and external parasitosis, but also brucellosis, abortions or body pain related to working activities appear in women. Even in advanced pregnancy stages women continue doing their daily works, reason by which abortions can occur. The fact that cheese is made using raw milk increases the likelihood to acquire brucellosis by *Brucella melitensis*. Concerning decision making structures, 76% of women decide to some management procedures such as weaning time, feeding time or milking time. Men decide vaccination against the illness, selling animals and products. Sometimes men farmers decide to ask a veterinarian (3%) for any vaccination programme for their animals. The economic power of property ownership belongs to men, who decide the price, amount and salary. Women is not usually involved in this decision making process (Darcan 2006).

4.4 Concluding Remarks

Increasing family income, financial independence while overcoming financial bottlenecks within the rural goat keepers are the obvious benefits expected from keeping goats by household members. Women and elder teenagers are more inclined towards goats than men due to an easy management of the goat flocks. A cultural bias against sheep in some ethnic groups should also be considered in Turkey.

Given that goat production is essential for some regions, future perspectives can include the use of local goat breeds improved with more productive breeds. At this way, people living in marginalized areas, especially in mountain areas, would have higher income and further business opportunities.

The future development of livestock farming systems in Turkey in term of intensive systems will largely depend on the application of modern management strategies, especially for planning and monitoring functions together with political and financial adjustments.

The potential of goats as an effective and feasible way of enhancing livelihoods of the Mediterranean region is still under-exploited. The identification of constraints to goat productivity and the inclusion of women in the development of need-based technologies and training programs are key factors in an effort to achieve the improvement of goat production, the increase of food security, and the enhance of rural livelihoods.

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Part II
Reproductive Strategies and Genetic Improvement

Chapter 5
Reproductive Strategies for Goat Production in Adverse Environments

Alejo Menchaca and Rodolfo Ungerfeld

Abstract Reproductive patterns in goats can be artificially manipulated by different strategies based in the control of endocrine system by the exogenous administration of hormonal compounds, or by manipulation of specific environmental factors. This chapter summarizes the main information on the possible on-farm applications of low cost-demanding techniques, as well as on advanced reproductive technologies that have greater impact on goat production systems. The recent improvement in the knowledge and manipulation of ovarian follicular dynamics in goats is the basis for the development of novel pharmacological protocols for fixed-time artificial insemination with which high pregnancy rate without estrus detection can be achieved. Alternatively, social-environmental factors can be managed to induce ovulations in anestrous; e.g., the male effect, female effect, or light control regimens, which require estrus detection or natural mating. In addition, the chapter updates the knowledge on advanced reproductive technologies related to superovulation for in vivo-derived embryos and to follicular aspiration for in vitro-produced embryos. Both technologies have been strongly improved in the last years and currently may be applied in farm conditions with positive results. Altogether, these strategies conform a complete toolbox for the management of goat production in different conditions, offering one tool for each need.

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5.1 Introduction

In mammals, reproductive patterns are consequence of the interaction of the endogenous regulatory mechanisms—mainly endocrine—and environmental signals. In farm animals, these patterns can be artificially manipulated by different strategies based on the control of the endocrine system by: (1) the exogenous administration of hormonal compounds, or (2) manipulation of particular environmental factors. Thus in both cases, the objective is to induce specific hormonal mechanisms to control sexual activity, testicular function, sperm production, follicular dynamics, luteal function, ovulation, embryo development, and/or pregnancy establishment and maintenance. Farmers and technicians adopt these strategies to improve reproductive efficiency, herd propagation, and genetic improvement.

This chapter summarizes the main information of low cost-demanding techniques that may be applied in farm conditions, which are simple and easy to use, and effective to improve reproductive outcomes even under adverse environments. In addition, an update in some advanced reproductive technologies is also included as their adoption may have great impact on goat production systems.

5.2 Seasonal Reproductive Pattern

Most goat breeds have a seasonal reproductive pattern (Chemineau et al. 1988; Malpaux et al. 1999). This means that females ovulate and come into estrus in limited periods of the year (the breeding season), and thus, the birth period is limited to some months after that season. In males, the greatest reproductive activity is achieved during summer–early autumn, when light time duration decreases. At the beginning of the breeding season, gonadotropin and testosterone concentration reach maximum concentrations, and semen quality is better than during the rest of the year (Chemineau et al. 1992; Chemineau and Delgadillo 1993). This also limits the natural ability of bucks to fertilize females that may come into estrus outside that period of the year.

The seasonal pattern adjusts the reproductive changes to the environmental conditions. Therefore, births occur in the period of the year when there is more available food, when climate is better, and thus, the probability of the offspring to survive is greater (Lincoln and Short 1980; Bronson 1989). The main regulator of seasonality is photoperiod variation and absolute day length (see review: Zerbe et al. 2012); thus, the seasonal pattern is related to the place in which each breed evolved. Those breeds that evolved closer to the Equator line have less seasonal changes in photoperiod, and thus display a longer period of cyclic activity along the year. This also means that those animals respond easily to artificial managements that aim to modify their basic seasonal reproductive pattern than animals from breeds that evolved in high latitudes (Bronson 1989). Therefore, it is important to know not only the basic physiological pattern of the species, but also the breed pattern and its specific origin.

Despite this natural limitation, farmers commonly need to their does to come into estrus and become pregnant according to productive periods. For example, dairy farmers need to produce and supply milk continuously throughout the year, or meat farmers receive in many countries better prices if they offer kid meat in the periods in which the market has limited offer. For this, there are several options that can be used to induce or stimulate reproductive activity in different times of the year, mainly based on exogenous hormonal treatments or challenging the physiological activity of the animals. Many treatments combine both strategies. It is also possible to use the breeding season length, or even the response to estrus stimulating treatments to select less seasonal animals, and thus have less seasonal flocks (Vincent et al. 2000; Notter 2001). Although this option is interesting to include in genetic improvement programs, it requires long periods to achieve significant changes.

5.3 Ovarian Follicular Growth Pattern

Ovarian antral follicles larger than 2 mm grow in a wave-like pattern, a phenomenon that has important implications for the control of goat reproduction (Rubianes and Menchaca 2003; Menchaca and Rubianes 2004). Follicular waves are characterized by a group or cohort of follicles that are recruited simultaneously and are visible on the ovary by ultrasonography at 2–3 mm in diameter (emergence). One of these follicles (or occasionally two in goats)—named the selected (dominant) follicle—continues growing while the rest go to atresia (selection). This dominant follicle grows during 3–6 days until reaching preovulatory size. If this happens during the last wave of the estrous cycle (ovulatory wave) ovulation occurs; or on the contrary, in non-ovulatory waves, the largest follicle regresses and goes to atresia losing its dominance (regression). After the largest follicle reaches its maximum diameter (and thus, ovulate or regress) and lose its dominance, a new cohort of follicles is recruited and a new follicular wave emerges (follicular turnover).

Most goats have four follicular waves during the estrous cycle, with a wide range from two to five waves per cycle. On average, the first follicular wave emerges the day of ovulation (Day 0 of the ovulatory cycle) and the following waves emerge at variable time during the estrous cycle. In goats, like other ruminants, follicular waves occur not only during the estrous cycle, but also during the anestrus and pregnancy (Rubianes and Menchaca 2003). The follicular emergence and turnover depend on follicle-stimulating hormone (FSH) and luteinizing hormone (LH) support, which is also influenced by other ovarian and metabolic hormones. In goats, as in other ruminants, there is an increase in plasma FSH concentrations before the emergence of each wave (Medan et al. 2005). Most of the information related to follicular dynamics has been demonstrated using the cow as an experimental model, and although the general mechanisms probably are similar between ruminants, some species-specific differences deserve further investigation. In general in ruminants, the dominant follicle produces steroidal and nonsteroidal products (inhibin, follistatin, activin, and other growth promoting and inhibiting factors) that act systemically, locally, or both to suppress the development of the subordinate follicles and prevent the emergence of a new follicular wave. This suppression acts both, via inhibition of plasma gonadotropin concentrations and reducing the follicular sensitivity to FSH. Initial growing follicles have FSH receptors in the granulosa cells; however, when FSH declines only the dominant follicle synthetizes receptors for LH in the granulosa cells. Only those follicles that are able to grow under low concentrations of circulating FSH continue growing. This shift from FSH- to LH-dependency allows the dominant follicle to grow until achieving the preovulatory size and, eventually, ovulate. At the same time, ovarian steroids progesterone and estradiol influence the secretion of LH. In the absence of progesterone (i.e., during the follicular phase), the LH pulse frequency increases and consequently, the dominant follicle grows more than 1 mm per day, releasing estradiol that promotes LH secretion, a positive feedback that ends in the preovulatory LH surge and ovulation. On the other hand, under high progesterone levels (i.e., during luteal phase or pregnancy), and also during the anestrus period, LH pulse frequency decreases and gonadotropin support of the dominant follicle is not enough to maintain preovulatory growth. The lack of this support leads to loss of steroidogenic ability and functional dominance of the dominant follicle, driving it to regression and finally atresia. Simultaneously, with the loss of the steroidogenic ability and the fall of estradiol and inhibin production, FSH is released again and thus, a new follicular wave emerges.

The knowledge on follicular dynamics, the influence of gonadotropins and steroid hormones, and how to manipulate them, are the key factors for effective ovarian control. Most of the reproductive technologies and hormonal protocols for estrus synchronization in farm animals were modified during the last years based on the manipulation of the follicular dynamics.

5.4 Pharmacological Control of the Ovarian Function

5.4.1 Protocols for Fixed-Time Artificial Insemination

One of the aims in estrous cycle manipulation is to synchronize the ovulations among different animals to inseminate them during a short period, even without estrus detection and achieving high pregnancy rates. The elimination of estrus detection avoids important time and extra labor, which historically was a limiting factor for the massive adoption of artificial insemination. Nowadays, fixed-time artificial insemination (FTAI) is probably the assisted reproductive technology most widely used in cows, ewes, and does, offering an excellent opportunity for rapid genetic improvement by an intensive use of artificial insemination. This technology is simple, easy to apply in farm conditions, non-expensive, and effective in terms of pregnancy rate.

There are several pharmacological alternatives to control the ovarian function and thus, apply FTAI. For that, the ideal protocol should control follicular dynamics, luteal function, and ovulation achieving the following goals:

- First, the treatment should induce follicular turnover and the emergence of a new follicular wave some days before the end of the treatment, in order to offer a young large follicle and healthy oocyte for ovulation;
- Second, a priming of progesterone exposure is required during some days before estrus and ovulation, mainly in anestrous females, to provoke appropriate pre-ovulatory and postovulatory conditions;
- Third, in cyclic females luteolysis must be ensured at the end of exogenous progesterone exposure period;
- Fourth, after estrus, LH surge and ovulation must be induced in a very short window period;
- Finally, to ensure pregnancy establishment and maintenance, the synchronization protocol should allow appropriate postovulatory conditions related to luteal function, uterine environment, and embryo development.

Thus, it is strongly important to control all these conditions to achieve acceptable pregnancy rates with FTAI, avoiding estrus detection.

Hormonal treatments currently available for FTAI produce predictable results as they depend more on the treatment itself than on the physiological status of the animal. Obviously, this does not mean that all animals will respond adequately, but the protocols recently developed control effectively the ovarian status. In general, the nutritional status, the period of the year (close or far from the natural onset of the breeding season), and the seasonal pattern of the breed would also affect the response.

Traditional treatments used some decades ago included a progestogen treatment to provoke an artificial luteal phase during 18–21 or 10–12 days followed by the administration of gonadotrophins, usually equine Chorionic Gonadotrophin (eCG or PMSG acronym). These treatments were designed in goats in the 1970s and 1980s mimicking the basic endocrine pattern of an estrous cycle (Corteel 1975; Corteel et al. 1988). After the knowledge in follicular dynamics generated by ultrasonographic studies in the 1990s and 2000s, treatments for FTAI were modified in cows, ewes, and does. Traditional long progesterone priming (e.g., 10 or 20 days) can induce insufficient concentrations of progesterone at the end of treatment. For this reason, from the 2000s, the recommended treatments in small ruminants are based in shorter treatments of 5–7 days of progestogen/progesterone priming (so named Short-term protocols) associated with prostaglandin $F_{2\alpha}$($PGF_{2\alpha}$) and eCG at device removal.

The Short-term protocols have been well characterized in sheep and goats (Menchaca and Rubianes 2004). The insertion of an intravaginal device containing progesterone induces high serum progesterone concentrations that promote the regression of the largest follicle ($\sim$5–7 mm) and the emergence of a new follicular wave synchronized in time in different animals. Serum progesterone concentrations are maintained high during 5–7 days, and thus, at the time of device removal a young and growing large follicle (e.g., ~5 mm) is present and continues growing until ovulation. One dose of $PGF_{2\alpha}$ and 200–500 IU eCG are given at device removal to induce luteolysis and final preovulatory follicular growth, respectively. The onset of the estrus is synchronized approximately 30 h later, preovulatory LH surge occurs at 40 h, and ovulation occurs 60–70 h after device removal. Cervical or intrauterine insemination is performed 54 h after device removal (i.e., some hours before ovulation). Pregnancy diagnosis can be performed by transrectal or transabdominal ultasonography from 30 or 45 days after insemination, respectively, and pregnancy rates range from 50 to 70% (Menchaca and Rubianes 2007).

5.4.2 Conventional Treatments for Estrus Detection

The development of new protocols for FTAI has several advantages for the control of reproduction and genetic improvement programs in livestock, particularly in goats. However, conventional treatments for estrus detection and insemination are still commonly used by farmers. In this case, the objective is to induce or synchronize the estrus in a shorter period than a normal estrous cycle, requiring estrus detection and insemination. Progesterone or its analogs are administered impregnated into intravaginal devices or by intramuscular injection during variables periods.

Progestogens exposure may be applied during 18–20 days (Moore and Eppleston 1979), but shorter progesterone treatments are also effective as it was explained in the previous section for FTAI. During the nonbreeding season, animals should also be treated with eCG, and in cyclic females the administration of a luteolytic dose of PGF2α is mandatory. Estrus behavior is recorded during 3–4 days after the end of the hormonal treatment, and insemination is performed 12–18 h after the estrus onset. In this case, estrous behavior should be controlled twice daily, and females detected in heat in the morning are inseminated in the evening, and those detected in heat in the evening are inseminated in the following morning. The final pregnancy rate is similar to that obtained with FTAI, with extra demanding labor for estrus detection and herd management.

As an alternative to the use of progestogens-based treatments, estrus synchronization may be achieved by inducing luteolysis with PGF2α analogs. The administration of one dose of this hormone during the luteal phase induces luteal regression in goats. As a consequence, progesterone concentrations decrease sharply, LH pulse frequency increases, the preovulatory follicle increases its growth rate secreting estradiol 17β, which induces estrus behavior within 4–5 days after the treatment. In cycling females, a single dose of PGF2α synchronizes estrus in 60–70% of the animals, but the females that are in the early luteal phase do not respond as they are refractory to PGF2α. Therefore, after estrus detection and insemination, a second dose of PGF2α is given to those females that did not respond to the first one; this second dose is followed by estrus detection during other additional 4 days. In this scheme, estrus detection is required during at least 8 days. An alternative to reduce the working days is to administer two doses of PGF2α to all females separated 11–14 days apart, and record estrus behavior only after the second dose, shortening the estrus detection period to approximately 4 days. As follicular development is not controlled, all these treatments require estrus detection, and thus, obtaining a less synchronized response.

The dispersion in estrus behavior is related to the status of the dominant follicle when PGF2α is administered. In the case when PGF2α is administered when the dominant follicle of a wave is in the late growing or early static phase, ovulation occurs early. This response is a consequence of the sensitivity of the largest growing follicle that still expresses LH receptors to this hormone, and thus, to its steroidogenic activity that induces estrus behavior and ovulation rapidly. On the other hand, if PGF2α is administered when the dominant follicle is in the mid- to late-static phase (i.e., when it is undergoing atresia), a new follicular wave emerges, and the time needed for the growth of a new preovulatory follicle delays ovulation some hours/days. This mechanism has also been clearly demonstrated in cattle (Kastelic and Ginther 1991) and sheep (Viñoles and Rubianes 1998; Menchaca and Rubianes 2004). As the status of follicular growth cannot be controlled by treatments based on the administration of PGF2α analogs, the dispersion in the interval to estrus and ovulation prevents the use of FTAI.

5.4.3 Other Hormonal Treatments for Reproductive Control

Since goat reproduction is influenced by photoperiod, melatonin has an important role in the control of sexual activity and fertility. This hormone must be administered during long periods to induce a positive effect and usually is given by subcutaneous implants that release melatonin continuously. In consequence, the animal registers the signal as if the daylight has almost disappeared. In general, the reproductive response is highly predictable in both, males and females, but it is evident at least 40–60 days after application of the treatments. The main limitations for the adoption of this strategy are the long delay before triggering a response, the high cost of the implants, and the lack of commercial products available in many countries.

Another interesting strategy is the use of eCG for promoting reproductive activity in males. This hormone joins to both, LH and FSH receptors (Murphy and Martinuk 1991), so it can be also used to induce gonadotrophic effects in the buck. Although there is scarce experience, it stimulates testosterone secretion in rams, and thus, their ability to stimulate ovulation in anestrous ewes (Ungerfeld et al. 2014). It has been recently used experimentally to improve semen production during the nonbreeding season in West African Dwarf bucks (Acevedo et al. 2015), improving also the semen freezability (Viera et al. 2015). However, these results need to be confirmed in other breeds, latitude, and periods of the nonbreeding season before reaching definitive conclusions and practical recommendations.

5.5 Non-pharmacological Strategies

For productive systems in which the main objective is the breeding of the females, in which genetic improvement is not a priority and thus, do not need to include artificial insemination, natural mating is the default breeding system. In these cases, estrus synchronization is not needed during the breeding season for natural mating, but during the anestrous season, estrus and ovulation must be induced to increase kidding/milking production throughout the year. In these cases, estrus and ovulations can be induced without the use of pharmacological strategies, obtaining more dispersed estrus which is not a limitation for natural mating.

5.5.1 Light Regimes

As it was mentioned, photoperiod is the main regulator of seasonality of goat reproduction. Therefore, artificial photoperiod may modify deeply the reproductive activity. Some intensive productive farms use these treatments to induce ovulations and estrus during the nonbreeding season, but are not easy to use in extensive production systems. However, these treatments can be used to stimulate the reproductive activity in males, and then use those bucks to stimulate ovulations in anestrous does, as it has been extensively studied (see review: Delgadillo et al. 2014). These treatments shift the seasonal pattern and then are used to stimulate bucks' libido and improve semen quality during the nonbreeding season. In the chapter of Delgadillo et al. of this book, there is a detailed description of the use of these treatments.

5.5.2 Socio-Sexual Stimulation

The introduction of males (the buck effect) induces an increase in the pulsatile secretion of LH in ewes and does (see review: Walkden-Brown et al. 1999), which may end with a LH surge followed by ovulation (Ott et al. 1980). Goats that ovulated did it 2.2 (Saanen: Chemineau et al. 1986) to 2.8 (Creole: Chemineau 1983) days after the introduction of the bucks. This ovulation is associated with estrus, but in most does is followed by a short ovarian cycle (5–7 days); afterward there occurs a second ovulation also associated with estrus that is followed by a normal luteal phase (Walkden-Brown et al. 1999).

The buck effect is effectively used in combination with photoperiodic treatments (Gateff et al. 2003). The continuous presence of bucks also stimulates female reproductive activity: Restall (1992) reported an early onset and later end of the breeding season in does that were in continuous or intermittent contact with bucks. Administration of a single injection of progesterone to all females when bucks are introduced prevents the appearance of short luteal phases and increases the percentage of does ovulating and coming into estrus during the first days (González-Bulnes et al. 2006). Intravaginal devices impregnated in progesterone or progestogens can also be used to hamper the short luteal phases (Alvarez et al. 2013).

The number of does that ovulates is greater when they are stimulated by bucks than with only buck's odor, and more does ovulate after full than after fence line contact with bucks, demonstrating that several signals from males act synergistically to stimulate ovulation (Shelton 1980; Walkden-Brown et al. 1993a).

Contact of anestrous does with does in estrus also induces ovulation and heat in an important percentage of the noncyclic females without the need of males (Alvarez et al. 1999; Walkden-Brown et al. 1993b). Walkden-Brown et al. (1993b) reported that the percentage of does ovulating in the presence of estrus does was similar to that registered in presence of estrus does and bucks, or bucks that had been in contact with estrus does during the previous days. Therefore, according to Walkden-Brown et al. (1993b), the presence of estrus does trigger the maximum response of anestrous does. However, more experimental data are needed to obtain definitive conclusions as other researchers did not obtain any response to estrus does (Véliz et al. 2002; Hogan et al. 2004). Moreover, Alvarez et al. (2001) observed a low percentage of does ovulating when they were in close contact with estrus does, but no response in does located in the pens near that of the estrus does.

Does in estrus can stimulate reproductive activity in bucks. Recently Giriboni et al. (2017) reported that the continuous stimulation with estrus does, even through a fence line, improves buck's semen quality throughout the year. Permanent contact with females also advances an earlier reproductive development in kids (Lacuesta et al. 2015). On the other hand, bucks reared isolated from females display a less intensive sexual behavior than those that were reared in contact with females even in their adult life (Lacuesta et al. 2015).

A greater percentage of bucks used determines a greater ovulation rate more than the proportion of does responding (Chemineau 1987). In fact, the ovulation rate increased from 1.8 to 2.6 when the buck:doe ratio increased from 1:15 to 1:3. As the reproductive activity of bucks is depressed during the nonbreeding season, at least in some conditions a low number of does responds or even no response is obtained outside the breeding season if bucks' sexual activity is not previously stimulated (Flores et al. 2000). As the percentage of females that ovulate increases near 100% if bucks are prestimulated by light + melatonin treatments, these authors consider that the reproductive condition of the buck is the main limiting factor to obtain a high response of anestrous does to the male effect. Also, the nutrition of the bucks may be used to increase their ability to stimulate ovulation in anestrous does; Walkden-Brown et al (1993b) obtained a higher percentage of does ovulating, coming into estrus and conceiving after joining them with bucks that received a high rather a low-quality diet during the previous year.

5.5.3 Female Social Behavior and Reproductive Output

There is a positive relationship between female's social rank and reproductive success in feral goats. For example, high-ranked mountain female goats have a greater kid production than low-ranked does (Côté and Festa-Bianchet 2001). Therefore, social status may affect the response to environmental signals regulating reproduction. Alvarez et al. (2003) observed that high-ranked dairy goats ovulate earlier than low-ranked individuals after the introduction of bucks. However, this result was not confirmed later (Alvarez et al. 2007). After buck introduction, the early increase of LH pulsatility is also greater in high than in low-ranked does (Alvarez et al. 2007), probably as a consequence of a more intensive contact between the former and the males (Alvarez et al. 2003). While in the first report the final number of goats that ovulated and resulted as pregnant was not affected by social status (Alvarez et al. 2003), these authors reported later that the percentage of does that ovulated was greater in high and medium-ranked does than in the low-ranked individuals group (Alvarez et al. 2007). We did not observe any relationship between does' social rank and pregnancy rate or litter size when fixed-time artificial insemination treatments were applied (Ungerfeld et al. 2007). Overall, it seems that more research is needed to determine how and in which conditions hierarchies may affect the response of does to the introduction of bucks.

5.6 Embryo Technologies for Goat Production

Ovarian superstimulation and conventional embryo production, and laparoscopic follicular aspiration and in vitro fertilization, are two technologies developed to maximize the reproductive ability of the females. The objective of both is to increase substantially the number of offspring of a given female. These technologies applied in large-scale programs have more impact in genetic improvement schemes than any other reproductive strategy described previously. However, particular requirements are necessary to implement these technologies.

5.6.1 Superovulation and Conventional Embryo Production

The administration of twice-daily decreasing doses of FSH during 3–4 days promotes the recruitment and growth of antral follicles acquiring the ability to reach ovulation altogether. Females are inseminated some hours before ovulation producing an average of five viable embryos per female donor. The quantity and quality of the embryos produced per female are highly variable and unpredictable, mainly due to the variation in the ovarian response to superstimulation. This is probably the main limiting factor for a wider application of this technology, as it affects both the efficiency and profitability of embryo transfer programs, being sometimes frustrating for technicians and farmers.

The follicular dynamics and the growth status of the largest dominant follicle at time of FSH treatment are the main determinants of the response to superovulation. For example, if the treatment is initiated before selection of the dominant follicle (i.e., at time wave emergence), the number of corpora lutea and embryo yield are greater than if the treatment begins in the presence of a large dominant follicle. Thus, the induction of the emergence of a new follicular wave allows to begin superstimulatory treatments in absence of a large dominant follicle, and thus, increases the number and quality of collected embryos. Similar to what was described for estrus synchronization, traditional treatments for superovulation were developed in the 1970s and 1980s before current knowledge of follicular dynamics, and thus, are being substituted by new protocols with greater promising success (see review: Menchaca et al. 2010). For example, the "Day 0 protocol" initiates the administration of FSH on Day 0 of the cycle, simultaneously with the emergence of the first follicular wave. For this, the same treatments described for FTAI are used to synchronize the ovulation, beginning the administration of FSH 84 h after progesterone device removal (i.e., soon after ovulation). In this superstimulatory protocol, FSH is administered twice daily in six total doses, inserting an intravaginal progesterone device during the FSH treatment. Two PGF2α doses are administered simultaneously with the last two FSH doses, and one dose of GnRH is administered 24 h after device removal. Does are inseminated 16 h after the administration of GnRH, and if frozen semen is used, females should be inseminated again 8 h later.

Embryo collection in goats is a challenging and exciting surgical procedure for veterinary practitioners. As embryos are located in the uterine horns around four days after insemination, embryo recovery is usually performed 6.5–7 days after insemination allowing easily to evaluate morulae and blastocysts quality. The standard technique for uterine flushing and embryo collection requires a minor surgery by laparotomy. For that, general anesthesia should be induced by ketamine and diazepam im, maintaining the surgical plane with isoflurane by inhalator via. The abdominal wall is incised (5 cm long) in the right-paramedian region cranial to the udder to access the reproductive tract, and then each uterine horn is flushed with 35 mL of collecting medium using an 18-gage i.v. catheter inserted next to the utero–tubal junction. The embryos are recovered in the collected medium filling a 90 mm Petri dish using a 9 FG Foley catheter inserted at the external bifurcation of the uterine horns. The collected embryos are morphologically evaluated under a stereomicroscope (40X magnification) and classified according to the criteria recommended by the International Embryo Technologies Society (IETS). Each embryo is classified regarding a quality score that ranges from 1 to 4: Grade 1 is excellent or good, Grade 2 is fair, Grade 3 correspond to poor quality embryos, and Grade 4 are dead or degenerated forms. As better is the quality of the embryos transferred, greater is the pregnancy rate obtained. Only Grade 1 embryos should be frozen or vitrified. This procedure may be repeated monthly in the same female, usually, by not more than three or four times with acceptable results. Fonseca et al. (2016) recently reported promising results with an alternative nonsurgical uterine flushing technique through the cervix.

Embryos are transferred into the uterine horn of recipient goats whose estrous cycle was previously synchronized. The technique requires the use of laparoscopy to examine the ovary so the embryo is transferred into the horn ipsilateral to the corpus luteum. The cranial portion of the horn is exteriorized using an atraumatic forceps through a small incision (1 cm approximately) in the right-paramedian region of the abdominal wall (i.e., 5 cm craneal to the udder). The embryo is loaded into a tomcat catheter, the uterine wall is punctured with a sterilized paperclip, and the embryo is located in the lumen of the uterine horn. One or two embryos may be transferred into the same uterine horn, and the expected pregnancy rate of fresh embryos is 50–60%. The embryos may be frozen maintaining an acceptable viability, allowing then for spatial and temporal dissociation between embryo production and transfer. The cryopreservation technology applied to embryo transfer was absolutely disruptive for international trade of embryos, genetic improvement programs, and animal health campaigns, contributing with the goat production systems in several countries around the world.

5.6.2 Laparoscopic Ovum Pick-up (LOPU) and in Vitro Embryo Production

In small ruminants, laparoscopic ovum pick-up (LOPU) and in vitro embryo production (Fig. 5.1) are currently well-developed technologies for the production of embryos with acceptable outcomes, allowing for the successful application of genetic improvement programs in goats (see review: Cognie et al. 2004). These techniques can also be used for the production of transgenic and genome edited animals in this species for livestock, pharmaceutical and biomedicine application (see review: Menchaca et al. 2016a). The availability of these modern biotechnologies worldwide in more laboratories and in different countries also contribute with local development of goat production in diverse conditions.

The standard method for oocyte retrieval in goats and sheep is the follicular aspiration assisted by laparoscopy (or LOPU). This technique humpers the poor results obtained with the traditional laparotomy technique and allows to repeat the procedure several times in the same female producing offspring from both, adult and prepubertal animals. The technique was firstly described in the 1990s (Tervit et al. 1992; Baldassarre et al. 1994) and is nowadays used in several laboratories. To maximize the number and quality of oocytes collected per donor, the females' estrous cycle should be synchronized and hormonally primed with progesterone and gonadotrophins. Progesterone or progestogen-containing intravaginal devices are applied usually for 9–11 days, together with a luteolytic dose of PGF2α or its

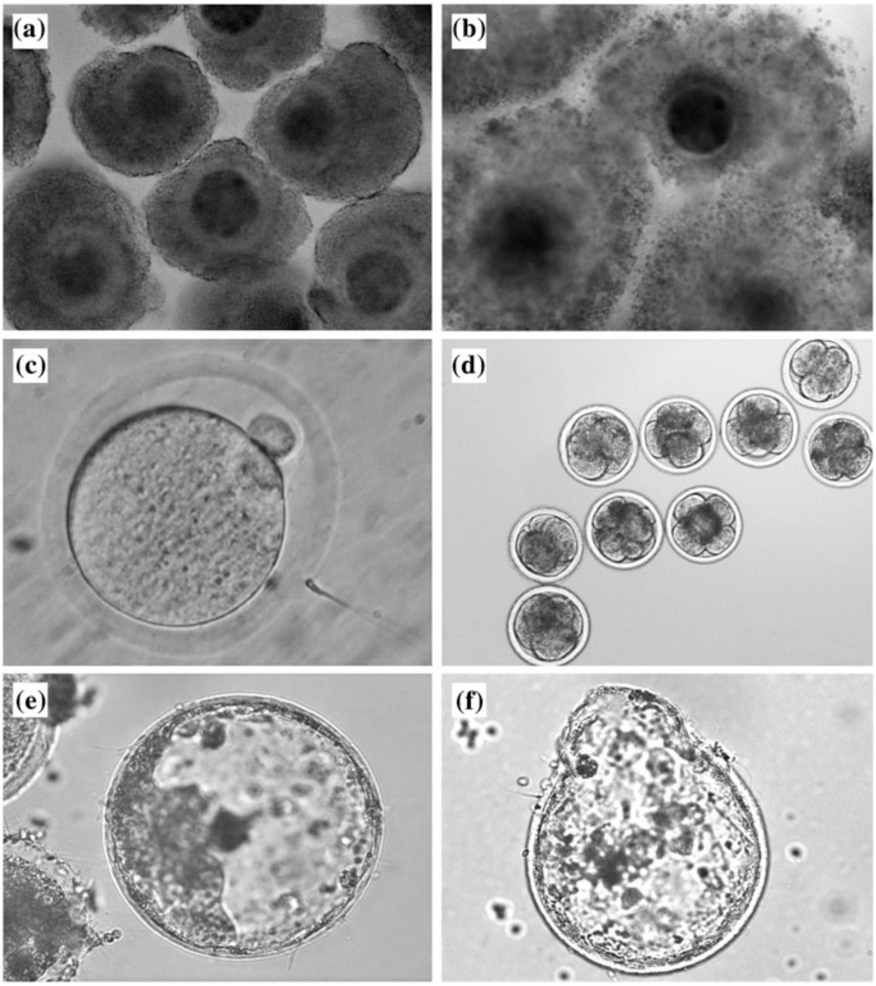

Fig. 5.1 In vitro embryo production in sheep and goats. Immature cumulus oocyte complexes (**a**) are obtained by follicular aspiration performed by laparoscopy or from ovaries collected from slaughterhouse. After in vitro maturation, the oocytes appear surrounded by expanded cumulus cells (**b**) before insemination. In vitro fertilization is performed by the addition of sperm to small drops containing the matured oocytes; picture (**c**) shows a metaphase II oocyte with the first polar body extruded in the perivitelline space and a spermatozoon attached to the zona pellucida. After fertilization, the zygotes are moved to culture medium and cell division begins; picture (**d**) shows four- to eight-cell embryos two days after fertilization. Picture (**e**) shows an expanded blastocyst after 6–7 days of *in vitro* culture ready to transfer to a recipient female (note the thin zona pellucida and the blastocoel surrounded by the inner cell mass and the trophoblast). A hatching blastocyst is shown in picture (**f**) with the rupture of the zona pellucida that usually occurs in the uterus after embryo transfer. Magnification 20X (pictures **a**, **b** and **d**) and 40X (pictures **c**, **e** and **f**). Photographs provided by A. Menchaca

analogs when the gonadotropin treatment begins. There are several treatments to stimulate the follicular growth before LOPU, but the most popular is the "One shot regime", which consists of one FSH and eCG doses administered 36 h before LOPU (Baldassarre et al. 2002). With this protocol, the expected recovery rate is 10–14 oocytes per doe. Females should be anesthetized to lye securely on a laparoscopy table similar to what was described for embryo flushing. The recommended laparoscopy equipment includes a 5 mm, 0° angle telescope, two 5.5 mm trocar/cannula sets (one for the laparoscope and one for the forceps), one 3.5 mm trocar/cannula set for the aspiration pipette; a 5 mm atraumatic grasping forceps; a fiber optic cable; and a light source. The oocyte aspiration set consists of a collection tube with an inlet connected through tubing to the aspiration pipette and an outlet connected through tubing to a vacuum pump. While looking through the laparoscope, the ovarian surface is exposed pulling the fimbria in different directions using the forceps and using the aspiration pipette the follicles are punctured one by one.

Following LOPU, the oocytes are subjected to in vitro maturation (IVM) and in vitro fertilization (IVF) to proceed to in vitro embryo culture, which is conducted following standard operating procedures. Briefly, for IVM the cumulus oocyte complexes (COCs) are evaluated under stereomicroscopy and those COCs of excellent or good quality are incubated in 100 μl drops of IVM specific medium under mineral oil for 24 h at 39 °C in a humidified atmosphere containing 5% CO_2. For IVF, spermatozoa are selected and capacitated using swim-up or percoll gradients, and COCs and sperm are co-incubated in specific media for 18–22 h at 39 °C in a humidified atmosphere containing 5% CO_2. The expected cleavage rate at 48 h ranges from 80 to 90%. After fertilization, in vitro embryo culture of the zygotes is performed using defined media and maintained at 39 °C in 5% O_2, 5% CO_2, and 90% N_2. Expected blastocyst rate under these conditions (number of blastocysts on Day 6 from COCs in IVF) is approximately 30–40% (see review: Menchaca et al. 2016b).

The in vitro-produced embryos are transferred to recipients whose estrous cycle was previously synchronized to be in estrus near the moment of IVM for in vitro-produced zygotes. Usually, the embryos are transferred in blastocyst stage, which is performed 7 days (goats) or 6 days (sheep) after IVF. Conventional slow freezing is not recommended because the in vitro-produced embryos are less cryotolerant than in vivo-derived embryos. Instead, the survival rate of in vitro-produced embryos is greater with vitrification techniques specially developed. Primary results obtained with vitrification by minimum volume methods like Cryotop produced promising results in small ruminants (Morató et al. 2011; dos Santos et al. 2015, 2017). The refinement of these cryopreservation protocols during the following years will surely improve goat embryo cryotolerance promoting the adoption of in vitro embryo technology in this species.

5.7 Final Remarks

Reproductive outcomes in goats managed under particular adverse environments depend on local experience and knowledge for adaptation or validation of technologies commonly used in other conditions. In addition to this species, several local or regional environment factors like photoperiod, food conditions, or dry and rainy seasons influence and/or determine the reproductive behavior and performance. The different available techniques should be considered and applied according to the productive purposes of each farm, region, or country. For this reason, this chapter focused on those technologies that can be easily adapted to different local conditions without high cost-demanding requirements. FTAI is a very simple technology that has a great impact in genetic improvement schemes since it allows massive genetic dissemination in large-scale programs. Artificial insemination may also be applied after estrus detection, requiring more extra labor and management than FTAI. Despite pharmacological treatments are mandatory for FTAI programs, alternative strategies may be used to induce estrus and ovulation for estrus detection or natural mating, which consist of socio-sexual and photoperiod management. The male effect is a useful tool to induce sexual activity in females during seasonal anestrus, an effect that is potentiated by the presence of females in estrus at time of male–female interaction. Furthermore, the manipulation of the photoperiod may be achieved by controlling the light regime for estrus induction to stimulate sexual male activity during the nonbreeding season.

In addition to these low-demanding tools, advanced reproductive technologies like superovulation and embryo transfer, or LOPU and in vitro embryo production can also be used in goats. These embryo technologies require more complexity, particular equipment and facilities, and the technicians require specific training and skills. However, significant improvement has been achieved for embryo technologies during the last years and wider adoption by the farmers is envisioned for the close future.

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Chapter 6
Using Socio-Sexual Stimulations for Sustainable Goat Production Under Subtropical Latitudes

José A. Delgadillo, Philippe Chemineau and Matthieu Keller

Abstract Several goat breeds from subtropical latitudes display seasonal variations of their sexual activity, which induce a seasonality of milk and meat productions. In females, the seasonal anestrous occurs during spring and summer, whereas in males, the sexual rest occurs during winter and spring. This seasonality is mainly controlled by the annual photoperiodic variations but the socio-sexual relationships can dramatically modify it. Indeed, the permanent presence of bucks rendered sexually active by appropriate photoperiodic treatments allows goats to ovulate all the year round. In addition, the sudden introduction of these photostimulated bucks into a group of seasonal anovulatory goats dramatically improves the occurrence of induced ovulations within the first 5 days after the contact between both genders. In subtropical latitudes, the combination of photoperiod and socio-sexual relationships is an original, cheap, and sustainable way to control the out-of-season sexual activity in goats, and therefore, the milk and meat productions.

6.1 Introduction

Mexican goats and their backcrosses with several imported breeds display seasonal variations of their reproductive activity at subtropical latitudes (Duarte et al. 2008; Delgadillo et al. 1999). This reproductive seasonality reduces the productivity of flocks, because milk and meat productions are also seasonal, inducing wide variation in producer incomes, and unavailability of goat products to consumers in

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some months of the year. To solve this constraint, hormonal treatments are generally used to induce ovulations during the seasonal anestrus; these hormonal treatments are usually associated with artificial insemination (Leboeuf et al. 2008). Therefore, exogenous hormonal treatments and artificial insemination are widely used in intensive management systems. However, in subtropical latitudes where most goats are under natural extensive production system, the use of the hormonal treatments is prohibitive because of their cost. In these extensive management systems, farmers need to use simple, effective, and non-expensive tools to modify the annual rhythm of reproduction of both male and female goats (Delgadillo and Martin 2015). In this chapter, we describe how photoperiodic treatments can be used to stimulate the sexual activity of bucks during the sexual rest, and how these photostimulated bucks can either to prevent the seasonal anovulation to occur or to induce and synchronize ovulations during the seasonal anovulation.

6.2 Characteristics of the Natural Extensive Goat Production System in Subtropical North of Mexico

In subtropical north of Mexico (latitude 26º N), as in other subtropical latitudes, around 95% of bucks and female goats are managed in extensive conditions (Sáenz-Escárcega et al. 1991). Animals generally graze from 10:00 to 18:00, eating only available natural vegetation without any food supplementation. At night, animals remain in outdoor pens near farmers' house. In this traditional extensive production system, males and females remain together throughout the year; females are used to produce milk and meat. Kids are nursed by their mothers and are weaned and sold at about 4 weeks of age. Because females and males remain together in the flock, there is no control of matings. About 70% of pregnancies occur during summer (June–September), leading to birth of kids in autumn and winter (November–February). These data would indicate that when females and males remain together throughout the year, the sexual activity of females begins in late spring or early summer (May–June). In contrast, when females remain isolated from males, their ovulatory activity begins in early autumn (September) (Duarte et al. 2008; Delgadillo et al. 2015).

In this traditional production system, where bucks and goats are kept together, the kidding season is not the best for milk and meat production, as well as for the survival of kids. This is due to at least three reasons: (i) parturitions coincide with a dramatic reduction of food availability for mothers, causing a low milk production for both kids and milk industries; (ii) a daily wide variation of environmental temperatures (5–30 °C), increasing mortality of kids until 50% in some flocks mainly by respiratory problems (Sáenz-Escárcega et al. 1991); and (iii) a dramatic reduction of the price of kids from December onward due to the increase of the

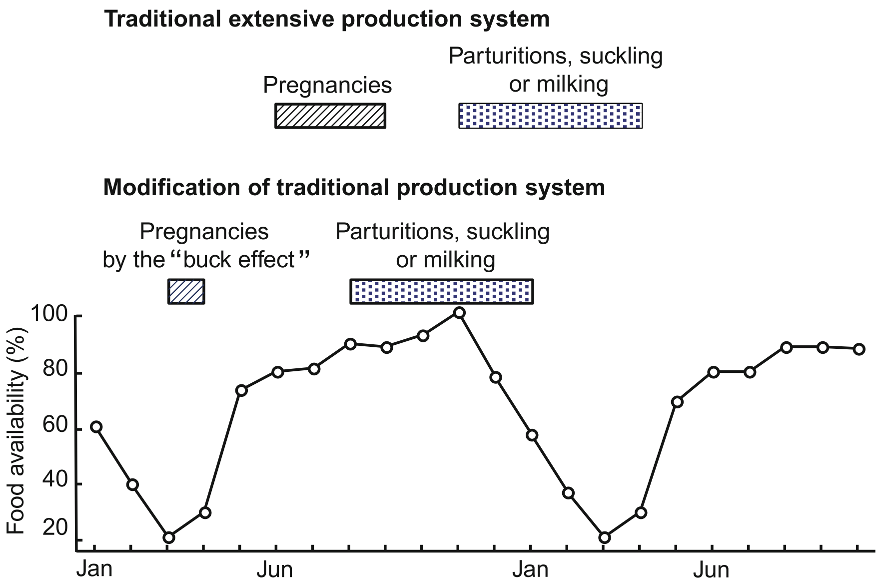

Fig. 6.1 Seasonal variations of natural food availability in the subtropical Mexico (○). In the traditional extensive production system where males and females remain together throughout the year, conceptions coincide with high food availability, but season of parturitions and milk production coincides with a dramatic reduction of food availability (▩). In contrast, when period of conceptions is modified by the "buck effect", season of parturitions and milk production coincides with high food availability (▧) (modified after Delgadillo and Martin 2015)

kid's availability. Similar problems may occur in females isolated from bucks, and mated in September–October, at the beginning of the breeding season. In these circumstances, farmers wish to advance kidding season for 2–3 months (August–October) allowing (i) parturitions to occur during the high pasture availability, and therefore, increasing milk production; (ii) reducing kid's mortality provoked by respiratory problems and diarrhea; and (iii) kids are sold at a higher price. In fact, price of kids born in August–October is higher (~35 euros) than those sold in December onward (~15 euros; Fig. 6.1).

To modify the season of mating, farmers need to avoid the occurrence of seasonal ovulation, or to induce ovulations during the seasonal anovulation. These two goals can be reached using males rendered sexually active by photoperiodic treatments (i.e., "photostimulated bucks"), and the socio-sexual interactions between bucks and females, a phenomenon known as the "buck effect" or "male effect".

6.3 Using Sexually Active Males to Prevent Seasonal Anestrous in Female Goats

6.3.1 Photoperiodic Treatments of Bucks Used to Prevent the Occurrence of Seasonal Anovulation

We can have sexually active bucks throughout the year using males displaying intense sexual behavior during their natural breeding season (i.e., from June to December in subtropical Mexico) (Delgadillo et al. 1999), and males submitted to appropriate photoperiodic treatments to induce intense sexual behavior during their natural sexual rest season (i.e., from January to June) (Delgadillo et al. 2015). To have sexually active males during the whole year, we investigated three groups of males, which were kept in shaded open pens (5×10 m), and exposed to artificial long days (16 h of light per day: artificial light from 6:00 to 9:00 and from 17:00 to 22:00) during 8 weeks, followed by natural photoperiodic conditions (groups 1 and 2) or melatonin treatment (group 3). The open pen had 15 daylight lamps of 68 W of energy each. Light-on and light-off were regulated by an electronic timer, and light intensity was at least 300 lx at the level of eyes of animals (Bedos et al. 2016). In these groups, long-day treatment was as follows: for group 1, from September 16 to November 15, and for group 2, from November 1 to December 31. At the end of the treatment, bucks were switched to natural photoperiod. Finally, another group of males was also exposed to long days from December 15 to February 15, followed by the insertion of two subcutaneous implants of melatonin (group 3), hormone that gives a signal of short days (Chemineau et al. 1992; Delgadillo et al. 2001). It is important to notice that the photostimulated bucks displayed intense sexual behavior about 6 weeks after the end of long days, and for about 8 weeks. Therefore, the photostimulated bucks displayed intense sexual behavior in January–February (group 1), March–April (group 2), and May–June (group 3), whereas the control bucks displayed intense sexual behavior from June to December (Delgadillo et al. 2015). Interestingly, the plasma testosterone concentrations and the sexual behavior of the photostimulated bucks were similar to those observed during the natural breeding season of bucks (Delgadillo et al. 2002; Bedos et al. 2016).

Therefore, these three groups of photostimulated bucks remained in contact with females in January–February (group 1), March–April (group 2), and May–June (group 3), when they displayed intense sexual behavior. Afterward, these females remained in contact with control bucks from July to December, when they displayed their normal intense sexual behavior. The control bucks were exchanged at the same time that the photostimulated ones (Delgadillo et al. 2015).

6.3.2 *The Permanent Presence of Sexually Active Males Prevents the Anovulation Season*

We have recently shown that it is now possible to prevent the seasonal anovulation to occur in female goats by exposing them to sexually active males from January (Delgadillo et al. 2015). To this end, it is important to use photostimulated bucks displaying intense sexual behavior from January to June, during their natural sexual rest followed by untreated bucks displaying intense sexual behavior from July to December, during their natural breeding season. Most goats exposed throughout the

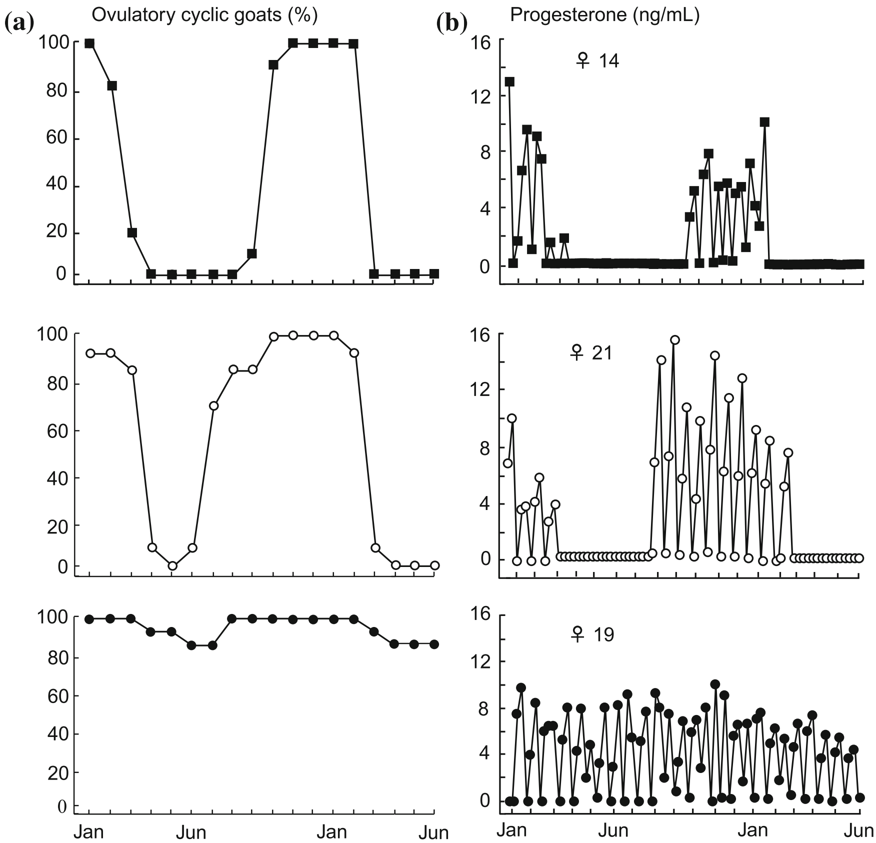

Fig. 6.2 Changes in ovulatory activity (**a**) in goats isolated from males (filled rectangle), in goats in permanent contact with photoperiodic-untreated bucks, displaying low sexual behavior between January and June (white circle), and in goats in permanent contact with photostimulated bucks displaying intense sexual behavior from January to June, followed by untreated bucks displaying intense sexual behavior from July to December (filled circle). Individual profiles of plasma progesterone concentration (**b**) in goats from the three experimental groups (modified after Delgadillo et al. 2015)

year to the photostimulated males (January–June) and to control ones (July–December), ovulate all the year round (Fig. 6.2). In contrast, the permanent presence of photoperiodic-untreated bucks, displaying low sexual behavior between January and May, did not prevent the seasonal anovulation and most females stopped ovulations during 3–4 months. Finally, goats isolated from bucks stopped to ovulate during 6–7 months (Delgadillo et al. 2015) (Fig. 6.2). Our data are the first showing that in goats from subtropical latitudes, the seasonal anovulation can be prevented by the permanent presence of sexually active males, thus leading to continuous ovulations throughout the year.

In addition, these data strongly suggest that the sexual activity of bucks is an important factor controlling the seasonality of ovulation of goats from subtropical latitudes (Delgadillo and Vélez 2010), as well as those from temperate latitudes (Chasles et al. 2016; Zarazaga et al. 2017). The prevention of the seasonal anovulation opens new non-pharmaceutical perspectives to control out-of-season reproduction in goats. Indeed, the ovulatory cyclic goats throughout the year allows farmers to choose the best seasons of kidding and milking according to the environmental and market conditions. It would be interesting to determine whether in other seasonal breeds of goats, or in other seasonal reproductive species of mammals, the permanent presence of sexually active males prevents the seasonal anestrous in females, as reported recently in the Rasa Aragonesa ewes (Abecia et al. 2015).

6.4 Using Sexually Active Males to Prevent Seasonal Anestrous in Female Goats

6.4.1 Photoperiodic Treatments of Bucks to Stimulate Ovulations in Seasonal Anestrous Goats

The photostimulated males used in the buck effect are generally exposed to artificial long days (16 h of light per day) during 10 weeks, from November 1 to January 15, followed by natural photoperiodic conditions. Interestingly, 6 weeks of long days starting on December 1 and ending on January 15 are enough to stimulate testosterone secretion and sexual behavior of bucks (Ponce et al. 2014). Independent of the duration of the long-day treatment, bucks are fully sexually active about 6 weeks after the end of the long days and for about 8 weeks. Therefore, photostimulated bucks can be used in March, April, or early May to stimulate ovulation during the seasonal anestrous (Delgadillo et al. 2002; Ponce et al. 2014). The characteristics of the photoperiodic treatments were described above.

6.4.2 Stimulation of the Sexual Activity of Seasonal Anestrous Goats by the Photostimulated Bucks: The "Buck Effect"

In seasonal anestrous goats, estrus and ovulations can be induced and synchronized by the sudden introduction of bucks, a phenomenon known as the "buck effect" (Shelton 1960; Ott et al. 1980; Zarazaga et al. 2012). The photostimulated, and therefore sexually active bucks induce more goats to display estrus and ovulations during the seasonal anestrous goats (>90%) than the control ones displaying weak sexual behavior (<10%; Bedos et al. 2010; Chasles et al. 2016) (Fig. 6.3). Most of the goats responding to the sudden introduction of males display a short estrous cycle, which induces estrus and ovulations two times in the first 10 days after the introduction of bucks (Chemineau 1987). For this reason, the photostimulated bucks remain with females for 15 days, obtaining a mean pregnancy rate of 75% (Fitz-Rodríguez et al. 2009; Bedos et al. 2012; Loya-Carrera et al. 2014). However, when bucks remain with females for 35 days, the pregnancy rate increases until 96% (Araya et al. 2016). Thus, the use of the photostimulated and sexually active bucks makes the "buck effect" an easy, adaptable, and non-expensive technique to modify the annual reproductive cycle of goats, rejecting dogmas concerning the socio-sexual interaction in both goats and sheep (Delgadillo et al. 2009):

(i) *Dogma 1: Females and males must be separated for at least 3 weeks prior joining them*

The photostimulated bucks induce the sexual activity of goats without previous separation between genders. Indeed, most goats display estrous behavior and ovulations even if they were (87%) or not (91%) previously separated from bucks, but exposed to photostimulated males. In contrast, none of the females displayed estrus or ovulations when exposed to untreated, sexually inactive bucks (Delgadillo et al. 2006). This datum simplifies the use of the buck effect, because in most cases farmers do not have enough space in the farm to separate both genders.

(ii) *Dogma 2: Females and males must be maintained in contact 24 h per day for several days to stimulate ovulations in most females*

The use of photostimulated bucks allows a reduction of the time of contact to four hours daily between bucks and goats without decreasing the ovulatory response (>90%) or fertility at parturition (87%; Bedos et al. 2010). Interestingly, one or two hours or even 30 min of daily contact between genders is enough to stimulate the ovulatory activity of goats, but ovulations occurred 2 days later than in those in contact with bucks during 4 or 24 h (Ramírez et al. 2017). This reduction of time of contact between genders can increase the number of stimulated goats per one buck by using the same bucks to stimulate various groups of females (Bedos et al. 2012).

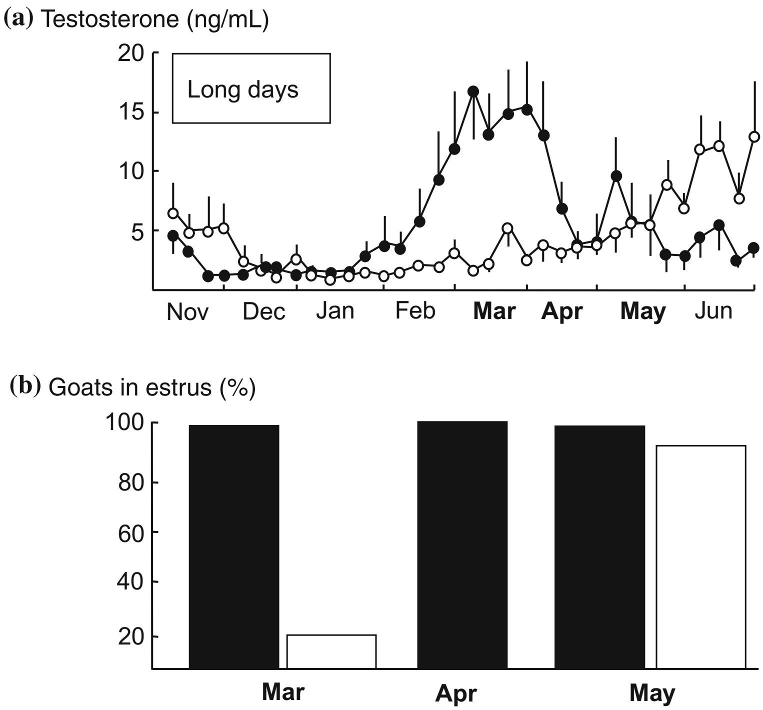

Fig. 6.3 Changes (mean ± SEM) in plasma testosterone concentrations (**a**) in male goats from subtropical Mexico subjected to natural photoperiodic variations (white circle), or to 10 weeks of artificial long days (16 h of light per day) from November 1, followed by natural photoperiodic conditions (filled circle). Estrus response (**b**) of seasonal anestrus goats from subtropical Mexico exposed to photostimulated bucks displaying intense sexual behavior (filled rectangle), or photoperiodic-untreated ones displaying weak sexual behavior (white rectangle) (adapted from Delgadillo et al. 2002 and Rivas-Muñoz et al. 2007)

(iii) *Dogma 3: Females respond better to the presence of males in intensive than in extensive management conditions*

The photostimulated bucks stimulate the estrous behavior in goats maintained in intensive as well as in extensive management conditions (>90% in both conditions). In fact, most goats display estrus when the photostimulated bucks remained in the open pens during the day, while females go out to graze and are joined only at night. In these circumstances, the daily contact between both genders is from 18:00 to 10:00 h (Rivas-Muñoz et al. 2007). Therefore, the photostimulated bucks stimulate the sexual activity of females without any modification of the extensive management system.

(iv) *Dogma 4: Novel males induce more females to ovulate than familiar ones*

The familiar (already known)-photostimulated bucks stimulate goats to ovulate at the same level than the novel-photostimulated ones (96% in both cases).

In contrast, not any goat ovulates when exposed to familiar or novel control bucks, displaying low sexual behavior (Muñoz et al. 2016). These data indicate that the sexual behavior displayed by the bucks is more important than their familiarity with females to stimulate ovulations. In addition, data indicate that farmers can use the same bucks (which are therefore familiar to females) during several consecutive years to stimulate ovulations in seasonal anestrus goats by using the "buck effect".

(v) *Dogma 5: Multiparous females responded better than nulliparous ones when exposed to males*

The photostimulated bucks are able to stimulate the estrus behavior and ovulations in multiparous as well as in nulliparous goats (>95% in both cases) (Luna-Orozco et al. 2008). This is an important practical result, because generally, the reproductive efficiency of nulliparous females is lower than in multiparous ones. Therefore, photostimulated males can improve reproductive efficiency in nulliparous goats.

(vi) *Dogma 6: The proportion of females displaying estrus is greater in sexually experienced than in sexually inexperienced females exposed to males*

The photostimulated bucks stimulate goats to display estrous behavior in sexually experienced as well as in sexually inexperienced ones (>95% in both cases) (Fernández et al. 2011). This datum suggests that when possible, young females can be separated from males to avoid undesirable pregnancies. Then, females can be joined with males to stimulate ovulations even if they are sexually inexperienced.

6.5 Concluding Remarks

The use of socio-sexual stimuli to control out-of-season goat reproduction is not a new story, but the fact that a set of recent experiments demonstrate that light-induced sexually active bucks are much more efficient than control bucks is a new one. Their ability to provoke maintenance of permanent ovulatory cyclicity during 2 consecutive years in seasonal goats and their dramatically improved efficiency to induce sudden out-of-season ovulations are two major results simultaneously of scientific and practical interest. The scientific demonstration of the prevention of seasonal anovulation by the permanent presence of sexually active bucks is a completely new result in any of the mammalian seasonal species studied so far, from small models to large ones. Practically, the advice could now be given to farmers to use this simple and cheap treatment on their bucks, starting 14 weeks before their expected use. The development of this technique to control goat reproduction constitutes a major step toward more sustainable goat livestock systems. It is cheap and efficient, it prevents the use of exogenous hormones which may be at risk for animal and/or human health, and it fits with the actual desire of consumers, who demand products more close to naturality.

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Chapter 7
Threatened Goat Breeds from the Tropics: The Impact of Crossbreeding with Foreign Goats

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Abstract Local goat breeds are able to adapt to specific environments due to the long process of geographic isolation, natural and—notably morphological—artificial selection they were submitted to, which resulted in characteristics that have allowed them to survive in harsh and poor environments. Continuous crossbreeding has promoted a quick replacement and decrease of local breeds, which has been relevant in Brazil. Although they are less productive than specialized foreign breeds, they are fully adapted to the tropics and, therefore, are able to produce with those particular conditions. They play important social and economic roles within the different continents, as they are essential in adverse areas where farming is difficult, and, in most situations, they are the only source of animal protein available for humans. In Brazil, for example, despite the numerous threats posed to local goat breeds, they still have a fair number of alleles by locus and good levels of heterozygosis. This is a concerning scenario that, alone, is enough to stimulate the establishment of conservation programs of local goat breeds in the country. The use of foreign breeds in tropical countries must be looked into carefully, especially in the case of extensive systems of production where local breeds prevail. Under these conditions, a challenge is faced: to increase meat production while maintaining genetic diversity within the breeds. Sustainable production systems may be accomplished if the great advantage of local breeds' multiple functionalities is considered.

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7.1 Introduction

The first United Nations Conference on Environment and Development, which took place in Rio de Janeiro in 1992, resulted in the creation of the Agenda 21, after which the Convention on Biological Diversity (CDB, in the Portuguese acronym) was set up. Its main goal was to promote the conservation of biological diversity, which is why it fostered sustainability, investigations of the components of biodiversity, as well as other actions such as in situ and ex situ conservation. The first evaluation of the status of the animal genetic resources (AGR) concerning nutrition and agriculture was carried out by FAO (2007). After that, strategies for the AGRs conservation worldwide were defined (FAO 2015; Leroy et al. 2016).

Because extinction is a stochastic process, the situation of domestic animals, especially that of the so-called "local" or "fully adapted breeds" (FAO 2007) must be studied, since they are important sources of animal protein in human nutrition. According to the International Union for Conservation of Nature (IUCN), the recognition of the accelerated losses in biodiversity has been gaining ground, especially with the increase in the number of species that have been severely endangered in the last decades. Colléony et al. (2017) asserted that the conservation policies depend on the commitment made by people and by each state. This commitment has evolved in the past decades with significant progress, one of which is the fact that the AGRs have been considered essential for the maintenance and the development of systems of livestock production around the world (Leroy et al. 2016).

Local breeds are able to adapt to specific environments due to the long process of geographic isolation, natural and—notably morphological—artificial selectionthey were submitted to, which resulted in characteristics that have allowed them to survive in harsh environments with little quality and amount of food. These breeds have been replaced by specialized foreign breeds, which cause a quick genetic erosion. This process has been documented by several studies (Egito et al. 1999; Ribeiro et al. 2004; Lima et al. 2007; Oliveira 2003, 2005, 2006, 2010; Periasamy et al. 2016; Thuy et al. 2016).

Small ruminants, such as goats, are key components in livestock and agricultural farming around the globe, and they contribute to food safety and to the reduction of poverty (Periasamy et al. 2016). Goats are spread all over the continents, and it is estimated that they amount to over one billion animals represented by almost 590 breeds (FAO DAD-IS 2015). They play important social and economic role within the different continents, which means that they are essential in adverse areas where farming is difficult, as they are the main available source of animal protein for the population (Awobajo et al. 2016; Periasamy et al. 2016; Rocha et al. 2016).

In the goat farming, the need for actions is more urgent due to the socio-economic role in the agroecosystem where they are. So, it is necessary to encourage the participation of all sectors of the activity, as well as to include farmers in decision-making processes. The process of marginalization that traditional systems of goat production undergo must be contained in order to prevent them from being replaced with intensive farming, which requires more and more foreign and high-maintenance animals (FAO 2007). As small farmers adopt enhanced species that require higher maintenance in hostile environments, several local, well-adapted, and old genotypes are left behind and tend to vanish unless efforts to preserve them are made (Klug et al. 2010).

Thus, there is a pressing need to establish conservation plans in situ and ex situ, and to provide food for the current and/or future market, as well as to use these animal resources for research, given their socio-economical potential and their historical-cultural and ecological aspects (Bodó 1989).

Many actions have been taken in Brazil focused to the knowledge and the protection of local breeds. Paiva et al. (2016) mentioned the national growth of animal germplasm banks, which have been created in order to guarantee the safety of AGRs. The concern to maintain these resources and to understand mating and the distribution of genetic variation for the conservation of endangered breeds is a result of the speed at which the animal and vegetal species vanish.

7.2 Foreign Breeds and Their Role in the Production Systems of Local Goat Breeds in Brazil

The evolution of domestic animals has been shaped by man throughout the generations, and the enlargement of the species followed the migration route and man's occupation of the regions. Hence, when America was colonized, the Iberian breeds were introduced by the Portuguese and the Spanish people. Then, these breeds evolved for centuries, adapting to new conditions of sanitation, climate, and management they found in the different habitats, which gave birth to the Brazilian breeds, also known as "local" or "Creole".

In the beginning of the past century, the search for more productive breeds led to the importation of foreign breeds that had high performances but were selected from temperate regions.

Continuous crossbreeding caused a quick replacement and decrease in the number of local breeds, which, despite having lower productivity than that of specialized ones (Nubian, Saanen, Toggenburg, and Boer breeds), were distinguished for being fully adapted to the tropics (Ribeiro et al. 2015).

The impact of crossbreeding on yield production of the local breed as well as on the foreign breeds raised on in a harsh environment where they do not fit is poorly documented (Table 7.1). In general, trials are made under experimental conditions with a controlled environment, different from the reality of the local rearing systems. So, the desired increase in production is not reached, and the impact on the local genetic pool is irreversible.

In hash and poor environment with low-input, the productive performance dramatically decreases due to the negative effect of the genotype-environment interaction and they become unfeasible.

Table 7.1 Comparative development of local and foreign goat breeds in the northeastern semiarid region of Brazil

Breeds/ Genetic group	Birth weight (kg)	Adult weight (kg)	Carcass yield (%)	Kidding rate (%)	Prolificacy	Duration of pregnancy (days)	References
Marota	1.84	36	–	87.4	1.29	146.4	Lima et al. (2001), Medeiros et al. (1993)
Moxotó	1.77	37	37–49	82.0	1.68	147.5	Santos Filho (1997), Silva and Araújo (1999), Lima et al. (2001), Mattos et al. (2006), Marques et al. (2014)
Repartida	1.80	36	–	–	–	147.4	Lima et al. (2001)
Canindé	1.86	37	41–44	86.0	1.67	147.4	Lima et al. (2001), Mattos et al. (2006), Lisboa et al. (2010)
Mestiços[a]	2.0	35–40	42–44	83.4	1.49	145.9	Lima et al. (2001), Fernandes Filho (2007)
Boer[a]	3.0	70	47–52	86.0	1.80	148.2	Figueiredo et al. (1982), Silva (2000)
Anglo Nubiana[a]	2.6	65	44–47	81.0	1.50	142.7	Figueiredo et al. (1982)
Bhuj[a]	2.2	60–70	–	–	–	142.0	Figueiredo et al. (1982)

[a]Animals reared on supplementation feed in the northeastern semiarid region

7.3 Demographic and Genetic Structure of Local Goat Breeds in Brazil

The demographic structure of a breed measures a number of herds, their geographic distribution, and the number of animals per herd, as well as other concepts such as the age pyramid and the generation interval. The main parameters for the evaluation of the demographic structure of a breed are the effective number and the inbreeding rate. They are inversely proportional and are the most important population parameters to determine if a given breed is at risk (Alderson 1992).

The genetic structure of a population or breed can be defined based on the amount of diversity and the way this diversity is organized within the individual, among, and between herds. The main parameters are Wright's F statistics (FIS, FIT, and FST) and, with these parameters, it is possible to assess the levels of endogamy between and within populations (Wright 1969).

The genetic structure of a population or breed suffers alterations along the evolutionary process due to factors such as selection, mutation, genetic drift, and migration; this latter being evaluated with concern to the entrance and/or exit of reproducers, which favors the gene flow. That being so, migration is a rather significant evolutionary force, both in improvement and in conservation programs.

Despite the great importance of local goat breeds for the Brazilian semiarid region, most are endangered, according to FAO (2007), either due to the improper use of genetic diversity and lack of conservation programs.

Demographically, the status of these breeds is quite concerning, with a low number of animals in the herds, and raised extremely isolated (Fig. 7.1), which is a limiting factor for the gene flow among populations of the same breed (Lima et al. 2007; Santos et al. 2008; Barros et al. 2011).

Furthermore, in Brazil about 75% of the herds belong to non-defined breeds, as they originate from crossbreeding among native animals (Moxotó, Canindé, Azul, Nambi, Gurguéia, and Graúna), with foreign breeds (Bhuj, Saanen, Murciana-Granadina, Boer and Nubian)—among which Nubian is the most common (Pimenta-Filho et al. 2000; Ribeiro et al. 2004). According to Oliveira et al. (2006), Nubian is the breed that has contributed the most to the dissolution of local herds. It is worth mentioning, though, that he varies from state to state. Rocha et al. (2004), for instance, observed that, out of the total of goats in the state of Pernambuco, only 9.4% belong to native breeds and Moxotó is the most common. This owes to the crossbreeding with Nubian and other breeds, such as Boer, which has been recently imported from South Africa in order to improve the production of meat of local herds. These measures have led to the decrease of these herds year by year. Some breeds cannot be found in the northeastern region, and they are undergoing genetic dilution (Lima et al. 2007), and they are all endangered, according to FAO (2007) and IUCN (2012). The criteria are established in accordance with a list of classification or categories that range from "out of danger" to the biggest risk of extinction.

The current threatened status of many populations resulted from the replacement of some local breeds by transboundary commercial breeds, following model breeding programs developed in Europe. This scenario can further explain the lower diversity observed in the indigenous Brazilian breeds when compared to that of goats from other regions, such as the Middle East (Cañon et al. 2006; Agha et al. 2008; Mahmoudi et al. 2011), Asia (Li et al. 2002; Dixit et al. 2008; Fatima et al. 2008) and West Africa (Traoré et al. 2009; Missohou et al. 2011).

Studies on Latin American goats reported similar overall values for the diversity parameters estimated for Brazilian local breeds (Menezes et al. 2006; Oliveira et al.

Fig. 7.1 Geographic distribution of local breeds in Brazil (Northeast Region: Alagoas, Bahia, Ceará, Maranhão, Paraíba, Pernambuco, Piauí, Rio Grande do Norte, and Sergipe states)

2006, 2010; Chacon et al. 2012; Ribeiro et al. 2012; Aranguren-Mendez et al. 2013; Ginja et al. 2017).

Despite the massive threats posed to local goat breeds in Brazil, they still have fair intra- and interbreed diversity, as is proved by Oliveira et al. (2005), Machado et al. (2000), Araújo et al. (2006), Menezes et al. (2006), Oliveira et al. (2006, 2007, 2010), Rocha et al. (2007) and Silva et al. (2012). Also, they present a considerable average number of alleles per locus and good levels of heterozygosis. Moreover, their average genetic distance among herds (FST) is at about 14% (Ribeiro et al. 2012), which is quite superior to those found in European goat breeds.

The impact of crossbreeding between local and foreign breeds has been widely discussed worldwide, but it was not until recently that investments in research aimed at assessing the effect of crossbreeding on the genetic structure of local populations have begun. In Brazil, Rocha et al. (2016) did a pilot study with Bayesian inference applied to data extracted from microsatellite markers on local and foreign breeds that are commonly used in the Brazilian semiarid region. The aim was to verify the impact of these foreign breeds on the genetic structure of local breeds. The authors observed that the impact of the crossbreeding practiced among the indigenous breeds is as common as that done between local and transboundary commercial breeds. The dilution resulting from the two situations is apparent and several indigenous Brazilian goat populations presented heterozygote deficit.

7.4 Conclusions

Brazilian local goat populations are significant resources in semiarid regions and sometimes they are the only source of nourishment for the local human population. On the other hand, they face constant threats, mainly due to crossbreeding with transboundary commercial breeds. This scenario is worrying and sufficient to consider the necessity to establish genetic conservation programs of Brazilian local goat populations.

The use of different genotypes must be looked into from the perspective of the production systems. The use of foreign breeds in tropical countries must be evaluated carefully, notably when it comes to extensive systems of production where local breeds prevail. Under these conditions, a challenge is faced: to increase meat production while maintaining genetic diversity within the breeds. Sustainable production systems may be accomplished if the great advantage of local breeds' multiple functionalities is considered.

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Chapter 8
Genetic Improvement of Local Goats

Nuno Carolino, António Vicente and Inês Carolino

Abstract Genetic improvement of domestic animals through selection of the breeding stock, including small ruminants like goats, has been acknowledged as a powerful tool. It has been used by mankind for the supply of the most varied products, and for increasing productivity and global yields. During the next decades, genetic improvement of goat populations can be a key factor for livestock in extreme conditions, being resistant to conditions resulting from climate change, and diseases, and providing good quality products in many regions of the globe. In a general program of genetic improvement and selection of goats, it will be fundamental to monitor the genetic progress and make the right choices of future breeders to achieve the genetic improvement of a herd. A selection plan should have well-defined improvement objectives, which will obviously differ according to whether the systems are for producing goat meat, dairy, dual purpose, or other more specific products (e.g., wool). Techniques and methodologies of selection have evolved at a remarkable rate, from individual selection to best linear unbiased prediction (BLUP) and genomics, allowing us to obtain ever more efficient and precise results when we combine different methodologies and information sources. The aim of this chapter is to present and discuss the breeding goals and selection strategies used in genetic improvement programs of goat populations and local breeds.

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8.1 Introduction

Goats are probably one of the best-adapted species to a wide variety of environmental conditions, particularly to difficult, arid agricultural regions characterized by poor climatic and soil conditions, shortages of food and water, extreme temperatures, and complex orography.

The genetic, morphological, and physiological characteristics of these animals with small body size, great agility, selective feeding habits, capacity to retrieve food, and browse (Morand-Fehr 1991), together with an unusual capacity of adaptation, give goats bred in extensive and semi-extensive production systems, an advantage over other species of ruminants (Fonseca 2015). Goats are, therefore, perfect consumers of agricultural subproducts in extreme, arid and semi-arid regions with little rainfall, low fertility, food shortages, etc.

In a number of underdeveloped countries, the goat continues to be the animal that best meets human needs (Miranda-de la Lama and Mattiello 2010). Goat production is also often fundamental in the settlement of populations in poor rural areas, such as some Mediterranean regions (De Rancourt et al. 2005), preserving social and cultural traditions and sustainable management of the rural environment. This contributes to the existence of breeding systems that are in balance with the environment and reduce the risk of fires.

Goats have been traditionally produced for milk and dairy products, meat, hides, and manure, but compared to other species of ruminants, they have had little productive relevance worldwide, i.e., in the European Union and in other developed countries. Goat meat and milk represent only 2% of the world's production, but its consumption exceeds 95 and 83%, respectively, in developing countries (Cardellino 2016).

More recently, intensive goat production has been increased, and recognition of the health benefits associated with goat milk and the organoleptic qualities of its products (Haenlein 2004; FAO 2013), has given a new perspective of the sector.

Currently, new challenges are arising in the animal production sector, mainly resulting from worldwide population growth and the subsequent demand for an increase in food supply. In the fall of 2011, the world population surpassed 7 billion and will grow to 8.6 billion in 2030, 9.8 billion in 2050, and 11.2 billion in 2100, driven by faster growth in African countries, according to forecasts by the United Nations (2017). However, it is fundamental to address other future challenges in terms of food, natural and territorial resources, conservation of water, soil, biodiversity and traditions, climate change, the quality of products, multifunctional and sustainable development in rural areas, and systems of production that are more respectful for the environment and natural resources.

Through the selection of breeding animals, animal genetic improvement has come to be acknowledged as a very powerful tool, enabling mankind to use animals for a wide variety of purposes, including the supply products (meat, milk, eggs, hides, and fibers), and many other functions (work, transport, clothing, tools, sport, leisure, etc.).

Selective animal breeding has been practiced for almost 300 years, and great advancements have been made since its early days (Oldenbroek and Waaij 2014). Despite Darwin's famous theory about the importance of selection "I soon perceived that selection was the keystone of man's success in making useful races of animals and plants," according to Hall and Hallgrimsson (2008), at the beginning of the nineteenth century, many of these concepts still needed to develop a scientific explanation.

After the domestication of different species, even though the selection of animals was done in an empirical way, it gradually produced great modifications in the morphology, physiology, and usefulness of most livestock species. According to Blasco (2013), animals were selected in different environments and for different traits, leading to the huge diversity among the modern breeds of today.

Over the years, based on different scientific premises which involved different "schools" and characters, animal genetic improvement led to notable results in a variety of livestock species, from ruminants to fishes, involving a wide spectrum of interesting traits. Thus, animals have been able to reach significant levels of productivity (Van der Steen et al. 2005), as well as patterns of adaptability, resistance, functionality, behavior, and outstanding products.

During the next decades, genetic animal improvement, particularly in goats, again may become a keystone in addressing the above-mentioned challenges of the farming sector in terms of food, agriculture, and territorial resources. In the ambit of improvement through selection programs, other objectives may be considered which have been less used so far, like the quality of food products, resistance to diseases, and production capacity in extreme situations.

A number of goat populations are able to produce in very difficult environmental conditions, (e.g., Osmanabadi goats in India are known for their extreme adaptive capability to high temperature and feed scarcity periods) (Sejian et al. 2015), whereby selection oriented toward productivity in situations of heat stress and higher food and water scarcity could be efficient.

The aim of this chapter is to present and discuss the breeding goals and selection strategies used in genetic improvement programs of goat populations regarding local breeds.

8.2 An Overview About Animal Breeding and Genetic Progress

Animal breeding involves the selective breeding of domestic animals to improve desirable and heritable qualities in the next generation (Oldenbroek and Waaij 2014).

The standard genetic model in quantitative genetics is that phenotype **P** is the sum of genotype **G** (sum of all genetic effects of genes) and environment **E** (all nongenetic effects) assuming no covariance between **G** and **E** (Falconer and Mackay 1996), and the phenotypic variance can be written as,

$$\mathbf{P} = \mathbf{G} + \mathbf{E}; \quad \boldsymbol{\sigma}^2_{\mathbf{P}} = \boldsymbol{\sigma}^2_{\mathbf{G}} + \boldsymbol{\sigma}^2_{\mathbf{E}}$$

Breeding value (**BV** or **A**) is the value associated with the genes carried by an individual and transmitted to its offspring. Breeding value is the sum of average effects of genes and is a property of the individual and the mating population. The difference between the genotypic value (**G**) and the breeding value (represented by **A**, additive genetic effects) is the dominance deviation (**D = G − A**).

Dominance deviation is due to the interaction between alleles within loci; the effect of combining genes together that cannot account for the effects of two single genes. Dominance deviation also depends on the gene frequencies in the population, i.e., a property of the individual and the mating population. Thus, genotypic value (**G**) = breeding value (**A**) + dominance value (**D**), and genetic variance, in a one locus model ($\boldsymbol{\sigma}^2_G$), is the sum of additive ($\boldsymbol{\sigma}^2_A$) and nonadditive genetic variances ($\boldsymbol{\sigma}^2_D$).

The total genetic variance in a multiple loci model, where interaction between different loci can occur, is called epistasis effects ($\boldsymbol{\sigma}^2_I$), and assuming no covariance between **G** and **E**, can be decomposed in:

$$\boldsymbol{\sigma}^2_P = \boldsymbol{\sigma}^2_A + \boldsymbol{\sigma}^2_D + \boldsymbol{\sigma}^2_I + \boldsymbol{\sigma}^2_E$$

We consider the genetic progress or response to selection (**R**) as the change in the breeding value of the population for a determined trait passed on from one generation to the next, and in the specific case of phenotypic selection, the rate of genetic progress (i.e., the response to selection per year) in any one trait is expressed by the following equation.

$$\mathbf{R} = \frac{\mathbf{S} \times \mathbf{h}^2}{\mathbf{L}}$$

This equation gives us an insight into the factors that drive genetic progress and can be split into three main components, where: **R** = Response to Selection; **S** = Selection Differential; $\mathbf{h}^2$ = Heritability ($\mathbf{h}^2 = \boldsymbol{\sigma}^2_{\mathbf{A}} / \boldsymbol{\sigma}^2_{\mathbf{P}}$), and **L** = Generation Interval.

The selection differential (**S**) is the difference between the base population mean and the mean of the selected parents (Fig. 8.1).

When a large proportion of animals is selected as future breeding stock, as is normal when selecting replacement females, the resulting selection differential will be small. When selecting males, it is common to select far fewer animals, resulting in bigger selection differential. In general, the smaller the proportion of animals selected, the higher will be their average genetic value, therefore the higher the

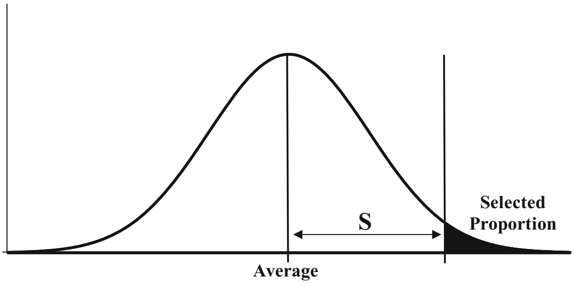

Fig. 8.1 Selection differential (S)

selection differential. Higher selection differentials for either male or female parents will increase the rate of genetic progress for the desired trait.

Heritability ($\mathbf{h^2}$) of a trait is defined as the proportion of the differences between animals, that is transmissible to offspring, and the proportion of phenotypic variation of additive genetic nature ($\mathbf{h^2 = \sigma^2_A / \sigma^2_P}$). Another definition is the efficiency of transmission of parental superiority (or inferiority) from one generation to the next.

According to Visscher et al. (2008), heritability allows a comparison of the relative importance of genes and environment to the variation of traits within and across populations. Despite continuous misunderstandings and controversies over its use and applications, heritability remains key to the response to selection in evolutionary biology and agriculture, and to the prediction of disease risk in medicine. Recent reports of substantial heritability for gene expression and new estimation methods using marker data show up the importance of heritability in the genomics (Yang et al. 2010; De los Campos et al. 2015; Martin et al. 2016).

Heritability, apart from giving us an idea about the "transmissibility" of a trait, how necessary it is for predicting the breeding value of animals according to their phenotypic records, and indicating the precision of this prediction, is, among other applications, necessary for estimating the desirable result of the selection (Gama 2002).

In general terms, the $\mathbf{h^2}$ is low in reproductive traits, intermediate in growth traits, and high for traits concerning the composition and quality of products. Estimates of $\mathbf{h^2}$ for the same trait can differ among populations since the additive genetic variance ($\boldsymbol{\sigma^2_A}$) depends on gene frequencies, the level of inbreeding, and whether or not selection was carried out in the population. The environmental and residual variance ($\boldsymbol{\sigma^2_E}$) depends on the environmental uniformity obtained, and the phenotypic variance ($\boldsymbol{\sigma^2_P}$) depends on the importance of the variances caused by dominance effects ($\boldsymbol{\sigma^2_D}$) and the epistasis ($\boldsymbol{\sigma^2_I}$) for the population in question. Furthermore, it depends also on the methodology and calculation procedures used.

The higher the heritability of a trait, the bigger the proportion of superiority of that trait that will be transmitted to offspring by both parents, and as a consequence, genetic progress will be higher.

A high heritability means that most of the variation that is observed in the present population is caused by variation in genotypes. It means that, in the current population, the phenotype of an individual is a good predictor of the genotype. However, it does not mean that the phenotype is determined once we know the genotype because the environment can change or can be manipulated to alter the phenotype. On the other hand, low heritability means that of all observed variation, a small proportion is caused by variation in genotypes, but it does not mean that the additive genetic variance is small and that a trait with low heritability cannot be efficiently selected (Visscher et al. 2008).

Generation interval (**L**) can be defined as the average age of parents when the offspring that is going to replace them is born and can be calculated as ½($L_{♂}$ + $L_{♀}$). A short generation length means that animals selected for breeding are mated in the herd at a younger average age. Reducing the generation interval will generally increase the rate of genetic progress.

The **S** is intuitive but less useful when we evaluate alternative selection strategies, whereby it is preferable to show the selection differential in units of standard deviation units, which we call intensity of selection ($\mathbf{i}=\mathbf{S}/\boldsymbol{\sigma}_\mathbf{P}$). The intensity of selection (**i**) can, therefore, be expressed, in the special case of truncation selection, as the phenotypic superiority of the individuals selected, expressed in standard deviation units, and if the distribution of the trait is normal, we can determine the proportion of individuals in a given interval of this distribution (Fig. 8.2). In fact, **i** corresponds to the **z/p** ratio, in which **z** is the height of the curve of standardized normal distribution corresponding to the point of truncation that defines the proportion of **p**.

Through the application of the **i** concept, we obtain the following equation for the selection response per year, in the case of individual selection:

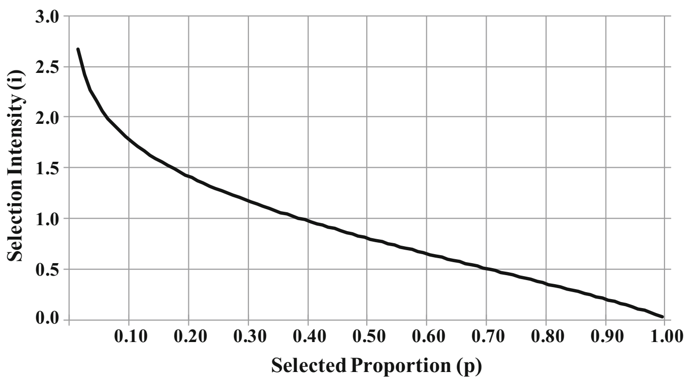

Fig. 8.2 Selection intensity (i)

$$\mathbf{R} = \frac{\mathbf{i} \times \mathbf{h}^2 \times \boldsymbol{\sigma}_\mathbf{P}}{\mathbf{L}}$$

As many traits are not quantifiable in individuals eligible for selection, but only in their parents, (limited to one gender, obtained too late, or postmortem, etc.), the **R** formula

$$\mathbf{R} = \frac{\mathbf{i} \times \mathbf{r}_\mathbf{AP} \times \boldsymbol{\sigma}_\mathbf{A}}{\mathbf{L}}$$

can be converted into a more general equation, applicable to different types of selection, in which $\mathbf{r}_\mathbf{AP}$ represents the precision of selection and $\boldsymbol{\sigma}_\mathbf{A}$ the additive genetic deviation standard. That is, the annual response to selection corresponds to the product of the intensity of selection, the precision with which the selection is carried out, and the additive genetic deviation standard, divided by the generation intervals.

The conclusions that lead us to the **R** equation are based on several assumptions, which in practice, often do not apply to the majority of species. For example, as males have a higher rate of reproduction than females, fewer males are needed for reproduction, so the selection of males can be more intensive than of females. Several interesting traits are recorded in only one gender, such as the obvious example of milk production and litter sizes, among others. This can lead to different degrees of accuracy in the evaluation between genders since for the females, we have records of the actual performance that will contribute to the evaluation, while for the males, we only have information about relatives. Similarly, different genders can have different generation intervals, for a variety of reasons.

However, this equation holds the key to designing breeding programs. Response per unit of time is proportional to the intensity of selection, the accuracy of genetic evaluation, and the square root of the genetic variance, and is inversely proportional to the generation interval.

The main problem in animal breeding through selection is finding the most suitable way to choose future breeding stock, male and female, to obtain the desirable genetic progress. According to Oldenbroek and Waaij (2014), the success of the selection decisions depends on several factors:

- How heritable is the trait under selection (i.e., the trait in the breeding goal)?
- How much genetic variation for that trait is there in the population?
- What is the average accuracy of the estimated breeding value (EBV), and thus the accuracy of selection?
- What proportion of the animals will be selected for breeding?
- In case genetic gain is to be expressed per year, rather than per generation: how long is a generation?

8.3 Breeding Goals

The general reasons for producing goats is linked to several factors: economic, political, social, climate and soil conditions, environmental, historic, and markets, among others, but it is important to always bear in mind what the outputs will be based on available resources.

The overall aim of a genetic improvement program is to increase yield for the breeders involved. It is therefore important to determine previously the best way to obtain genetic progress of the traits which, directly or indirectly, will economically benefit the farmers, according to the demographic, productive, and genetic characteristics of the population, and taking into account available means and strategies for the sector.

Thus, defining the improvement objectives is a fundamental stage in a selection-based breeding program (Ponzoni and Newman 1989; Koots and Gibson 1998; Kinghorn and Simm 1999), and the relative contribution of each trait for the output of the livestock farm is evaluated, taking into account the cost of including that trait (Graser 1994).

Breeding objectives are those traits that are intended to be improved by selection, supposedly by increasing the economic efficiency of the production system, but may not always be used as selection criteria, depending on how easy estimation, cost, and technical quantification is. The relative importance of the genetic progress of the different traits of a breed for a certain production environment should be taken into consideration, as well as the main factors that influence them.

The correct economic evaluation of each desirable trait in a given goat population within a production system requires the calculation of the expected economic profit per unit of genetic change of that trait, which, according to Bourdon and Golden (2000), should involve genetic and economic questions.

One of the main problems in defining improvement objectives has been the difficulty in correctly determining the economic weight of different traits. According to Ponzoni and Newman (1989), the activities of animal genetic improvement through selection encompasses two large areas: (i) one in which the genetic values of those traits that are of interest, and (ii) another in which the economic impact of the selection is studied, and can be quantified by the economic weight of the different traits.

To evaluate the economic benefits of a genetic improvement program through selection, it is necessary to take into account the period of time between the beginning of the selection process, and when the selected animals enter the production system, which in goats, particularly dairy goats, is relatively long.

Breeding objectives must be set at local, regional, or national levels by local stakeholders (and not by outsiders) to truly reflect the real needs of the area/region in question. Farmers must support the direction of change. The conflicts that may occur between the long-term goals, expressed at the organizational or national level, and the interest of farmers in short-term benefits could be solved either by regulations or incentives for participation in a cooperative or national breeding plan (FAO 2010).

If we want to determine the relative importance of different traits in the breeding objective we can, as an alternative to calculation of relative economic weights, insert some restrictions on the change in specific traits or define what the desired gain is in each trait. Whatever the choice of method to determine each weight of different traits, the following additional points must be considered (FAO 2010):

- Although the long-term goals determine the breeding objectives and the role of each trait, the short-term benefits for farmers must be considered to get good farmer participation and arouse their interest and active participation in the breeding program;
- In almost all situations, it may be difficult to exactly assess the change in all desired traits in economic terms, but fundamental traits must always be considered in the selection program;
- Special care and attention must be taken in dealing with adaptive and fitness traits, especially if antagonistic genetic relationships exist between these and primary production traits.

Generally, in dairy goats, both in intensive and extensive systems of production, improvement objectives are especially related with milk production and content (Lopes et al. 2017). Milk yield can be defined as total production, part-lactation production following weaning or peak yield (Mavrogenis 1995).

In dual purpose (meat-milk) production systems, improvement objectives are often related with a lifetime doe productivity, like fertility, prolificacy, conformation or type traits and maternal traits, growth or weight at weaning. In meat production systems, improvement/breeding objectives are normally the end product of the production system, measured by live weight, growth rate, or carcass weight.

In some regions, wool production or other more specific traits are also recognized, like resistance to parasitism (Gunia et al. 2012; Phocas et al. 2016), but generally, the main targets of genetic improvement for goats around the world have been milk and meat.

The longevity, the amount of time breeding females stay active in a herd by avoiding death or culling, is a trait of economic relevance in commercial goat breeding herds as it affects lifetime reproductive output (Pellerin and Browning 2012). Traits like body size, body conformation, and coat color were also identified as breeding goals in indigenous goat breeds of Ethiopia (Abegaz et al. 2014).

The issue of whether to directly select, in harsh environments, for adaptive traits, in addition to the most important traits such as production, reproductive performance, and growth, is debatable (Philipsson et al. 2011). As the physiological adaptability of the animals can be expressed or evaluated by their performance, selection based exclusively on performance can be enough to monitor the adaptive mechanisms involved in their maintenance, like for example, heat balance. Generally, favorable correlations suggest that adaptability traits would not be compromised by emphasizing selection for performance (Burrow et al. 1991;

Mueller 2006). Adaptation traits (disease resistance, heat tolerance, and survival) were considered critical in the Ugandan farmers' preferred breed (Onzima et al. 2017).

In a dynamic breeding program of goats seeking the optimal utilization of the genetic resources available, breeding objectives must be revised and confirmed regularly, based on achievements, taking into consideration the evolution of the population under the improvement program, and potential alterations in market conditions and agricultural policies.

8.4 Making a Breeding Program

According to various authors, including Gama (2002), Dekkers et al. (2004), and Oldenbroek and Waaij (2014), the "design and optimization of animal breeding programs," with no exception for goats, the different situations and particularities of a breed should be considered, as well as the production system in which it is inserted, so that each stage is successful.

The success of a breeding program implies systemization of the planning, and execution of the different activities to be undertaken (Gama 2002). According to Oldenbroek and Waaij (2014), for the long term, the subsequent breeding activities could be carried out in a breeding program reported in Table 8.1.

Table 8.1 Breeding program scheme. Adapted from Oldenbroek and Waaij (2014)

Steps of the breeding program
1. Definition of production system
2. Definition of breeding goal
3. Collection of information —Phenotypes —Family relationships —Genotypes
4. Determining selection criteria —Genetic model —Breeding value estimation
5. Selection and mating —Prediction selection to response —Consequence of mating decisions
6. Dissemination —Structure of breeding program —Crossbreeding
7. Evaluation —Genetic improvement —Genetic diversity

8.4.1 Intra-Herd and Global Selection

A breeding program by selection may be carried out either in one specific herd or area, or more comprehensively by involving different breeders or regions that will become the basis for selection in the breed targeted for improvement.

The works of several authors (Dekkers and Schook 1990; Roden 1994; Neopane and Pokharel 2005; Oldenbroek and Waaij 2014) suggest that the global or more comprehensive selection (involving a larger number of farms), provides higher annual genetic results than in intra-breeding selection. These results are linked to the intensity of the selection, as well as to the genetic parameters of the traits to be improved, whereby a larger number of phenotypic records and a higher genetic variability is expected in a global situation, leading to more selection precision and a lower rate of inbreeding.

8.4.2 Extinction Risk Status of a Breed

In certain situations, it is advisable to outline a breeding program for a breed that is danger of extinction, whereby several precautionary measures should be taken, even if it implies a loss in terms of genetic progress. That is, if well used, the breeding program can enhance the improvement of the breed, with a slower genetic improvement process and making it more competitive, but never compromising the genetic diversity. In endangered breeds, the breeding program must comply with characterization and conservation practices, namely, with ex situ practices. Although theoretically and intuitively selection and conservation being antagonistic, actually there are alternatives that allow for this compatibility. Furthermore, as demonstrated in the equation that quantifies genetic progress (**R**), genetic variability (represented by $\boldsymbol{\sigma_A}$—genetic additive standard deviation) is a determining common parameter for a selection or conservation program.

The BLUP—Animal Model was well studied (Quinton et al. 1992; Muir 2000), because it uses information about all the relatives kin, cause higher levels of inbreeding than other selection methodologies, and therefore larger losses of genetic variability. If the selected trait was affected by inbreeding depression, the response period with BLUP can be inferior. Thus, several selection methods were studied that maximized genetic progress and minimized the increase in inbreeding rate (Meuwissen 1997; Grundy et al. 1998, 2000; Meuwissen and Sonesson 1998; Weigel 2001; Avendaño et al. 2003; Sorensen et al. 2005).

Currently, using genomic selection, several studies have also been carried out to evaluate the impact of this methodology on genetic variability (Sonesson et al. 2012; Wolc et al. 2015). In a study conducted with goats, Brito et al. (2017) mention the importance of examining the levels of genetic diversity of a population, since genetic diversity is the most important element for improvement and has practical implications for the implementation of genomic selection.

According to Sonesson et al. (2012), a desirable control of inbreeding could be achieved when it was managed using the same information as is used to estimate breeding values, i.e., pedigree-based inbreeding control with pedigree-based estimation of breeding values, and genome-based inbreeding control with genome-based estimation of breeding values. In addition, the genome-based estimation of breeding values allows management of changes in genomic inbreeding, so changes in pedigree-based inbreeding are probably no longer relevant.

8.4.3 Production Aspects

Goat production systems are clearly differentiated among countries, regions, and breeds. In some regions, like the Mediterranean and the Balkans, most goats are produced in extensive systems for dual meat-milk purposes.

The diversity of goat genetic resources and production systems, associated fairly closely with the traditions, and soil and climate conditions of each region, makes available a variety of products (Carolino et al. 2016), but obviously has implications for the respective improvement strategies, namely in the improvement objectives, in the data collection system, and animal selection. We can distinguish four different types of programs according to the following production objectives:

- Meat goat breeding program;
- Dairy goat breeding program;
- Dual propose goat breeding program;
- Others (wool, resistance to parasitism, etc.).

8.4.4 Selection Nucleus and Breeding Program Scheme

A well-organized selection scheme should include a selection nucleus comprising a series of farms that may have to undertake a larger number of tasks, and can later disseminate the genetic progress to others.

In a breeding program, the organization, discipline, and conscientious involvement of participating breeders is crucial. Tenacity with respect to the breeding goal, accuracy in collecting phenotypes, genotypes, and pedigree registration, and last but not least, discipline in selection and mating are all important human factors that should be kept under control.

Pyramidal selection schemes were adopted for different breeds and species around the world, and consist of the organization of several subgroups called levels. There are normally three levels: nucleus, multipliers, and commercial herds (Fig. 8.3). Occasionally, there are only two (nucleus and commercial), and sometimes there are more than three (an extra multiplier level). Regardless of the number

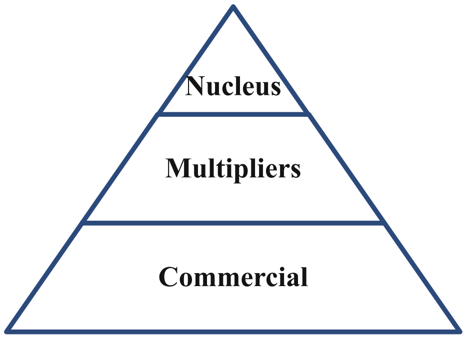

Fig. 8.3 Typical breed structure consisting of three tiers in the shape of a pyramid

of levels, the basic structure is very similar, normally represented in the shape of a pyramid.

In terms of performance, these pyramidal selection schemes can be of open nucleus or closed nucleus. In closed nuclei, the flow of genes occurs only from the top of the pyramid to the base, an example of which is the selection programs of pigs and poultry. In the open nuclei pyramid scheme, the flow of genes can occur both from the top to the base or from the bottom upward, and there are successful cases in ruminants. The selection nucleus is comprised of the best animals that can be recruited in any level of the pyramid. Although it depends on several factors, namely the proportion of animals in the nucleus, generally, an open nucleus scheme can get better genetic progress and a lower rate of inbreeding, but always with bigger health risks.

In many species used by mankind (e.g., goats), breeding programs have a simple or flat structure in which an intense selection of males takes place, as only a limited number of males is needed to breed and produce the next generation. Females can be selected too since many of them are needed as dams to produce the next generation, but this selection is less effective. In these species, the breeding animals (especially females) are in the hands of individual owners who make their own decisions on selection and mating. As a consequence, breeding goals change often, so the recording of traits and pedigrees is less complete, and selection and mating can hardly be influenced. This results in a low genetic improvement rate over generations.

Goat herd books play a prominent role in the breeding program. They do the pedigree recording and set the rules for the characteristics of the males and females to be selected as parents for the next generation. The rules for the males are often much more strict and only a limited number is approved for breeding. Often a lot of emphasis in this approval is given to confirmation. For the females the rules are very loose, female culling is seldom practiced.

8.5 Different Selection Methodologies

Selection methodologies in different animal species have evolved considerably around the world in the last few years, including goat production. The procedures and different selection schemes are determined by factors such as breed, specific function (e.g., meat or dairy), and method of production.

The annual genetic progress of a trait is determined by several parameters (precision and intensity of the selection, genetic variability, intervals between generations; see point 8.2), which in turn depends also on the amount and type of information available (individual or family), the way it is used, and the selection method of the animals (Van der Werf 2000). According to Falconer and Mackay (1996), Gama (2002), and Carolino (2006), the main selection methods are as follows:

- Individual selection
- Family selection:
  - Pedigree selection
  - Sib selection
  - Progeny test
  - Within-family selection
- Combined selection
  - Selection Indexes

    Simple selection indexes
    Special selection indexes (restricted selection index, retrospective selection index, traits defined as ratios, etc.)
  - BLUP—Animal Model
  - MAS (Marker-assisted selection)
  - GS (Genomic selection)

8.5.1 Individual Selection

In individual selection, animals are chosen based on their performance, which makes this methodology the simplest one. Although in certain situations it can provide satisfactory results, namely in traits with high heritability, this methodology is fairly limited when the aim is to select traits that have only been evaluated in one gender (e.g., milk production), evaluated too late (e.g., productive longevity), or evaluated after death (e.g., meat and carcass characteristics).

In these situations, it is clearly advantageous to resort to family-based selection, which uses the phenotypic information of individuals with different degrees of kinship to the individuals to be selected (offspring, half-sibs, etc.)

8.5.2 Family Selection

Falconer and Mackay (1996) recommended family-based selection for low heritability traits, or when these cannot be measured in the individuals to be selected. However, the possibility of increasing selection precision depends on the amount of available family information and the degree of kinship among individuals previously analyzed and those to be selected. In intra-family selection, the standard for selection is the deviation of the phenotypic value of the individual in relation to the family average.

The progeny test is a widely used selection methodology in animal genetic improvement, especially in dairy livestock (goats, bovines, and dairy sheep), in which the standard of selection, as the name indicates, is based on the performance of the progeny. It is particularly useful when a trait is limited to one gender, and for Falconer and Mackay (1996), intuitively it appears to be the ideal selection method since theoretically the average figure estimated of the progeny of an individual is close to its real breeding value.

However, despite being able to provide more precision in selection and consider four selection paths (sires of males, dams of males, sires of females, and dams of females), this methodology can have certain drawbacks (Van der Werf 2000). The limited number of animals that can be tested and the huge exigency in terms of efficiency and organization of the entire testing process can result in excessively extended generation intervals and a decrease in selection intensity.

Different goat breeds (e.g., Alpine and Saanen in France, Murciana-Granadina and Malagueña in Spain, Boer in South Africa, New Zealand, Australia and USA) include individual testing (individual selection) in the first stage of their improvement programs, and later in the progeny test (Ménissier 1988; Kinghorn and Simm 1999; Carolino 2006).

8.5.3 Combined Selection

Selection indexes are surprisingly useful when the aim is to select one or more traits simultaneously from several sources of productive information. With indexes, the breeding value of an individual $\left(\hat{\mathrm{A}}_i\right)$ is obtained from the value of the actual index $\left(\mathrm{I} = \hat{\mathrm{A}}_i\right)$, which maximizes the probability of correct ranking of individuals according to their real breeding value $\left(\hat{\mathrm{A}}_i\right)$. The selection indexes can also be used in the selection of different traits, introducing the concept of global merit or aggregate genotype (*H*), defined as a linear function of the genetic values of traits used as improvement objectives, considered for their respective economic weight. Thus, a selection index can combine different types of phenotypic information of various traits $\mathrm{I} = \sum_i^n b(x_i - \mu_i)$, so as to predict the global value $\mathrm{H} = \sum_i^n (a_i \mathrm{A}_i)$ of each individual, in which b_i, x_i, μ_i, and a_i correspond, respectively, to the selection index coefficient (or weight), the phenotypic value of an individual, the average and to the economic weight of trait i.

The traits in I are the selection criteria and the traits in H are the breeding objectives. In matrix notation, the aim is to build an index $I = b'X$ which allows to maximize the response in $H = a'A$. The coefficients in an index without restrictions can be obtained through the resolution of the system Pb = Ga, which according to Hazel (1943), maximizes the correlation (r_{IH}) between the selection index (I) and the global value (H). For Bourdon (1997), easily and inexpensively measurable traits that are correlated with H should be appraisal factors in the selection index, while selection objectives should include traits that have economic impact on the production system.

Certain changes can be introduced (Cunningham et al. 1970; Gibson and Kennedy 1990) in the general theory of index selection developed by Hazel (1943) to provide particular features (Gama 2002), namely desirable responses, total or partial restrictions of one or more traits, use of defined traits as products or ratios, or function in retrospect.

In recent decades, the "BLUP—Animal Model" has widely been used at an international level in different species, including goats, to estimate genetic parameters and for genetic evaluation (estimate of genetic values), for one or more traits, which could include different types of models and fixed and random effects.

The BLUP—Animal Model is an extension of the selection index methodology, with a few substantial differences (Simm 1998), and when compared to phenotypic selection it presents several advantages (Ronningen and Van Vleck 1985; Henderson 1994; Mrode 1996; Van der Werf 2000), namely:

- best in the sense that it maximizes the correlation between the real breeding value (A) and the estimated breeding value ($\hat{A}$); in other words, it minimizes the prediction error variance, ($A - \hat{A}$);
- solutions are obtained through a linear function of the observations;
- solutions are unbiased in the sense that the expectancy of the real value, given the estimated value, is the actual real value (that is, $E(A|\hat{A}) = A$). True breeding values are distributed around predicted breeding values;
- involves the prediction of the real genetic values of the individuals in the population.

The real breeding value of the animals is never known, but an estimate can indicate what the animal will be worth when used as breeding stock. This can be obtained with varying precisions, according to the amount of available information, genetic parameters, and other factors (Arnason and Van Vleck 2000). The breeding value represents the value of the individual in a selection program for a specific trait or the sum of the effects of each allele which affects that trait, and can be quantified by twice the deviation of a large number of progeny (theoretically) of that individual in relation to the population average.

The BLUP—Animal Model based on the concept of the infinitesimal model, which assumes that the traits are determined by an infinite number of *loci*, each infinitesimally small, independent, and additive, has proven enormously successful in genetic improvement of a great variety of species, breeds, and traits, showing great strength even in traits controlled by a reduced number of *loci*.

In practical terms, these characteristics or special features of the BLUP—Animal Model have certain advantages, and mean that the breeding value of an individual selected for this methodology takes into account:

- The genetic value of all its kin (due to the inclusion of the kinship matrix);
- The breeding value of the participants in the different matings, (that is, a male will not be affected for having mated with females of inferior quality, nor benefit from having mated with females of superior quality);
- All the available productive records (repeated records of the same individual or family members, etc.)
- The fixed effects to which a record is subject to (e.g., different environments).

One unavoidable aspect of the BLUP—Animal Model that must always be present is that the genetic value of an animal for a given trait can only be predicted if it, or its kin, have productive records of that trait. A possible disadvantage of the BLUP, studied by various authors (e.g., Verrier et al. 1994; Muir 2000), is that it may not be optimal in a medium and long term if the right precautions are not taken. This is due to the fact that by using information about all the relatives, there is a tendency to continuously select, from different generations, individuals that are related, resulting in higher levels of inbreeding than with individual selection, and thus a bigger loss of genetic variability. If the selected trait is affected by inbreeding depression (decrease in survival or adaptation capacity, and in productive and reproductive performance due to inbreeding), the response period with the BLUP can be inferior to individual selection.

Several works were carried out to use selection methodologies which maximized genetic progress, and minimized the increase of inbreeding rate (Meuwissen 1997; Sorensen et al. 2005).

Marker-assisted selection (MAS) is the process of using the results of DNA testing in the selection of individuals to produce offspring for the next generations. The information from the DNA testing, combined with the observed performance records for individuals, is intended to improve the accuracy of selection and increase the possibility of identifying organisms carrying desirable and undesirable traits at an earlier stage of development. Complex traits, including many of economic importance, are controlled by many genes and are influenced by the environment. When an animal has a favorable performance record for a certain trait, it means that, based on phenotype and pedigree, the animal has inherited a greater than average number of favorable alleles of each gene affecting that specific trait.

MAS has presented substantial advances in recent years, particularly in certain traits like resistance to diseases, product quality, or morphological characteristics. Potential benefits of genomic selection of small ruminant breeding programs can be expected (Shumbusho et al. 2013, 2016), and there are currently several genetic tests for use in goats available in the market (Alpha-S1 Casein, Freemartin, G6-Sulfatase deficiency, and Scrapie resistance).

Despite the unquestionable success of the infinitesimal model, which assumes that traits are determined by an infinite number of *loci*, there has been a mounting number of works that suggest that there might be a finite number of *loci* responsible for the variability of quantitative traits, like milk and meat production. Numerous studies demonstrated the distribution of the effects of these *loci* in quantitative traits, proving that few genes can have a large effect while many genes can have small impacts. A *locus* with a specific known effect in a quantitative trait is called quantitative trait locus (QTL).

According to Lopes et al. (2017), initially, the use of marker-assisted selection in animal genetic improvement was more complicated due to the fact that it was difficult to identify the markers associated with QTL's with panels with low-density markers (microsatellites). Even so, genetic markers have recently been used successfully in commercial selection programs of different species and breeds. Such major genes were associated with various reproductive, disease, or production traits of interest to the breeders. They include as examples: Prp for scrapie resistance in goats (Barillet et al. 2009), casein genes for protein content in goat milk (Leroux et al. 1990), and 11.7-kb deletion for polledness in goats (Pailhoux et al. 2001).

The study of the genome in the different species of interest for agriculture, would prompt the identification of *loci* that affect traits with economic importance in the majority of species, through the development of platforms of genotyping of SNP's in high density (thousands of SNP's) throughout the whole genome (Matukumalli et al. 2009). More recently, using these platforms or high-density panels to detect simultaneously thousands of single nucleotide polymorphisms (SNP's), genome-wide association studies, the power and precision of the results of the markers linked to QTL's, opening new opportunities for MAS. Although using different methodologies and analysis strategies, the genome-wide selection (GWAS) will allow for the simultaneous prediction of the effects of the various markers that influence a certain trait and can be used in the selection of genetically superior individuals.

The availability of genome sequencing data has opened up new fields of investigation in domestic ruminant species with sequenced genomes. The development of high-density SNP arrays and their application in genome-wide association studies has facilitated the identification of regions that control quantitative traits in dairy cattle; however, much less is known about the *loci* controlling milk traits in goats (Martin et al. 2017).

In a recent study, Martin et al. (2017) identified a large number of QTLs for dairy traits in Alpine and Saanen goats. Furthermore, they identified two mutations in the DGAT1 gene, associated with a reduction in fat content, and proved their causality with a functional test. These results advance understanding of the genetic architecture of caprine milk composition and will be useful for future breeding programs. Both mutations were associated with a notable decrease in milk fat content. Their causality was then demonstrated by a functional test. These results provide new knowledge on the genetic basis of milk synthesis and will help improve the management of the French dairy goats breeding programs.

According to Rupp et al. (2016), genomic selection based on phenotypic, genotypic, and pedigree data opens new perspectives for breeding programs in ruminants. This is especially true for milk selection where selection of sires is hampered by a progeny testing period and genomic schemes have been immediately profitable. Genomic selection in ruminants can also be useful for meat production breeds, especially for traits that are measured later in the life of the reproductive females, such as reproductive ability, breeding seasonality, and longevity as well as for invasive or destructive evaluation measures of carcass composition and meat quality, which are typically recorded on the relatives of selection candidates and require animals to be sacrificed. Genomic selection also has potential to increase the resilience of small ruminant enterprises (Rupp et al. 2016).

This new approach, however, has certain prerequisites in order to be carried out successfully (Meuwissen et al. 2001; Cantor et al. 2010). Costly investment is still required for the acquisition/genotyping of currently available commercial chips (e.g., Illumina Caprine 50 K BeadChip); although the cost per individual/SNP has gone down, present prices are still quite high. Alternatively, studies of genome re-sequencing can be done, which also require some investment, but information of a large number of individuals with precise genealogical and phenotypic information is still necessary, namely productive records of the traits to be selected.

With these new methodologies, and using GWAS, the aim is to establish prediction equations that quantify the genetic variation of each *locus* that influences a certain trait that is of interest to breeders, and which also allows for an estimate of the genomic value of each animal based on knowledge of its genotype.

According to Ramos et al. (2009), Perez-Enciso et al. (2015), Rupp et al. (2016), and Brito et al. (2017), the development of next-generation sequencing technologies (NGS) made it possible to use information about wide regions of the genome in the normal routine of genetic evaluations, which triggered considerable interest both in the fields of animals and plants, increasing the selection response and genetic progress.

Combining information from genetic tests and performance records into the selection process will be better than using phenotype, performance, and markers separately. The challenge is to determine what emphasis marker information should be given in the global selection decisions in the future.

8.6 Concluding Remarks

Goats are part of the rural world and are produced in some of the most varied and inhospitable regions of the planet. Due to their genetic, morphological, and physiological traits, these animals are, beyond any doubt, excellent converters of poor resources into animal protein and food with a high biological value. They are often the only animals that are able to survive in environments and conditions that are averse to most kinds of production animals.

The big challenges faced by humanity in terms of food security and conservation of the planet imply that goat production may have to be subjected to modifications and developments in a near future.

An animal genetic improvement is unquestionably a powerful tool which resorts to the most recent and advanced technologies, without ignoring more empirical knowledge of the different areas of animal genetics, thus enabling goats to adapt rapidly to the demanding challenges of the twenty-first century.

The biodiversity in goats and their production systems has an enormous potential for the genetic improvement of adaptive traits that can be valuable in the face of a scenario of eminent climate change and the demand for increased food production.

The genetic improvement of goat breeds that are adapted to harsh regions and adverse climates, are resistant to diseases, and are already accustomed to transform natural resources, could reinforce the worldwide importance of these small ruminants.

Correctly defined improvement objectives for each case and circumstance, that are perfectly in line with the most efficient selection methodologies, will be determinant for the biological and economic success of selection programs and for the future use of goats for the good of humanity and the conservation of the planet.

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Part III
Goat Nutrition, Nutritional Disorders and Meat Quality

Chapter 9
Murciano-Granadina Goat Nutrition Including Local Feed Resources

Eduarda Molina-Alcaide and Manuel Romero-Huelva

Abstract The Murciano-Granadina goat represents about 30% of dairy goats in Spain. This breed is widely spread around Europe, America and Africa due to its ability to adapt to difficult environments and its high milk production as well. Adequate feeding is the basis for the development of animal production and requires a good knowledge of both nutrient and energy requirements of a particular breed and the nutritive value of available feedstuffs. Information on nutrient and energy requirements of Murciano-Granadina goat has been generated in recent decades. Information on the nutritive value of conventional and unconventional local foods has been provided in the past decades. The use of unconventional foods could be useful to decrease feeding cost and overcome other limits in animal production. Unconventional feedstuffs may have added value as well improving the composition of milk, especially fatty acid profile, and decreasing methane emissions. The proper use of by-products, many of them with high water content, requires implementing technologies for conservation. The response of animals to local feeds in arid and semi-arid regions could be influenced by the animal's experience or degree of specialization/adaptation to a particular ecological niche.

9.1 Introduction

The disparity between the growth of the human population and that of food to meet their needs is increasing. Livestock can play a very important role as food supplier. However, animal production is limited by various factors such as competition with humans for food, especially cereals and soy. In arid and semi-arid ecosystems, with scarce and poor quality pastures, additional limitations to the animal production

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exist as well. The use of unconventional feedstuffs could contribute to the development of sustainable animal production systems in this type of ecosystems.

Goat is the species of ruminants that was first domesticated. The world goat population is around 1000 million heads corresponding 2% to Europe. In the European context, Spain with more than 2.7 million goats ranks the second position after France. Approximately 50% of caprine production in Spain is concentrated in Andalusia (MAGRAMA 2015). The Murciano-Granadina goats derived from the oldest two breeds (see Chap. 15 of volume 2) in the Iberian Peninsula and the most widely distributed not only in Spain but also in other countries due to its special suitability for adverse conditions and its high milk production, which is mainly produced in intensively managed farms (Pardo et al. 2016). However, these intensive systems are highly dependent on the use of concentrates whose ingredients are expensive and frequently imported. Thus, low-cost dietary strategies based on local unconventional resources need to be implemented. The response of the animal to diets depends on the interaction between the energy and nutrient requirements of a particular species or breed, and the ability of that diet to supply the energy and nutrients required by the animal (Aguilera 2001). There is also an interest for the development of dietary strategies that not only attend to the needs of the animal but also improve its health and that of the consumers reducing the environmental impact as well.

9.2 Energy and Nutrients Requirements

Specific information concerning energy and nutrient requirements of Murciano-Granadina goat breed (Fig. 9.1) has been generated during past decades (Aguilera et al. 1990; Prieto et al. 1990; Lachica et al. 1997). The metabolizable energy (ME) required for maintenance of this breed was stablished in 443 kJ/kg$^{0.75}$/day, being the overall efficiency of utilization for maintenance 0.73. An average value of 422 kJ/kg$^{0.75}$ per day for castrated adult males and growing females has been proposed for maintenance requirements. Energy cost of eating ranges from 9.02 for roughages to 1.55 J/kg body weight (BW)/g dry matter (DM) intake for concentrates. Walking requires 3.35, 31.7 and −13.2 J/kg BW and metre for horizontal, ascending and descending movement, respectively. For lactating animals, the maintenance requirements of energy were stablished in 401 kJ ME/kg$^{0.75}$ per day and its efficiency for lactation in 66.7% and that for energy retention 0.907 times that for milk production. In addition, a requirement of 4.20 MJ of ME/kg of 4% fat-corrected milk produced has been calculated. Endogenous urinary N and total maintenance N requirement have been calculated to be 119 and 409 mg N/kg$^{0.75}$ per day, respectively. For lactating animals, those values were estimated to be 218 and 478 mg N/kg$^{0.75}$ per day, respectively.

Fig. 9.1 Murciano-Granadina dairy goat. Image by courtesy of UNIPROCA, SC (provided courtesy of CAPRITEMA, SL farm)

9.3 Unconventional Feedstuffs

Feeding unconventional feedstuffs to livestock is an old practice, but the low nutritive value and the imbalanced nutrient profile limit usually their use (Table 9.1). In Spain, the industry of feed production reuse 6–7 million tonnes of by-products per year (García Rebollar and de Blas Beorlegui 2016) that represents almost 30% of the ingredients used by the sector (Algarra 2015).

Most of the agro-industrial by-products have a seasonal production and many of them are rich in water and whose utilization requires the implementation of technologies for their stabilization and conservation, such as silage, multinutrient feed blocks (MFB), pellets, etc. Ensiling is an easy and cheap way to stabilize and process big amounts of feedstuffs either alone (e.g. citrus pulp, tomato pulp and brewer´s grain) or mixed with other ingredients (olive leaves, olive cake, carrots, artichokes mixed with barley or wheat straw, maize silage, hay, etc.). However, there are some major concerns as high moisture (40–60%) that limits the amount to be included in a diet and its delivering to farms, the possible presence of aflatoxins

Table 9.1 Chemical composition of by-products used in Murciano-Granadina goats feeding

Ingredient	Dry matter (%)	Crude protein (%)	Ether extract	NDF	Sugars	Fatty acids	Secondary compounds	References
Rice bran	90	11–14	12–18%	16–21%	21–28% starch	Palmitic, linoleic and oleic	ND	Criscioni and Fernández (2016)
Citrus pulp	20	6	2.6%	25%	25% pectins and 23% sugars	ND	ND	López et al. (2014)
Soybean hulls	89	11.8	2.5%	58%	1.5% sugars	ND	ND	López et al. (2014)
Orange pulp	20	6	2.6%	25%	25% pectins and 23% sugars	ND	ND	Ibáñez et al. (2016)
Corn gluten	89	24	3%	36%	16.9% starch and 1.6% sugars	ND	ND	López and Fernández (2013)
Lemon fruit	18	6.6	1.6–4%	33%	19%	ND	ND	Madrid et al. (1996)
Olive leaves	58	7	5.6%	41%	ND	ND	8.3% total CT	Molina-Alcaide et al. (2003) and Yañez-Ruiz et al. (2004a)
Olive cake	87	7.8	5.5%	62%	ND	ND	13% total CT	Yañez-Ruiz et al. (2004b)
Silage of artichoke	24.4	12.3	7.5%	ND	ND	ND	ND	Monllor et al. (2016)
Crop residues	87–93	7–29	0.7–5.8%	ND	ND	ND	ND	Morales et al. (2000)
Cassava by-products	28.2	4.8	1.3%	19.6%	ND	ND	2.9% CT	Meffeja et al. (2000)

(continued)

Table 9.1 (continued)

Ingredient	Dry matter (%)	Crude protein (%)	Ether extract	NDF	Sugars	Fatty acids	Secondary compounds	References
Citrus pulp	88	6.2	2%	31.3%	ND	ND	ND	Bueno et al. (2002)
Cotton by-products								Belewu and Ademilola (2002)
Maize stubble and stovers	28.9	6.9	1.2%	65.5%	ND	ND	ND	Meffeja et al. (2000)
Wheat straw supplemented with broiler litter	–	15–35	2.4%	43.8%	ND	ND	ND	Animut et al. (2002)
Green house tomato wastes	8	16	2%	30%	ND	ND	ND	Romero-Huelva et al. (2012)
Date-palm leaves	93	1.9	4.4%	54.4%	ND	ND	ND	Pascual et al. (2000)
Pea plant	90	7	ND	64%	ND	ND	ND	Soto-Navarro et al. (2004)

CT Condensed tannins; *NDF* Neutral detergent fibre; *ND* Not detected and/or listeria that could affect the taste making them undesirable for the animals. However, appropriate ensiling is a promising technique.

MFB could be another alternative to store agro-industrial by-products. Making MFB involves mixing one or more by-products, a binder (quicklime, cement and clay), water and common salt, as well as urea with or without molasses (Ben Salem and Nefzaoui 2003). They should be air-dried until hardness criteria are met. Depending on their formula, MFB can replace partially or totally concentrate feeds, which alleviate feeding costs without detrimental effects on livestock performances. This explains the increasing adoption of MFB technology in about 60 countries (Makkar et al. 2007). Although MFB is a good alternative to ensiling, it is still difficult to implement them in practical conditions in developed countries.

Conserving agro-industrial by-products as pellets with a diameter varying from 3.5 to 5.5 mm, which promote higher intakes, is another option. Pelleting requires previous drying of by-products and mechanization. In the last years, several systems have been successfully adapted to dry by-products (trommel, convection solar oven, solar drying, etc.). However, those technologies have some major limitations (cost, time, temperature, nutrient value of end product, and others).

9.3.1 Olive By-Products

Focusing on Murciano-Granadina goat feeding different by-products have been used in the last years. Olive leaves (OL) from pruning or olives cleaning have been traditionally used in ruminants feeding during periods of scarce feed supply. Their nutritive value is low, especially for protein (Molina-Alcaide et al. 2003). In unproductive animals, the intake of OL, OL treated with polyethylenglicol (PEG) and OL supplemented with barley and faba beans were 545, 571 and 528 g DM/animal/day, respectively. Purine derivatives excretion in urine, an index of microbial protein synthesis in the rumen, was 424 mol/kg$^{0.75}$ (Yañez-Ruiz et al. 2004a), similar to the value found with diets of medium quality. Supplementation of OL with readily degradable carbohydrates (barley) and protein (faba beans) leads to an adequate microbial activity in the rumen. Since PEG inactivates condensed tannins and it did not affect OL protein availability, other secondary compounds different from tannins may be responsible for the low availability of protein from OL. In vivo digestibility of dry matter and organic matter of OL depends on the preservation of OL and on the wood content (Delgado-Pertíñez et al. 2000). Attention has been paid to the presence of Cu in OL that is used to protect against fungal and could restrict their use in practical feeding. Alkaline phosphatase activity in the serum of Murciano-Granadina goats increased 50% after feeding OL ad libitum during 28 days (Yáñez-Ruiz and Molina-Alcaide 2008) which may reflect a hepatic dysfunction.

Two-phases dried and destoned olive cake (2POC) has been also used in unproductive Murciano-Granadina goats feeding (Yañez-Ruiz et al. 2004b). Animals received diets based on alfalfa hay and a concentrate (based on barley), and/or 2POC treated or not with PEG. The dry matter intake was 918, 809 and 831 g/animal/day, respectively. No sign of kidney or liver damage was found with diets including 2POC (Yáñez-Ruiz and Molina-Alcaide 2007). Ensiled olive cake with sunflower oil in Murciano-Granadina goat diet did not affect feed intake and increased milk yield (Arco-Pérez et al. 2014). Silages including OL, olive cake and barley (2:1:1 ratio in fresh matter basis) did not have any detrimental effect on the goat's welfare (Pardo et al. 2016)

9.3.2 Citrus By-Products

Different by-products derived from citrus have been also used in Murciano-Granadina feeding. Citrus pulp or soybean hulls were used to replace 61% of corn grain in the diet of lactating goats without effect on milk yield, although diet with by-products promoted higher milk fat and methane production than the control goats (López et al. 2014).

Orange pulp and soybean hulls replaced 59% of barley grain without any effect on nutrient digestibility, milk yield, methane production and saturated fatty acids (FA), but the conjugated linoleic FA in milk increased and protein decreased (Ibáñez et al. 2016).

A 50:50 alfalfa hay:dried lemon, 50:50 barley straw or 50:50 urea-barley straw were supplied at maintenance level to castrated males.

Dried lemon was included up to 300 g DM/animal/day and it was reported (Madrid et al. 1996, 1998) that intake and digestibility of dry matter and organic matter of a diet based on urea or NaOH-treated straw could only be improved by supplementation with lemon fruit at modest levels.

9.3.3 Horticultural Wastes

Wastes of horticulture utilization could be promising. Artichoke silage included in diets based on alfalfa hay and a mixture of cereal and legume grains did not affect (Table 9.2) milk yield and composition (Monllor et al. 2016).

Tomato and cucumber fruits from greenhouse horticulture were included in feed blocks that replaced 50% or 35% of the concentrate in diets of unproductive and lactating goats, respectively without effect on nutrient digestibility and milk yield, decreasing feeding cost and methane production and improving milk FA profile (Romero-Huelva et al. 2012; Romero-Huelva and Molina-Alcaide 2013). Silages including tomato wastes have shown promising results regarding greenhouse gases emissions (Pardo et al. 2016).

Table 9.2 Effect of diets including by-products on dry matter intake, organic matter digestibility and milk yield and composition in Murciano-Granadina goats

Diet						Milk			References
Forage (g/day)	Concentrate (g/day)	Unconventional resource	Physiological state	Dry matter intake	Organic matter digestibility	Yield	Composition	Fatty acids profile	
Alfalfa hay (800)	1600	Orange pulp	Lactating	No effect	+4%	No effect	No effect	ND	Ibáñez et al. (2016)
Alfalfa hay (800)	1600	Soybean hulls	Lactating	No effect	−14%	No effect	No effect	ND	Ibáñez et al. (2016)
Alfalfa hay (1000)	500	Olive cake	Lactating	No effect	No effect	−18 to −21%	Lower protein and fat yield	+23 to +41% CLA	Molina-Alcaide et al. (2010)
Cereal Straw (250)	1500	Dry citrus pulp	Lactating	No effect	No effect	No effect	Higher milk fat content	ND	López et al. (2014)
Cereal Straw (250)	1500	Soybean hulls	Lactating	No effect	−7.3%	No effect	Higher milk fat content	ND	López et al. (2014)
Alfalfa hay (1000)	650	Tomato	Lactating	Lower trend	No effect	No effect	Lower lactose yield/content	Higher LA, LNA and total PUFA	Romero-Huelva et al. (2012)
Alfalfa hay (1000)	650	Cucumber	Lactating	Lower trend	No effect	No effect	No effect	Higher LA, LNA and total PUFA	Romero-Huelva et al. (2012)
Alfalfa hay (800)	1300	Soy hulls/corn gluten feed	Lactating	No effect	ND	No effect	Higher fat yield	ND	López and Fernández (2013)
Alfalfa hay (300)	150	Tomato	Dry-non pregnant	No effect	−7.4%	ND	ND	ND	Romero-Huelva and Molina-Alcaide (2013)

(continued)

Table 9.2 (continued)

Diet						Milk			References
Forage (g/day)	Concentrate (g/day)	Unconventional resource	Physiological state	Dry matter intake	Organic matter digestibility	Yield	Composition	Fatty acids profile	
Alfalfa hay (300)	150	Cucumber	Dry-non pregnant	No effect	−5.9%	ND	ND	ND	Romero-Huelva and Molina-Alcaide (2013)
Alfalfa hay (600)	200	Olive cake	Dry-non pregnant	No effect	ND	ND	ND	ND	Molina-Alcaide et al. (2009)
Cereal Straw/ Alfalfa hay (300)	None	Citrus pulp	Male goats	From +5 to +21%	From +12.5 to +36.5%	ND	ND	ND	Madrid et al. (1996, 1998)
Pasture	None	Shrubs and fodders	Kids	ND	ND	ND	ND	+36.6% oleic acid −12.3% myristic acid	Zurita-Herrera et al. (2015)

LA Linoleic acid; *LNA* Linolenic acid; *PUFA* Polyunsaturated fatty acids; *ND* Not detected

9.3.4 Other By-Products

Other by-products, either alone or as mixtures, have been used in Murciano-Granadina goat feeding. The replacement in dairy goat diet of 47% (DM basis) of conventional ingredients (corn, wheat bran, sunflower meal and soy) in the concentrate with by-products (tomato fruits, citrus pulp, brewer´s grain and yeast), reduced feeding costs and enteric methane emissions, improved the FA profile in milk without compromising nutrient utilization or milk yield and composition (Romero-Huelva et al. 2017).

Rice bran that contains high levels of oleic and linoleic replaced oats in a forage:concentrate (35:65) diet for lactating goats (Criscioni and Fernández 2016) without differences in nutrient and energy utilization or milk yield. On the contrary, methane production and glucose decreased, and milk fat and monounsaturated FA increased resulting in a lower atherogenicity index for milk.

Wastes of Rosemary distillation do not alter milk yield or quality (Jordán et al. 2010). Corn gluten was used without effect on energy metabolism and performance of animals (López and Fernández 2013). Leaves of date-palm ground supplemented with a source of nitrogen could be an alternative to barley straw (Pascual et al. 2000).

9.4 Dietary Strategies Using Unconventional Feedstuffs

Dietary strategies based on low-quality forages, crop residues, wastes or by-products require specific supplements since those feedstuffs are poor in nitrogen. Ruminal degradable protein promotes a more efficient ruminal activity than non-protein N in diets based on shrubs or high fibre roughages (Molina-Alcaide et al. 1996; Carro and Miller 1999). Crude protein in legume seeds is high and variable (25–45%) and they could be an interesting source of vegetal protein. Faba beans, peas, lupins and chickpeas seeds supplemented cereal straws and olive leaves beans and peas having similar suitability than soya as protein supplement optimizing ruminal fermentation (Yáñez-Ruiz et al. 2009). Lupins, faba beans, bitter vetch and vetch have been used as a source of crude protein in diets for goats (30% of total protein in diet). Faba beans was the best choice regarding nitrogen availability and metabolism although all the legume seeds showed high crude protein, rumen degradability and intestinal digestibility of rumen undegraded fraction (Ramos-Morales et al. 2010a, b). Pea plant as supplement in diets based on by-products with decreasing intake did not affect ruminal fermentation or nutrient digestibility (Soto-Navarro et al. 2004). Bampidis et al. (2011) advised to use not more than 300 g of legume seeds/kg diet to avoid deactivation of ruminal fermentation due to the presence of secondary compounds.

A special attention has to be paid to the plant secondary compounds (e.g. phenolics, saponins, alkaloids, non-protein amino acids, essential oils and glycosides) when using unconventional feedstuffs in ruminant feeding. Tannins and saponins are the most widely present in by-products, tree leaves and shrubs (Bryant et al. 1992). These compounds could have both beneficial and adverse effects depending upon their nature, level, structure, diet ingredients, animal species, physiological stage and intake (Makkar 2003). Foliage, fruits and seeds of fodder shrubs and trees have been reported to suppress ruminal protozoa population (Jouany et al. 2007).

Recently, some researchers (Wang et al. 2009; Patra and Saxena 2010) suggested that by-products in animal diet could reduce methane emissions and urine nitrogen excretion due to the presence of plant secondary compounds (Table 9.3). Grape marc and lees from wine production containing moderate levels (18–200 g/kg of DM) of condensed tannins (Molina-Alcaide et al. 2008; Greenwood et al. 2012), could reduce nitrogen excretion by animals. The net effect of condensed tannins is an increased flow of protein to the small intestine, where proteins may or may not be available for digestion depending on the astringency and concentration of condensed tannins. When dietary crude protein exceeds animal requirements, condensed tannins could improve animal performance; however, when crude protein is low and fiber concentration is high condensed tannins are nearly always detrimental (Waghorn 2008).

Tannins might also have beneficial effects on ruminant physiology, production and health (Hoste et al. 2006). Indeed, they have potential positive effects as nutraceuticals with anthelmintic properties on small ruminants (Alonso-Díaz et al. 2010). Celaya et al. (2010) observed how the inclusion of heather (*Calluna vulgaris* and *Erica* spp.) and/or oats (*Avena sativa*) reduced gastrointestinal nematode parasitism and increased goat performance.

Leucaena leaves contain mimosine that is toxic, but after adaptation, goats can degrade it increasing their rate of productivity (Ghosh and Bandyopadhyay 2007). It has also been described the benefits of lycopene on milk antioxidant properties of sheep feed tomato pomace (Sgorlon et al. 2006).

Special attention has to be paid to the added value of unconventional feedstuffs in animal feeding as well. The use of wastes and by-products rich in fat could have interest to improve FA profile in animal products. Replacing 50% of concentrate in Murciano-Granadina goat diet with feed blocks including crude 2POC promoted increased oleic, linoleic and rumenic acids in milk (Molina-Alcaide et al. 2010). Those studies showed the potential of using olive cake not only to provide cheap fiber and energy to ruminants but also for healthier animal products in terms of FA profile. The inclusion of wastes from fruits of tomato and cucumber increased polyunsaturated FA in goat milk (Romero-Huelva et al. 2012).

On the other hand, methane emission from enteric fermentation is of concern worldwide due to its potential as greenhouse gas (Wright and Klieve 2011), 25 times higher than that of CO_2. Thus, ruminant production systems play an important role in climate change (Steinfeld et al. 2006; Martin et al. 2010), accounting for 45% of the anthropogenic methane emissions (Ellis et al. 2007). Globally, goat milk and meat production are responsible for $\sim$174.5 million tonnes of carbon dioxide equivalents (CO_2-eq), which are mainly associated with methane (CH_4) and nitrous

Table 9.3 Effect of diets including by-products on rumen pH, concentrations of volatile fatty acids and ammonia nitrogen, microbial flow and methane production in Murciano-Granadina goats

Diet				Rumen fermentation					References
Forage (g/day)	Concentrate (g/day)	Unconventional resource	Physiological state	pH	Volatile FA	Ammonia-N	Microbial N flow	Methane production	
Alfalfa hay (800)	1600	Orange pulp	Lactating	−2.7%	+83.4%	+247%	ND	No effect	Ibáñez et al. (2016)
Alfalfa hay (800)	1600	Soybean hulls	Lactating	−2.7%	+69%	+154%	ND	No effect	Ibáñez et al. (2016)
Alfalfa hay (1000)	500	Olive cake	Lactating	ND	ND	ND	−15.2 to −37.7%	ND	Molina-Alcaide et al. (2010)
Cereal Straw (250)	1500	Dry citrus pulp	Lactating	No effect	−20.5%	−48%	ND	+42%	López et al. (2014)
Cereal Straw (250)	1500	Soybean hulls	Lactating	No effect	+30.9%	−27.8%	ND	+39.4%	López et al. (2014)
Alfalfa hay (1000)	650	Tomato	Lactating	No effect	−26.8%	−35.2%	−19%	−34.4%	Romero-Huelva et al. (2012)
Alfalfa hay (1000)	650	Cucumber	Lactating	No effect	No effect	−34.1%	+16.6%	−36.5%	Romero-Huelva et al. (2012)
Alfalfa hay (800)	1300	Soy hulls/corn gluten feed	Lactating	No effect	No effect	+56%	ND	ND	López and Fernández (2013)
Alfalfa hay (300)	150	Tomato	Dry-non pregnant	No effect	+20%	No effect	−22.7%	−26%	Romero-Huelva and Molina-Alcaide (2013)
Alfalfa hay (300)	150	Cucumber	Dry-non pregnant	No effect	+22.8%	No effect	No effect	No effect	Romero-Huelva and Molina-Alcaide (2013)

(continued)

Table 9.3 (continued)

Diet				Rumen fermentation					References
Forage (g/day)	Concentrate (g/day)	Unconventional resource	Physiological state	pH	Volatile FA	Ammonia-N	Microbial N flow	Methane production	
Alfalfa hay (600)	200	Olive cake	Dry-non pregnant	No effect	No effect	No effect	−33 to −42%	ND	Molina-Alcaide et al. (2009)
Cereal Straw/ Alfalfa hay (300)	None	Citrus pulp	Male goats	ND	ND	ND	ND	ND	Madrid et al. (1996)
Pasture	None	Shrubs and fodders	Kids	ND	ND	ND	ND	ND	Zurita-Herrera et al. (2015)

FA Fatty acids; *VFA* Volatile fatty acids; *ND* Not detected oxide (N_2O) emissions, respectively, from enteric fermentation and manure management (Zervas and Tsiplakou 2012). Nowadays, there is an increased interest in the development of dietary strategies that could reduce methane emissions from ruminant enteric fermentation (Tavendale et al. 2005; Knapp et al. 2014; Caro et al. 2016). As far as we know, a few studies have investigated the effect of diets based on the use of by-products on methane emissions by small ruminants. Brewer grains (Moate et al. 2011; Romero-Huelva et al. 2017) and tomato and cucumber fruit wastes (Romero-Huelva et al. 2012; Romero-Huelva and Molina-Alcaide 2013) have shown antimethanogenic potential, which may rely upon diets chemical composition and especially with the presence in those by-products of plant secondary compounds.

Really and for the future, a great interest is also directed to the potential to enhance animal productivity and health by rumen microbiome manipulation, which is rather limited by the resilience of the ecosystem once established in the mature rumen. It has been suggested that the microbial colonization that occurs soon after birth opens a possibility of manipulation with the potential to produce lasting effects into adult life (Yáñez-Ruiz et al. 2015). Early experience ingesting feeds increases preference for and latter consumption of those feeds by animals (Provenza and Balph 1990; Abecia et al. 2013) and that could open an interesting new approach to use unconventional feedstuffs in ruminants feeding.

9.5 Conclusions

Murciano-Granadina goat nutrition may be based on diets including very many different local by-products which may reduce feeding cost and methane emissions, and improve products quality.

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Chapter 10
Synergies Between Goat Grazing and Shrub Biomass in Mountain Areas

Duarte Marques, Marco Fachada and Hélder Viana

Abstract North and Center of inland Portugal is characterized by mountain areas with low productivity, and susceptible to desertification. The human settlements have low densities and the people are aged leading to agriculture abandonment contributing to the increase of wildfires. The rural population with low resources finds in the extensive livestock production a source of income making possible the survival in those inhospitable areas. The use of traditional agro-silvo-pastoral practices is essential for rural development, as it includes a set of ecosystem services contributing for the soil and water conservation and biodiversity maintenance. The goat grazing, in particular, is essential for the prevention of wildfires as they feed mainly in the shrubland areas, reducing the biomass load and, consequently, the fuel available for forest fires. The synergies created by goat production result, thus, in a direct economic benefit from cattle production and indirect ecological aspects, by reducing the probability of potential fires. An experimental study using targeted grazing, in the mountain municipality of Vila Pouca de Aguiar, North of Portugal, was carried out between 2012 and 2014 to analyze the feasibility of implementing this technique in order to manage the territory, leading to the minimization of occurrence and severity of fires. Nevertheless, this study needs an

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additional temporal period for a conclusive analysis, although evidences suggest that this method can play an important role in fire prevention.

10.1 Introduction

Mountain areas represent a significant part of European territory occupying around 40.6% of countries areas. Considering the EU territory, 75.9 million people (20.3% of the population) live in mountain municipalities and around 60% of the total population lives in or near mountain areas (Nordregio 2004).

In Portugal, the percentage of mountain municipalities is 39.1% (36,140 km^2), with around 2.7 million people (26.5% of the population) living in that territories (Nordregio 2004). These mountain regions are essentially in North and Centre of the country, where the agriculture and forestry are often perceived as vital in economic terms for cultural diversity and a significant source of employment. These areas played an essential role, both for the maintenance of ecosystems and for the economic and social development of the territories and for the safeguarding of the associated cultural heritage. The interest of these areas is internationally recognized and protected by Natura 2000 Network.

The imbalance and/or the absence of pastoralism affect not only agricultural activities and production, but also all the related goods and services and, particularly those effects associated with the control of shrub vegetation and its impacts on the wildfire regimes (Bowman et al. 2011). The absence of pastoralism, in the last decades, in many areas has led to an increase in density and shrub volume, thus promoting changes in vegetation (e.g., invasion by weeds and shrubs), causing ecosystems modifications and in their biodiversity (Carmel and Kadmon 1999; Mancilla-Leytón et al. 2013), increasing the risk of fire, and the occurrence in shorter periods leading to the process of desertification.

The practice of pastoralism is decreasing with population aging, lack of rejuvenation in most rural areas, low economic profitability of livestock activities (related to the lack of product differentiation and higher overhead costs) (Viana et al. 2016), but also by the lack of infrastructures, the disappearance of qualified professionals (shepherds) and the lack of transmission of traditional knowledge of pastoral practice.

The goat production is commonly an activity with low levels of knowledge and innovations as well as low sectorial organization (“verticalization”). Moreover, the sector vision is very limited, there is scarce perspective of a wider valorization of its products, and environmental value services, as landscape management and biodiversity conservation is rarely perceived. Environmental services, directly linked to animal production, include the shrubland control which is considered a critical factor on the occurrence and severity of wildfires, by the biomass reduction. The loss of knowledge related to the management of the herd, in open mountain areas, accentuates the abandonment of these pasture areas. In addition, the difficulty in managing breeding herds in collective pastures, the animal health problems and the lack of association are serious impediments that explain, in part, the isolation of these areas. The development of individualism and the weak community management of these pasture areas are, undoubtedly, among the most important barriers of the communitarian mountain cattle grazing.

The process of rural abandonment has resulted in an expansion of homogeneous fire-prone vegetation communities, with increase of fuel loads (Moreira et al. 2001). The fire prevention, detection and suppression implies a substantial portion of the forest management budget in Mediterranean countries.

Traditionally, understory vegetation in established forests and plantations was managed by manual or mechanical methods. Manual and mechanical removal is expensive, normally several times costlier than using livestock. Nevertheless, livestock grazing has negative and positive impacts on forest vegetation (Carmel and Kadmon 1999), it is a fact that properly managed grazing animals can ensure an economical and environmental friendly method of suppressing shrubs proliferation (Greiman 1988; Newsome et al. 1995). Thus, find correct management strategies to minimize the fire hazard associated to this characteristic Mediterranean vegetation (highly flammable) is fundamental.

This chapter addresses a study where the traditional goat pastoralism practice, with the main objectives for meat, milk or wool production, was reoriented for managing the territory and to provide important ecosystem services. The study analyzes the feasibility of implementing an alternative method to mechanization for management of shrubland and understory in order to find a sustainable model for management of the territory and assed if wildfires occur with same frequency and severity after implementing goat grazing.

10.2 Goat Production and Shrubland Biomass

10.2.1 Goat Production in the North and Centre of Portugal

In the northern and central Portugal, the extensive mode of goat raising is an agro-cattle activity, particularly linked to agricultural territories with fragmented areas, where is evident the complementarity between agriculture and forestry. In this system, goats are disseminated in large areas or pastures and the shepherd has no control over them, especially on their reproduction. It is the traditional system, the oldest and most adopted, as well as being the least costly for the owners.

These mountain territories belong to disfavored zones, facing social and economic deficits of various types. The existing concern about sustainability and jobs creation in rural areas, gives the opportunity to the re-invention or re-orientation of goat production for the management of the territory, allowing not only the reduction of fossil fuels (e.g., necessary on mechanical operations for shrubs control), thus increasing the carbon storage, but also, at the same time, creating jobs and well-being in less developed regions. By using the shrublands (poor and susceptible to erosion) and forest areas where other species cannot survive, goats play an important role in the profitability of these marginal areas, contributing to the settlement of rural populations and minimizing the abandonment of rural areas.

According to the Portuguese Institute for Financing Agriculture and Livestock data (IFAP 2016), goat population in Portugal was 327,557 animals in 2011 and 334,498 animals in 2015, showing a slight increase of 2% (6941 animals) over four years. However, in the northern region of Portugal the situation was reversed, with 97,317 animals in 2011 and 93,493 animals in 2015, revealing a decrease of 4% (3824 animals) in goat population over four years (Fig. 10.1).

Within the Portuguese autochthonous goat breeds, the Bravia goat is the most predominant, in the North region, since it has rustic characteristics that makes it adapt well to the territory. Bravia breed is almost wild, growing also in a herding regimen, oriented by a shepherd and a few guarding dogs. Its aptitude is exclusively for meat production. The size of these animals is of medium range, but with a clear sexual dimorphism (the males weight between 35 and 50 kg and the females between 25 and 40 kg) (Costa 2015), having short and thin legs, giving them enough agility to run across the most inhospitable and irregular terrains that characterize their feeding territories. The hair is short (but longer and rougher in the males), resulting in a proper adaptation to the climate and vegetable cover of these mountain regions. The broods of Bravia goats from that area are covered by the European certificate Protected Geographical Indication (PGI)—Cabrito do Barroso (Reg. (CE) nº 1107/96, JOUE nº L 148, of 12/06).

The average density is about 110 goats per farm, with a rate of 1 male per 30 females (INE 2017). The traditional farms are quite basic, without major equipment, but newer and improved ones have already stables in masonry, are electrified (sometimes using photovoltaic panels) and the young shepherds have technical knowledge acquired outside the family environment. In 2015, 94 farms raised this breed; however, only 85 are found currently (Ancabra 2017). These exploitations are concentrated mainly in the Alvão-Marão and Peneda-Gerês mountains, with only 2% being distributed in the rest parts of the northern region of Portugal.

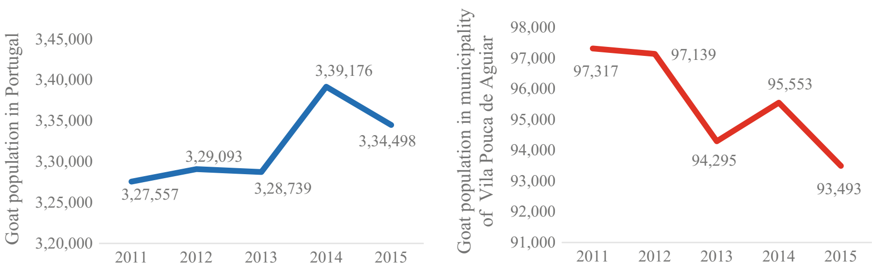

Fig. 10.1 Evolution of goat population in Portugal (left), and North (municipality of Vila Pouca de Aguiar) region (right) from 2011 to 2015. *Source* Ancabra (2017)

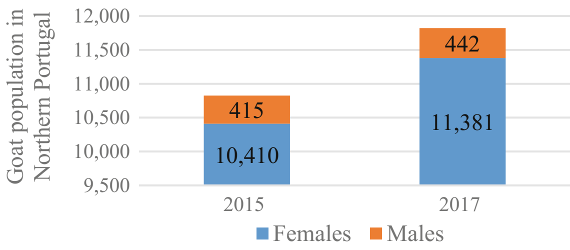

Fig. 10.2 Evolution of Bravia goat population, in northern Portugal, from 2015 to 2017. *Source* Ancabra (2017)

According to Ancabra (2017), Bravia breed was composed by 10,825 animals (10,410 females and 415 males), in 2015, having a slight increase to 11,823 (11,381 females and 442 males), in 2017 (Fig. 10.2).

10.2.2 Wildfires Versus Pastoral Activity

Forest fires are an inseparable component of these territories that, for years, shaped the landscape and the current vegetation's biodiversity. In Portugal, as in other Mediterranean countries, after the occurrence of wildfires, the rainy season comes after the summer, increasing the potential for runoff and erosion. Fire is, thus, the main cause of increasing the risk of desertification, in areas with this type of climate (González-Pelayo et al. 2006).

Pastoral burning is responsible for 20% of all wildfires in Portugal, accounting for 11% of the total surface burned, of which 78% is non-forested land. The remaining fires (non-pastoral origin) burn more forest (56%) than shrubland (37%) (Catry and Rego 2008).

Depopulation and rural abandonment transformed agricultural and silvo-pastoral habitats into vast areas with vegetation ready to serve as fuel for the fires. In these mountainous areas of the North and Central Portugal, where extensive pastoralism has an effective expression, the occurrence of fires is high, as well as the number of fires of pastoral origin. In these areas, it's common to use the fire to destroy the vegetation, in particular, the bushland. The objective is to maintain a dominance of the shrub and herbaceous strata in detriment of the arboreal, in order to have pastures available to feed goats or cattle, essentially. These practices increase the potential of fires specially in the spring and summer. Figure 10.3 shows the probability map of fires with pastoral origin, created with forest fires data from 2002 to 2007.

The Municipality of Vila Pouca de Aguiar and, in particular, the study area of this work [Forest Intervention Zone (ZIF- Zona de Intervenção Florestal) of Jales] (Aguiarfloresta 2014) were affected by forest fires since long time ago. The fire has been frequent in these areas, consuming forest and shrubland, as can be observed in Fig. 10.4. Between 2000 and 2010, the fire consumed 24,611 ha, with 1832 occurrences, in the Municipality of Vila Pouca de Aguiar (DGRF 2010) and

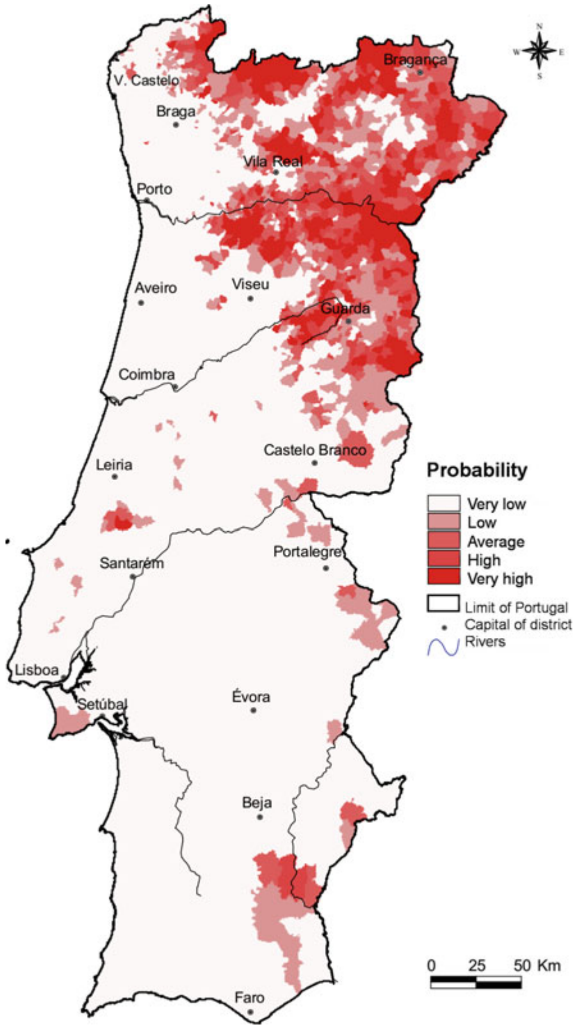

Fig. 10.3 Probability map of fires occurrence with pastoral origin, in Portugal. *Source* Catry and Rego (2008)

considering the ZIF of Jales (Aguiarfloresta 2014), 4218 ha were burned (average of 213 ha per year), essentially bushes. The landcover burned is essentially forest stands, shrubland, but also agricultural areas, including pastures are affected. The fires are cyclic and distributed through the area of study (Fig. 10.5).

As can be seen, almost 56.1% of the area was affected by fires, over a period of 10 years, and some areas burned three times.

Unlike other regions, where fire exclusion policies are being reconsidered, due to fuel accumulation and subsequent large wildfire events (Reinhardt et al. 2008), in Mediterranean countries, the suppression of fire is an ongoing objective (Vélez Muñoz 2009). Fuel loads are hardly ever managed at the landscape level and wildfire prevention efforts concentrate on a network of fuelbreaks designed to

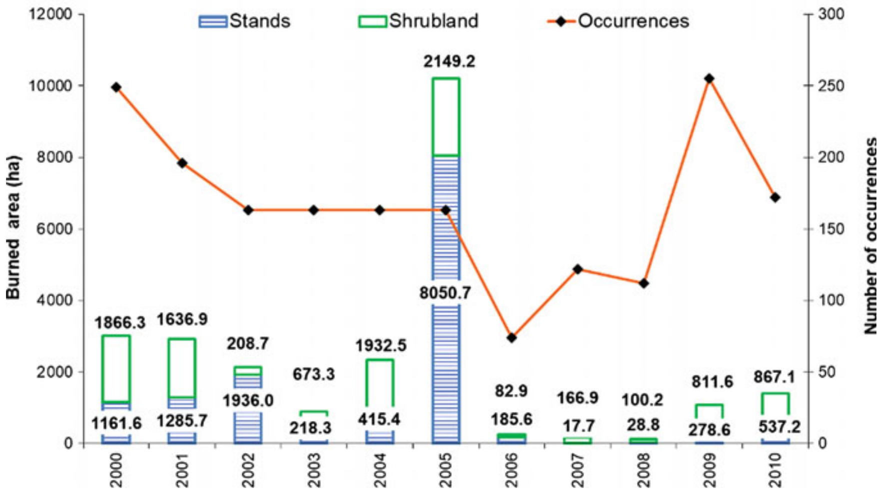

Fig. 10.4 Forest fires in the municipality of Vila Pouca de Aguiar (2000–2010). *Source* DGRF (2010)

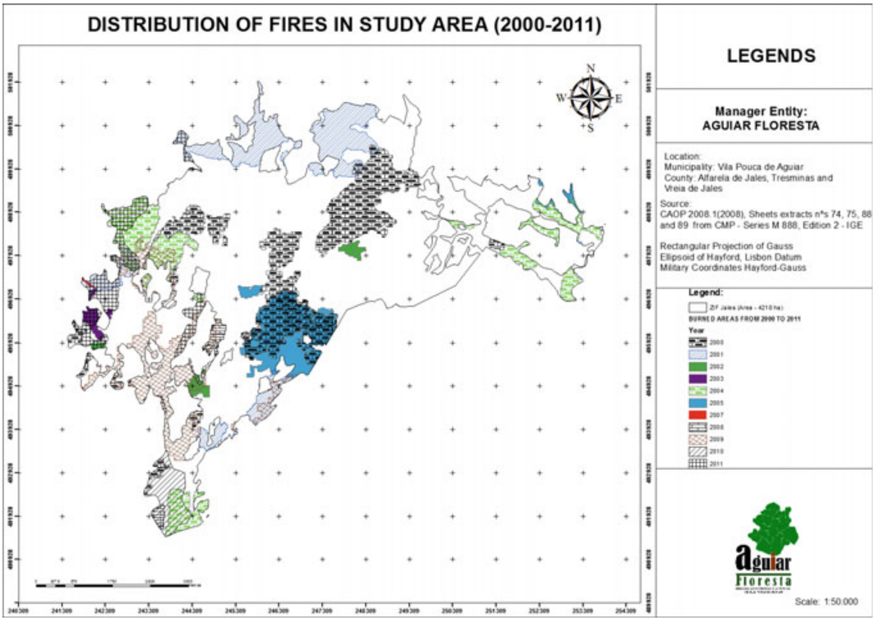

Fig. 10.5 Spatial distribution of wildfires in the study area (2000–2011). *Source* Aguiarfloresta (2014)

contain the spread of wildland fires and improve the chances of suppression forces successfully attacking fire (Agee et al. 2000). This widely applied prevention strategy is costly, particularly considering that is does not improve ecosystem resilience or mimic any natural or cultural landscape process (Reinhardt et al. 2008). In an attempt to improve the strategy of prevention by maintaining fuel-breaks, it has frequently been proposed that stock grazing should be incorporate into fire prevention programs (e.g., Franca 2001; Rigueiro et al. 2005; Launchbaugh et al. 2008). Extensive livestock grazing contributes to a more diversified heterogeneous landscape, and it can be locally intensified along fuelbreaks (e.g., Ruiz-Mirazo et al. 2011). The capacity of livestock to effectively control shrub growth is supported by scientific evidence (Magadlela et al. 1995; Torrano and Valderrábano 2005; Jáuregui et al. 2007) so targeted grazing could be expected to successfully reduce fuel loads. The integration of this agricultural practice into an environmental protection program (such as wildfire prevention) is valued not only for being cost-effective and sustainable, but also for a number of associated positive externalities (González-Rebollar et al. 1999; Ruiz-Mirazo 2011).

Treatment programs for shrubland management, including mechanical, chemical, prescribed fire and targeted grazing, are used to reduce brush density and growth. Livestock grazing, namely with goats, has low external inputs, offering the most cost-efficient method of managing many plant species but, on the other hand, entails significant management expertise. Small areas without major obstacles or impediments, may be fenced without great difficulty, but where fencing is not possible (due the size of the area or topographic features), grazing will be only possible using open-herded techniques with support of shepherd and herding dogs (Sharrow 2006).

In many circumstances, a combination of different treatments is required before the vegetation composition can be shifted in the desired direction. Targeted grazing can effectively reduce shrub re-growth after a mechanical or prescribed fire intervention, increasing the longevity of these traditional methods (Campbell and Taylor 2006).

The use of domestic grazing for wildfire prevention in fuelbreaks represents a cheaper option than alternative manual clearing (up to an average of 23% of this method) (Varela Redondo et al. 2007). For managing fuelbreaks (normally between 60 and 120 m wide), the Spanish goats seems to be more suitable than other breeds, such as Angora goats. Spanish goats are larger and also the marketable kids are larger. This breed is hardier and has a wider range of weather adaptability. The stocking rate should depend on the density and vigor of plants regrowth, on whether the purpose is to eliminate brush or simply to restraint it and whether the goats will be in the pasture permanently or intermittently (Campbell and Taylor 2006). Table 10.1 shows different grazing rates applied in different countries, where goats were used to control shrubland biomass, including in our study area, Vila Pouca de Aguiar.

Green and Newell (1982) recommended for USA (Pacific Northwest), stocking rates for goats of 0.2–1.2 ha per goat, the first year after clearing, depending on the amount of regrowth, reducing the stocking thereafter. An experiment in Mexico

Table 10.1 Grazing rates applied to control shrubland biomass in different countries

Country	Land use/occupation			Goats' breed					Grazing range[a] (n° goats/ha)	Intensity grade			Herd manner	
	Conifer forest	Fuel break	Dense/ continuous shrubland	Angora	Spanish	Payoya	Bravía	Other		Light	Moderate	Intensive	Controlled by shepherd	Fenced area
Portugal (Vila Pouca de Aguiar)			x				x		>1000[b]			x		x
Spain (Doñana Natural Park)	x					x			2.7		x		x	
Israel		x						x	1.37		x		n.a.	n.a.
New Zealand			x					x	15			x		x
USA (Pacific Northwest)		x		x	x				0.83		x		x	
USA (Texas)		x			x				0.82		x		n.a.	n.a.
Mexico		x						x	1.37		x		n.a.	n.a.

[a]Average value in the first year of grazing; *n.a.* information not available
[b]This density corresponds to a herd of 50 goats (in average) in fenced plots with 500 m^2 during 2–4 days

stocked goats at 0.36 and 0.73 ha per goat/year (with these, there was slight grass use and there was selectivity among the brush species). In Texas, using 1 goat for each 1.2 ha, the stocking didn't control brush regrowth. In Israel, a density of 0.65–0.73 ha per goat was recommended on a continuous basis. In New Zealand, when brush was uniformly dense and continuous and up to 1.8 m tall, were used 15 goats per ha, for 12 months grazing season opened at the stand. It seems that 7 goats per ha, have prevented reversion to brush or mixed brush and weeds (see Green and Newell 1982).

In Spain, it was studied the effect of goat grazing on understory vegetation of 100 ha of *Pinus pinea* forest, over a period of 42 months, where domestic goats were excluded since 2002 (Mancilla-Leytón et al. 2013). This experiment showed that the phytovolume (sampled twice a year, using the point-intercept method), of ungrazed plots increased by 36%, while bare soil had decreased by 5%, thus increasing the flammability by 25%. Contrarily, in the grazed area the phytovolume decreased significantly by 32%, with an increase of bare soil of 51% and the flammability reduced by 22%. The stocking rate may be heavier for short periods and frequently should be to get utilization of unpalatable species without excessive, continuous browsing off palatable shrubs.

Stocking rate and timing are strategies for grazing that can be applied to enhance consumption of the targeted woody plants and meet ecological objectives, such as fire risk reduction. Selective breeding may be a way to increase the consumption of undesirable plants. The heritability of preference for plant species that were generally avoided by goats, average nearly 30% (Warren et al. 1983; Campbell and Taylor 2006). For this, it is important to be aware of the amount of forage available and anticipate current and immediate forage demand for livestock. Brush management frequently requires short grazing periods with high stock densities, having thus enough grazing pressure to have a detrimental effect on shrubs. It is important to browse targeted plants when they are more palatable for animals, enhancing their ability to consume them (e.g., during summer, shrubs and young hardwood trees are normally more palatable to sheep and goats, than conifers).

10.2.3 Shrubland Biomass

The study area (ZIF of Jales) (Fig. 10.6) is mostly occupied by permanent grasslands and pastures, with 2027 ha (48.0%). It also has a significant area of agricultural land with 1286 ha, corresponding to 30.4% of the territory. The forest area is very small (698 ha), corresponding to 16.6% of the area, mostly occupied with maritime pine (*Pinus pinaster*), black oak (*Quercus pyrenaica*) and chestnut (*Castanea sativa*). Less representative are urban areas (3.3%), inland waters (1.4%) and rocky outcrops (0.3%).

Like other mountainous areas of the North and Center of Portugal, the shrublands are dominant, as the natural pastures have less expression. These pastures contain great ecological, economic, cultural and landscape value. Shrubland, as

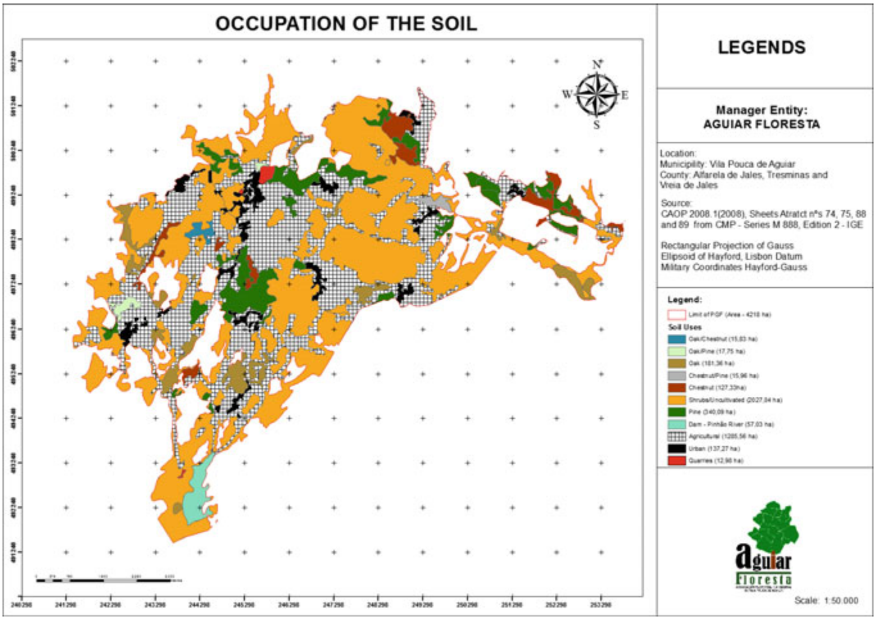

Fig. 10.6 Landcover map of forest intervention zone (ZIF) of Jales. *Source* Aguiarfloresta (2014)

dominant occupation, constituted by diverse plant formations, are the main source of feeding of goats in extensive silvopastoral regime.

The dietary characteristics of goats, able to select vegetation, allow them to adapt to changes in food supply throughout the year. Through their feeding habits, they can change the floristic composition, productivity, structure and nutrient cycle of plant communities. In fact, such as the fire, grazing is a disturbing factor of plant communities. In both processes, their action causes plant mortality, release of resources and opportunity for the emergence of other individuals in plant communities. In terms of soil conservation, some studies carried out in different countries have demonstrated that unmanaged grazing have affected severely the above ground vegetation biomass, soil organic matter and large-sized soil aggregates (Qasim et al. 2017).

The mean height and density of vegetation is also altered by the effects of grazing. Thus, the combination between food strategy and animal loads can be used to achieve certain habitat management purposes. One of the most common uses of grazing, as a management tool, is the control of fuel biomass for fire prevention.

The accumulation of combustible fuels in forests, mainly in coniferous forests, turns them highly vulnerable to wildfire. Some shrubs defend themselves against herbivores with structural features like spines or thorns. Other species contain chemicals that avoid animals to eat them.

Goats can utilize woody vegetation on which other livestock would starve, so they are usually present during the final stages of land degradation. In the

Mediterranean area of USA (Mediterranean-climate regions of California), goats were considered the only "last link in a vicious chain of land devastation brought on by indiscriminate burning, cutting, grazing, slope denudation and cultivation" (Green and Newell 1982). Targeted grazing can reduce vegetation fuel loads and ladder fuels, minimizing the risk of destructive wildfires, while protecting forests, houses and other rural infrastructures (Sharrow 2006). Goats in Arizona and California (USA), have strategically browsed in the chaparral region to reduce fire risk; sheep and goats have been applied in the Pacific Norhtwest to control invasive shrubs like black-berries (*Rubus* sp.) and gorse (*Ulex europaeus*). Test results show that properly managed, goats eliminated or controlled woody vegetation at the same time that herbaceous vegetation reoccupied the site. The creation of open canopy systems can lead to the improvement of pastures, with latter increase of available grass food for small herbivorous or grain-eating birds (such as the Wild Rabbit—*Oryctolagus cunniculus*—or the Red-Legged Partridge—*Alectoris rufa*—), that are very important elements on the food-chain of many endangered species in Iberia Peninsula (such as different species of birds of prey, the Iberian wolf—*Canis lupus signatus*—or the Iberian lynx—*Lynx pardinus*—).

In the Mediterranean basin, plants have co-evolved with gregarious herbivorous that heavily graze vegetation. Domestic breeds have been grown for economic reasons (meat and milk purposes) for thousands of years, increasing the income for human population and, at the same time, acquiring an environmental dimension with the control of understory vegetation, thus reducing the fire risk and increasing global forest structural diversity (Mancilla-Leytón et al. 2013). There are great differences in how readily animals will eat woody plants, depending on the type of animals (sheep, goat and cattle). One must consider the type, the breed and class of livestock, as well as the size and topography of the area to be managed with targeted grazing. Of relevance is if the plant community is predominantly herbaceous grasses and forbs or woody shrubs (Sharrow 2006). The digestive system of goats is adapted for extracting nutrients from woody tissues and detoxifying secondary compounds as tannins and terpenes (Campbell and Taylor 2006). Also, goats have larger livers (in relation to their body size), than sheep or cows, being their detoxifying capacity greater than the other livestock.

10.3 Methodology

10.3.1 Study Area

The study area corresponds to the ZIF of Jales (process nº 153/07—AFN), with a total area of 4218 ha, including the parochies of Alfarela de Jales, Vreia de Jales and Tresminas, in the council of Vila Pouca de Aguiar, Alto Tâmega region (NUT III—nomenclature of Territorial Units for Statistics), North Portugal (Aguiarfloresta 2014).

The climate can be characterized as wet temperate, with dry and moderate summer. The average of annual temperature varies between 10 and 12.5 °C. The total annual rain precipitation varies between 800 and 1000 mm in the North Eastern zone, and up to 1200–1400 mm in the West part. This rainfall occurs between 75 and 100 days/year. Frost/frozen days reach 60–70 days per year in the South part and 70–80 days in more northern areas.

The soils are in general thin and with low permeability, dominated by granite and in minor areas by schist bedrock. The types of soils present are cambrisols, luvisols and lithosols.

More than 60% of the area is covered by forest, shrublands and grasslands, being the Maritime Pine (*P. pinaster*) the dominant tree species, followed by the Pyrenees Oak (*Q. pyrenaica*) and Sweet Chestnut (*C. sativa*). Closer to streams and rivers there are also Black Alder (*Alnus glutinosa*) and Ash (*Fraxinus angustifo*lia). Within the shrubland, the most representative species are: Heather-bell (*Erica cinereal*), Labdanum heath (*Pterospartum tridentatum*), Rockrose (*Halimium allyssoides*), Gorses (*U. europaeus*), Brooms (*Cytisus* spp. and *Genista florida*) and Blackberry (*Rubus ulmifolius*). These shrubs are normally between 20 and 120 cm high.

Within this area a wide variety of wild species of animals exists, from small birds to major mammals. Among the birds we can refer the Red-Legged Partridge (*A. rufa*), Mistle Thrush (*Turdus philomenos*), Wood Pigeon (*Columba palumbus*), Montagu's Harrier (*Circus pygargus*), Nightjar (*Caprimulgus europaeus*), Black Kite (*Milvus migrans*), Buzzard (*Buteo buteo*) and Short-Toed Eagle (*Circaetus gallicus*). Among mammals, the most commons are the Rabbit (*Oryctolagus cuniculus*), Brown Haer (*Lepus europaeus*), Red Fox (*Vulpes vulpes*), Badger (*Meles meles*), Hedgehog (*Erinaceus europaeus*), Wild Boar (*Sus scrofa*) and Roe Deer (*Capreolus capreolus*).

10.3.2 Experimental Design and Methods

The main objective of the study, under the project "Economountain—Biodiversity economy in the mountains of Vila Pouca de Aguiar", was to compare the evolution of selected vegetation parameters, in particular, the shrubland phyto-volume, before and after the oriented goats grazing (Santos 2014).

The method consisted in the targeted grazing, in fenced plots with 500 m^2, with a herd of 50 goats (density of 1000 goats/ha). The intensity of the intervention was of 2–4 days in each plot, depending on the shrub load. In total, around 10.6 ha were grazed, in the period 2012–2014 (Fig. 10.7).

The study was implemented in winter and spring periods, with a higher number of plot/parcels being grazed in winter (six from a total of nine plots). During those days with very adverse climate conditions (heavy raining and freezing days), the goats were not introduced in the field. It was observed that these adverse climate conditions, influenced negatively the animal well-being (essentially when

Fig. 10.7 Targeted goat grazing in Vila Pouca de Aguiar (several views) (Provided by the authors)

temperatures were very low). Also, these extreme climate circumstances affected the logistic operation and manner of the animals, to be oriented by the shepherd.

The selection of the experimental grazing plots was made according to the vegetation type, in a way to ensure the maximum number of distinct places within the ZIF territory (Fig. 10.8).

The vegetation was monitored using the method of interception line, which consisted in the evaluation of the vegetal cover percentage and measurement of species height for posterior volume calculations. The volume is, in fact, the indicator parameter of the existing biomass. Inside each plot, three permanent transepts, georeferenced, were distributed in the plot area and measured with three repetitions, before and after grazing. In each transept three shrub stratus were considered: low (up to 20 cm), medium (between 20 and 120 cm) and high (more than 120 cm).

10.4 Results and Discussion

This study demonstrated that the targeted grazing technique has an immediate effect in the vegetation, seeming to be efficient to reduce the biomass volume. Table 10.2 shows the main results observed in this experiment.

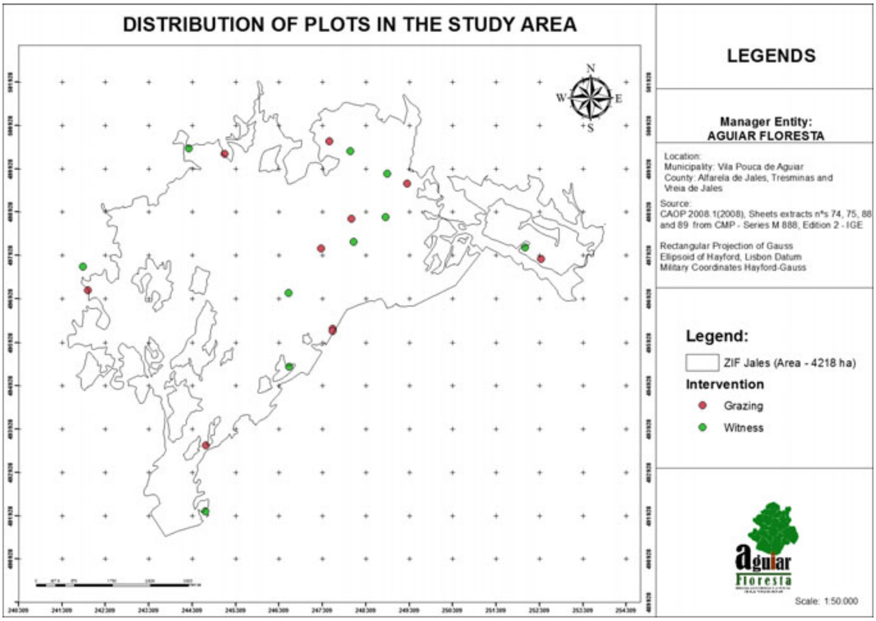

Fig. 10.8 Distribution of the experimental grazing plots

The results of Economountain study show that there are clear differences in the plant cover, high and volume, between the grazed plots and non-grazed plots, comparing to the initial inventories of the testimonial plots, with the same type of shrublands (Manso et al. 2014).

After the 1st grazing intervention, there was a reduction of the shrub vegetation volume, in all sites (more than 50% in low shrubs plots), but, at the time of the 2nd grazing intervention (6 months later, only in some plots), the vegetation volume was similar to the values before grazing. This shows the enormous capacity of regrowth of this Mediterranean vegetation. Comparing with a study carried out in Dão-Lafões region (Central Portugal) (Catry and Rego 2008) with the objective of using goat grazing in the management of understory vegetation, with different intensities and animal densities of grazing. At this respect, Catry and Rego (2008) concluded that there is an inverse proportionality between the frequency of grazing and the levels of biomass under-canopy and that the parameters estimated in a fire simulation were reduced in almost 50%, in comparison with the non-grazing plots.

The variation of the vegetal cover, through time, depend on the type of shrubs. It was observed, in all plots, a reduction of the vegetation cover, after 1st grazing, being that the biggest differences occurred in the plots classified as medium shrubs (−28%).

Concerning the shrub species composition, the most significant reduction was observed in plots with low shrub, occupied with Labdanum heath (*P. tridentatum*),

Table 10.2 Main results of targeted grazing technique in Vila Pouca de Aguiar

Parameter	Low shrubs				Medium shrubs				High shrubs			
	Witness		Grazing		Witness		Grazing		Witness		Grazing	
	R	1st	R	1st	R	1st	R	1st	R	1st	R	1st
Cover (%)	84.6	84.1	75.4	62.3	52.9	60.7	46.7	33.9	92.9	71.6	65.9	49.5
Height (cm)	18.5	36.4	15.3	14.6	41.4	42.4	37.7	24.7	115.0	158.1	139.0	134.8
Volume (m^3/ha)	1570.8	3062.8	1324.1	1015.7	2382.4	2966.0	1876.3	927.0	13,804.5	13,384.7	9575.7	7086.1

R—Time before goat introduction
1st—At the end of 1st grazing intervention time (measured, in average, two months after goats' introduction)

in plots with medium shrub, occupied with Rockrose (*H. allyssoides*), and in plots with high shrubs, occupied with the Brooms (*Cytisus* spp.).

In terms of species' biodiversity, there was not evident impact, even if the project period (2012–2014) was relatively short to obtain more robust conclusions on this. Nevertheless, Catarino et al. (2000) reported, in a study developed in Estrela and Malcata Mountains (Central Portugal), that soil practices and grazing management have a determinant impact on biodiversity. While some of those practices can improve the biodiversity richness, other can represent a serious threat for their conservation. Analyzing the floristic richness, they concluded that both vascular plants and bryophytes have lower species diversity, due the disturbances caused by intensive agriculture, being the rotational system of agriculture and grazing very important for the conservation of priority habitats (Directive Habitats 92/43/CEE).

In term of soil modifications was evident the pH reduction between 0.2 and 0.5, but four months after the first grazing the pH values returned to the initial ones.

The level of organic matter on the soil increased in almost all experimental plots, excepting 2 of them. This observation is particularly interesting and unexpected, since it is unknown any literature with references on this aspect and by the opportunity this represents to soil recovery in the Mediterranean regions, where Organic Matter on the soil is, normally, low.

This study demonstrated that the targeted grazing method has an immediate effect on the reduction of biofuel load, and probably depending on the goat density used. However, this technique can have a second effect on the florist recovery after successive interventions through time. The demonstration of this effect, although lightly, showed by the monitorization was, in this case, affected by the short project lifetime. Given the strong vegetation recovery, the effect of biomass reduction can be less important than the initially expected.

Goats will eat a wider variety of plants than other type of animals, but unless they are subject to grazing pressure, will only eat plant parts that are in a favorable growth stage from species they relish. The question of whether goats should be herded or fenced for control is still an arguable one. Probably the best option would be a combination of both practices. Goats are least selective on first-year brush regrowth, becoming more selective as the brush is older. In California, under moderate or intermittent stocking, reduced the brush cover, while annual grasses and forbs increased during two to four years browsing periods. They can survive and even become profitable while consuming only coarse forages on which cattle and sheep have difficulty to survive (Merrill and Taylor 1976; Merrill 1975; Green and Newell 1982). Grasses and forbs were dominant in goats' diet, especially during spring on lightly grazed range.

Ruiz-Mirazo et al. (2011) following the reduction of biomass fuel, during 2008–2009, within the fire prevention programme of Andaluzia (Spain), highlighted that conservation grazing can be an effective method in fuel management, being also, up to certain level, economically sustainable.

One of the major difficulties of the study implemented in Portugal was the short execution period available, mainly for monitorization processes after grazing. Thus, it was a concern to have, at least, data collection in two Spring periods. Despite this limitation, it was possible to obtain results that show the usefulness of the project as well as relevant benefits with moderate costs, even if far from the necessary consistence that initial objectives pursued. The first tests of application of targeted grazing confirm a cultural impact: there was a clear reluctance from the shepherd to keep their animals in under-optimal conditions (even if quite far of being sub-nutrition conditions). This reluctance was overpassed with the development of the project and, at the end, there were no execution problems with the model adopted, only practical issues to solve the diffusion of the technique, existing a general recognition of the usefulness and objectives to reach with targeted grazing. Nevertheless, there is a progressive orientation of this technique along time, for lower grazing rates, to better respond to the shepherd interests, what lead to some reflection about the way the interests of the shepherd don't affect too much the services desired with grazing. Both the high costs related with management absence, as the recent concerns with sustainability and job creation, give opportunities to the re-invention of animals use and breeding directed to territory management, not only by reducing fuel fossils needed to mechanical operations, increasing the carbon sink effect but also creating jobs and well-being in local populations.

10.5 Concluding Remarks

This study can strongly contributes for the recognition and acceptance of animal usage, in this case goats, for territory management by using direct grazing technique. Goats are particularly well-matched for the management of shrublands, since they normally consume more shrubs than other types of domestic herbivorous.

One of the first evidences of the study is that the speed of biomass treatment with animals is very variable, depending very much on the management model used. Additionally, the targeted grazing technique was more effective in medium shrubs than in low or high shrubs (in which it seems to be less viability). However, this datum is not conclusive because some vicissitudes observed along the project execution, including wildfires in some plots, that restricted the execution of the original plan. Given this, only the information obtained in low shrubs can be considered fully solid. We should also mention that in this model of targeted grazing, when there is a monitorization and regular presence of the shepherd/owner of the goats, there is a natural propensity to apply a more "light/smooth" technique, in a way to ensure the best feeding conditions possible to the animals.

Maintaining the vegetation with low volume and low growth contributes to reduction of fire hazard. However, the traditional grazing territories are, nowadays, under different threats, namely because of the lack of policies, that prevent the implementation of efficient territorial strategies. Also, the small differentiation of products, makes the grazing activity quite dependent on the markets and their fluctuations, often not allowing a sufficient compensation. This can be widely improved with the support of technical capacity of owners and associations present in these territories. The recognition of the cultural, social and economic services generated by the shrublands, could allow a better valorization of these activities and implement collective actions with the different users. In fact, grazing and farming, among other benefits, can contribute to the adaptation of climate change, rebuilding soil organic matter and restoring degraded soil biodiversity, in what can be called as regenerative agriculture. These effects also contribute for the carbon drawdown and improvement of the water cycle, critical feature in Mediterranean regions.

Grazing does not necessarily preclude ecosystem resilience, and by adopting practices of conservation, grazing can even maintain natural or cultural landscapes. Extensive livestock management can play a role in fire prevention when intensified locally along the firebreaks and selected areas. However, before applying this method it is essential to define the objectives to reach, to analyze the type of vegetation, to define the goat density to use in the sites, and the frequency of grazing. Only with a combination of correct variables, this methodology can contribute effectively to decrease the forest fires hazard in the critical periods (July–September) in the region.

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Chapter 11
Nutritional and Metabolic Disorders in Dairy Goats

João Simões and Carlos Gutiérrez

Abstract This chapter aims to describe significant aspects of the most common nutritional/metabolic diseases caused by insufficient or disbalanced nutrients intake, such as carbohydrates, proteins, vitamins, and macro or trace minerals, and their repercussion in goat metabolism. Goats are opportunistic feeding behavior animals, choosing the best nutrients in both hard environments or even in feed availability periods. In some conditions, e.g., poor quality forages in nutrients, and/or when energy or nutrient requirements overpasses their intake capacity and availability, goats may not keep metabolic homeostasis. Pregnant toxemia, urolithiasis, polioencephalomalacia, and selenium or vitamin E deficiency are major diseases with impact in production, reproduction and/or health in both low- and high-producing goats or their kids. İn high-producing dairy goats, due to their higher nutritional demands, increased incidence of the called "production diseases" is observed. Subacute ruminal acidosis, lactational ketosis, hepatic lipidose, hypocalcemia and low milk fat syndrome are also major problem in dairy herds to require special attention. Risk factors of these disorders should be taken into account in nutritional and feed management programs. A holistic approach regarding these programs and herd health management are crucial to control or prevent nutritional and metabolic diseases in farms.

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11.1 Introduction

Goats should consume feeds with energy and essential nutrients to cover basic functions (maintenance and normal activity) plus productive functions (growth, pregnancy and lactation), particularly in those breeds selected for milk or meat. To achieve both energy and nutritional requirements, this species adapted its feeding behavior and metabolism to harsh environments. Goats are very selective browsers/grazers, flexible, broad-scale and opportunistic feeding behavior animals (Mellado 2016), but previous personal dietary experiences, i.e., the personal information should also be taken into account (Morand-Fehr 2003). The feeding behavior also is affected by goats' social hierarchy. Barroso et al. (2000) reported that the most aggressive goats, apparently the large sized up and horned animals, are socially in the top; and this hierarchy affect the animal production. Additionally, the usual selection of forages when they are found abundantly decreases when their availability is scarce. Even if goats use social information, observing the feeding behavior of other individuals, the personal information seems to be prioritized when both information types are in conflict (Baciadonna et al. 2013).

Essential nutrients would be water, carbohydrates, proteins (amino acids), lipids, fat-soluble vitamins (A, D, E and K) and water-soluble vitamins (B complex and vitamin C) and minerals such as macrominerals (calcium, phosphorus, magnesium, potassium, and sodium) and microminerals (e.g., cobalt, copper, iodine, iron or selenium). Goats, as most mammals, can synthesize the needed vitamin C and thanks to ruminal and intestinal microorganisms can also synthesize vitamins K and B vitamin complex. However, when ingestion of essential nutrients is significantly lower than daily requirements for a long enough period of time, then deficiencies would occur. Nutritional and metabolic deficiencies are more commonly seen in high milk producing goats, but in kids with increased daily weight gain are also commonly at risk.

A great variety of diseases are related with energy and nutritional imbalance at digestive and other body systems exchanging animal's homeostasis, affecting several biological and biochemical systems and presenting lesional alterations in tissues and organs. Lactational ketosis, pregnancy toxemia (PT), fatty liver in adult's goats and hypoglycemia/hypothermia in kids (perinatal period) are common worldwide disorders of energy metabolism. Other diseases are caused by deficiencies or excess of vitamins and minerals (e.g., hypocalcemia and hipovitaminosis B1 or hypervitaminosis A and D), some others are (also) multifactorial and are provoked, or at least related, with nutrition, e.g., urolitiasis, and ruminal acidosis. However, it is necessary to empathizes that related nutritional disorders are not limited to these previous one. Several other nutrient-related disorders can also affect goats, such as, but not exclusively, caused by poisoning plants, fertilizers, poor feed storage (e.g., *Listeria monocytogenes* in silages, mycotoxins and botulism) and altered gut microbiome (enterotoxemia due *Clostridium perfringens* toxins production).

The present chapter supposes a review of the apparently more significant nutritional and metabolic diseases encountered in raising and managing goats around the world.

11.2 Lactational Ketosis and Pregnancy Toxemia

Lactational ketosis and PT (also named gestational ketosis) are manifestations of hyperketonemia in goats. In fact, both diseases are related with blood β-hydroxybutyrate (BHBA) levels usually greater than 0.4 mmol/L (Albay et al. 2014; Doré et al. 2015). These metabolic disorders are provoked by energy imbalance, i.e., negative energy balance (NEB) originated when outputs (to pregnancy or lactation) overpasses intakes (inputs) with detrimental energy flux. Lactational ketosis takes place in early *post-partum* and is normally related with high milk producing goats and more rarely with low-producing goats. In cows, it is considered a "production disease" with high prevalence in the first month of lactation. However, prevalence data are scarcely reported in goats, but probably a similar pattern to cows occurs (Zobel et al. 2015). PT, or the "twinning disease", develops *ante-partum*, in the last 2–6 weeks of pregnancy due to enormous energy demands of fetuses (Edmondson et al. 2012). The prevalence of PT varies, according to farms and regions, from 1–4% to 40–60%, reaching a mortality >80%, in both does and fetuses, even when a cesarean section is made as treatment (Andrews 1997; Rook 2000; Bousquet 2005; Ismail et al. 2008; Lima et al. 2012).

Ante- and *post-partum* hyperketonemia can represent a major nutritional and metabolic problem in goat production relating subclinical and clinical forms of the disease with milk production (Zobel et al. 2015) and animal losses, even in low-producing does. Commun clinical signs of lactational and gestational ketosis are reduced activity levels, ataxia, teeth grinding and anorexia (Brozos et al. 2011; Lima et al. 2016). In PT, anorexia with absence of ruminal motility and recumbency was even suggested as poor prognostic indicators in goats (Lima et al. 2016). Moreover, hyperketonemia also provokes immunity and inflammatory alterations with decreasing immunoglobulins serum levels of IgG, IgM and IgA (Hefnawy et al. 2010) and lymphocytes (Hefnawy et al. 2011), and increasing haptoglobins (González et al. 2011). Consequently, hyperketonemia can have a significant adverse influence in the general health and welfare of does.

11.2.1 Energy Metabolism and Hyperketonemia in Does

It is know that goats are well adapted to arid and semiarid environments, and show an appreciable feeding selectivity, choosing the best available forages when grazing (Mellado 2016) and consuming feed until approximately 5–6% (DM/daily) of BW. The daily DM intake increases progressively until the 2nd month of lactation, always after the lactation peak, and progressively decreases until the next kidding mainly due to the compression of the gravid uterus to the rumen. Consequently, during the first two months of lactation, energy requirements due to milk production are higher than the energy input, and lipolysis (glucagon-mediated) occurs trying to compensate this disbalance. The loss of body condition score (BCS) is a natural consequence of this process. In a subsequent lactation phase, when the input surpasses the lactational output of energy, lipogenesis (insulin-mediated) takes place with BCS improvement. Normally, this process stop at the last month of gestation, in this last case due to fetus energy requirements. At this time a new NEB occurs and will be prolonged during early lactation phase.

Briefly, during NEB, an intense adipose tissue (triacylglycerols storage) mobilization provides high plasmatic levels of nonesterified fatty acids (NEFA) from triacylglycerol hydroxylation and are transported into liver. In the hepatocyte mitochondrial apparatus, NEFA are metabolized (ketogenesis) into three types of ketones: acetone, acetoacetate and BHBA. These ketones are a source of energy, as acetyl-Coenzyme A precursor (after Acyl group combination with the limiting factor: coenzyme A), mainly in mitochondria of skeletal muscles, mammary gland (including ketone transformation to fatty acids), heart and kidneys (Heitmann et al. 1987) with acid lactic production (causing metabolic acidosis). In normal conditions, and in pregnant and non-pregnant ruminants, all ketones are also significantly produced and absorbed from rumen to body. So, hyperketonemia occurs when the NEFA mobilization and their hepatic metabolism reach significant high levels, normally accomplished some degree of hepatic steatosis also denominated hepatic lipidosis or fatty liver disease (Fig. 11.1).

Hepatic lipidosis is due to slow exportation of lipoproteins from hepatocyte membrane to blood in ruminants (Kleppe et al. 1988), although can also be caused by cobalt or vitamins E and B_{12} (cyanocobalamin) deficiencies (Johnson et al. 2004; Radostits et al. 2007). In consequence, a diffuse accumulation of lipids in hepatocytes occurs. This assumes special importance during a great lipid

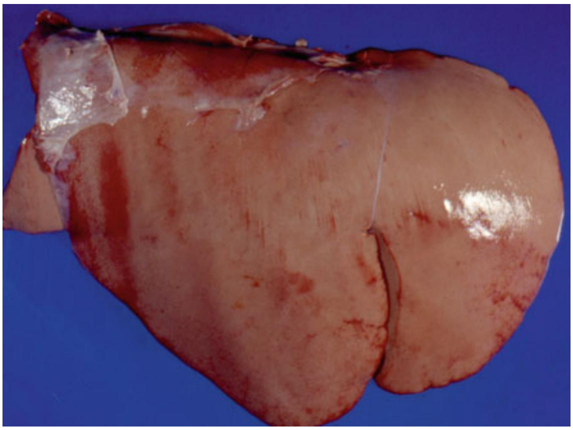

Fig. 11.1 Fatty liver with enlargement of the organ (hepatomegalia) and signs of rib's compression. Typical finding at *post-mortem* examination in a goat died from pregnancy toxemia (provided by the authors)

mobilization, when lipoprotein export limitation is more obvious. This lipidosis was associated with a decrease of hepatic metabolic functions (Bobe et al. 2004). When hepatic fat concentrations reach >35% of liver weight, a poor prognosis can be established, at least in dairy cows (Herdt 1988).

11.2.2 Pregnancy Toxemia

PT occurs during last 4–6 weeks of pregnancy. Multiparous does with high (≥ 4) or low (≤ 2) BCS and multiples fetuses (twins, triplets, …) are considered more susceptives (Chartier 2009; Brozos et al. 2011).

A low DM/energy intake associated with a quickly fetuses growth, reaching 60–80% of total live BW during last weeks of gestation are the main etiological factor. In fact, 30–40% of glucose apported by the dam during this period is consumated by fetuses, and it is know that the fetuses have energy flux priority. At this time, pregnancies with two or more fetuses increase energy requirements until 180 and 240% of a single fetus, respectively (Ermilio and Smith 2011).

Several other risk factors are the environment, such as ventilation, thermal amplitude and poor litter box, as well as lack of exercise and stress (Chartier 2009). Additionally, during this period, hormonal alterations such as the decrease of insulin serum levels, due to an improvement of steroid hormones (gestation) and glucagon, also stimulates ketogenesis (Vernon et al. 1981; Sensenig et al. 1985).

Primary PT is related with poor quality of forages or poor nutritional management (e.g., abrupt feed changes) whereas any disease provoking a decrease of DM or energy intake causes a secondary PT (Radostits et al. 2007). High BCS seems to lead to intra-abdominal pressure due to physical presence of abdominal adipocytes reducing the rumen volume (Morand-Fehr 2005). In does with low BCS, the few body fat reserves are quickly mobilized entraining an extreme condition of subnutrition.

Blood levels of BHBA are used to improve the subclinical and clinical PT diagnosis and management. However, BHBA threshold to confirm PT is not well defined and values between 0.8 and 1.7 mmol/L have been reported (Trevisi et al. 2005; Ismail et al. 2008; Brozos et al. 2011; Sadjadian et al. 2013; Pichler et al. 2014; Zobel et al. 2015). In an attempt to minimize this problem, Doré et al. (2015) proposed a dynamic scale predicting the PT according to each one of last five weeks; in the 5th, 4th, 3rd, 2nd and 1st week *ante-partum*, the threshold value was 0.4, 0.4, 0.5, 0.6 and 0.9 mmol/L, respectively; but the values of sensitivity (61.8–73.7%) and specificity (58.4–89.7%) of this classifications were considered low. Zobel et al. (2015) suggested a cut-off of 1.7 mmol/L to define PT and lactational ketosis. Additionally, glucose tissue intolerance is well documented in some goats affected by PT (Lima et al. 2016), which present hyperglycemia but whose occurence remains poorly understood. Even blood glycose concentration can be used, together with BHBA level, at farm level for PT and lactational ketosis control, although theses levels represent a handicap for individual treatment of does. Further research is needed to refine this metabolic query.

11.2.3 Lactational and Gestational Ketosis Prevention

The prevention of both diseases are related with the minimization of risk factors reported above.

Special attention should be given to treatment and prevention of general diseases (e.g., footrot, parasitism, pneumonia, etc.) (Rook 2000). Stress minimization improving adequate facilities and welfare are two other significant aspects to take in account. However, the crucial steps are related with *ante*- and *post-partum* nutritional management (Zobel et al. 2015). Feed should apport adequate energy and nutrients, under a controlled intraruminal environment, supervising significant decrease of pH, i.e., minimizing ruminal acidosis by adequate carbohydrate/fiber ratio intake.

The BCS evaluation, which must be improved during the second half of lactation at adequate levels, between 3 and 4 score points. Finally, both PT and lactational ketosis can be dynamically monitored *ante*- and *post-partum* using serum levels of BHBA as a tool (Doré et al. 2015; Zobel et al. 2015).

11.3 Hypocalcemia

Hypocalcemia is a mineral disorder with particularities between domestic ruminants. It is assumed that hypocalcemia occurs due to Ca demands, higher that it can be replaced in blood and interstitial fluids (Goff et al. 2014). According Wilkens et al. (2012, 2014), goats show efficient adaptation to Ca dietary restriction.

In goats, the total Ca levels in blood serum varies from 8.9 to 11.7 mg/dL (2.2–2.9 mmol/L) (Kaneko et al. 1997), and the cation Ca^{2+} form is the diffusive portion to tissues (blood acid-base balance can affect Ca^{2+} levels). Hypocalcemia occurs below this normal range and can present both subclinical and clinical forms. The first symptoms occur at blood serum Ca levels reach 6 mg/dL, but can decrease until 2 mg/dL, or even less, before doe reach death (Yamagishi et al. 1999). Ataxia and recumbence are two major clinical signs of hypocalcemia, other than all consequences provoked by skeletal, cardiac and smooth muscle cells relaxation (Fig. 11.2).

Similar to cows, and inversely to ewes (Oetzel 1988), with milk yield increases in high-producing goats, hypocalcemia (milk fever) is developed during early lactation. In fact, during lactation a significant flux of Ca arises from blood to milk (DeGaris and Lean 2008) and milk contents high Ca concentration, approximately 130 mg/dL (32.5 mmol/L) (Bar1owska et al. 2011). However, hypocalcemia can also occurs *ante-partum* in goats, due to high fetuses Ca requirements (Härter et al.

Fig. 11.2 Clinical form of hypocalcemia in a peri-parturient multiparous goat. Note the sagging udder in an old high milk producing goat (provided by the authors)

2017), especially from 80 days of pregnancy onward when maternal body Ca reserves, mainly in bones, are transferred for fetal development and colostrum production (Härter et al. 2015). During pregnancy, Härter et al. (2017) estimated 60.4 mg/kg daily net requirements of Ca for maintenance in goats.

The Ca homeostasis is regulated by hormonal ambience (the serum Ca level is increased by parathormone and decreased by calcitonin) but calcitriol (11,25-$(OH)_2D_3$), the active form of vitamin D, assumes an important role. İn fact, dietary Ca restriction (0.22% Ca in DM) increases plasma concentrations of endogenous calcitriol, which, in turn, improves intestinal absorption of Ca in goats, but without renal excretion exchangement (Wilkens et al. 2012; Herm et al. 2015). Moreover, calcitriol also is related with Ca mobilization from bone in early lactation (Wilkens et al. 2014). Herm et al. (2015) suggested that the higher calcitriol production in goats than in ewes can justify the greater ability to regulate Ca homeostasis observed in goats. Calcitriol also improves milk excretion by mammary epithelium when sufficient intracellular glucose is available (Sun et al. 2016).

Goats can efficiency adapt to dietary anion–cation balance, namely in presence of anionic diets that causes metabolic acidosis, which increases the rate of intestinal Ca absorption and a greater bone resorption rate (Liesegang et al. 2006; Liesegang 2008), but without blood Ca levels improvement.

11.4 Obstructive Urolithiasis

Obstructive urolithiasis is a common disorder in goats (Amarpal Kinjavdekar et al. 2013), as well as in other ruminant species, originated by cristaloid calculi formation which develops from an initial organic matrix (e.g., proteins and cells) followed by mineral deposition in the urinary tract (Osborne et al. 1985). The most frequent uroliths in goats are composed by struvite (ammonium magnesium phosphate) and silicate, followed by apatite (calcium phosphate), calcium carbonate and calcium oxalate (Gutiérrez et al. 2000; George et al. 2007; Makhdoomi and

Gazi 2013), and can be found in renal pelvis, bladder and uretra (Ewoldt et al. 2006) (Fig. 11.3).

The urethral obstruction caused by calculi, which can be partial in small ruminants (Makhdoomi and Gazi 2013), is mainly observed in males due to the long and sinuous traject of urethra. The urethral obstruction mainly occurs in distal loop of penial sigmoid flexure, but also can be located in proximal loop and urethral process. Crystals can be observed in the prepuce hairs of some males in those farms with urolithiasis problems. Affected goats present anorexia, bloat, pain (false colic), dysuria/stranguria, restlessness and progressive ventral abdominal distention due to urine infiltration, and uremic odor when urethral rupture occurs. The rupture of urethra always needs a surgical correction which intents to open a new via for urine excretion (Van Metre and Fubini 2006).

The etiology of obstructive urolithiasis is multifactorial, even diet assumes a main role, and varies according to the system production, region and season (Nwaokorie et al. 2015), and physiologic/health status of animals. Struvite (pH: 7.2–8.8), calcium carbonate and calcium phosphate (pH: 6.6–7.8), are developed very well under alkaline urine ambience and mineral supersaturation (Jacobs et al. 2001; Straub et al. 2005; Jones et al. 2009). Table 11.1 reports the main factors involved in calculi formation.

The prevention includes the elimination or minimization of risk factors according to the respective calculi type (Ewoldt et al. 2006). The Ca:P ratio should be 2–2.5:1, and Mg should be limited to 0.2–0.6% of DM (phosphatic magnesium-based calculi). Water intake should be increased (3–5% of DM) to promote diuresis and consequently crystals elimination. Acidification of urine at pH 5.5–6.5 range can be achieved using anionic salts (e.g., sodium chloride, calcium chloride or ammonium chloride) provoking dissolution of alkaline uroliths. However, these salts can decrease the feed palatability and, thus, acidificants can present inconsistent efficacy. Jones et al. (2009) suggested a target DCAD of 0 mg/kg in DM. The ammonium chloride can be preventively added to diet at low levels (0.5–1% of DM) to prevent the feed unpalatably.

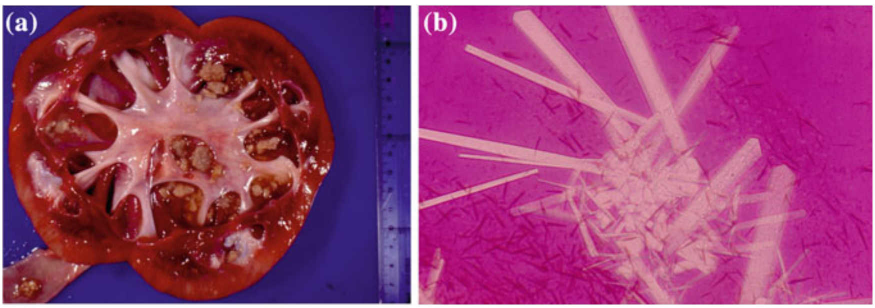

Fig. 11.3 Hidronefrosis (**a**) in a goat died from urinary obstruction (struvite calculi). Urianalysis (**b**) at microscope (×40) showing a cluster of struvite crystals in another goat with a disbalanced diet in favor of concentrate (provided by the authors)

Table 11.1 Main risk factors involved in urolitiasis occurrence in goats and sheeps

Factors	Effects	References
Hot and dry climates	Water restriction/metabolism	Sahinduran et al. (2007)
Low water intake	Concentrate urine and decrease diurese	Stratton-Phelps and House (2004)
Water hardness	Excessive minerals	Medina-Escobedo et al. (2002) and Sahinduran et al. (2007)
Castrated animals	Low diameter of uretra	Kannan and Lawrence (2010)
Urinary pH > 7	Improves apatite, calcium carbonate, and struvite uroliths formation	Hesse and Heimbach (1999)
Urinary pH < 7	Improves silicate uroliths formation	Wagner and Mohebbi (2010)
Fed high grain rations	Improves struvite uroliths formation	Corbera et al. (2007)
Pelleted rations	Reduces salivary excretion of phosphorous (struvite or apatite)	Corbera et al. (2007)
High content of P and Mg in diet	Crystals (struvite and apatite) increase in alkaline urine	Stewart et al. (1990)
Calcium and oxalate-rich forages with low phosphorus and magnesium at grassland	Improves calcium carbonate uroliths	Halland et al. (2002)
Vitamin A deficiency	Urinary tract infection and metaplasia of uroepithelium	Packett and Coburn (1965)
High (phyto)estrogens intake	Uretral mucosa alteration	Jones et al. (2009)
Urinary tract infection	İnflammation process by: *Ureaplasma* spp. (also increase urine pH); *Streptococcus* spp.; *Escherichia coli*	Cornelius et al. (1959) and Livingston et al. (1984)
Urine mucoproteins and proteins with polyelectrolytes	Matrix formation	Packett and Coburn (1965) and Osborne et al. (1985)

Both water intake improvement (sodium chloride) and urine acidification (ammonium chloride) procedures are also used at farm level to treat all animals when alkaline uroliths occur. In unsurveilled urine pH individuals, uretral rupture in fast grown males (high DM intake) are an indicator of urolitiasis problem in the herd. However, Freeman et al. (2010) suggested that urolithogenic crystals by microscopic observation is an easy test to predict uroliths formation.

11.5 Polioencephalomalacia

Polioencephalomalacia is a metabolic disorder associated with thiamine deficiency in both adults and young ruminants including goats (Thomas et al. 1987; Lima et al. 2005; Chigerwe and Aleman 2016). Thiamine or vitamin B_1 is a cofactor in the metabolism of carbohydrates necessary for their supply to the neurons in the brain as exclusive source of energy (Kevelam et al. 2013). Consequently, alterations following the death of nerve cells occur promoting a cerebrocortical necrosis, the synonymous denomination of polioencephalomalacia (Gould 1998). However, the specific biochemical mechanisms of these degenerative lesions are not well understood. Interactions between sulfur based metabolism and reduced activity of thiamine pyrophosphate, the active form of thiamine, seem to play a major role (Olkowski 1997; Amat et al. 2013a, b).

Thiamine is synthesized by ruminal bacteria in normal conditions (Alves de Oliveira et al. 1996). Alterations in ruminal fauna reduce the production of thiamine, accelerate the thiamine degradation or inactivation leading to a lack of absorption of this vitamin. Thiamine degradation occurs by Thiaminase I enzymatic catabolism (Kraft et al. 2014). Thiaminase II seems not have a significant role, but it is under reappraisal by some researchers (Murata 1982; Amat et al. 2013b). Thiaminase I can be produced by bacteria (e.g., *Bacillus* spp. and *C. sporogenes*) (Brent and Bartley 1984; Cebra and Cebra 2004), whose population increases in rumen when goats ingest highly digestible carbohydrates and low roughage, provoking subclinical or clinical ruminal acidosis with dysbiosis in ruminal flora and fauna. Thiaminases I (and II) replace the thiazole moiety by organic nucleophiles (Costello et al. 1996; Toms et al. 2005). In dependence of a cofactor (cosubstrates present in ruminal fluid, e.g., proline, pyridoxine and imidazol), thiaminase I produces thiamine analogues which inhibe thiamine dependent reactions. Levamisole and promazines substances seem to act as cofactor under specific ruminal conditions (Cebra and Cebra 2004; Amat et al. 2013a, b). Treatment (Vitamin B_1 and corticosteroids) can be effective in early phases and polioencephalomalacia prevention is related with elimination or control of main causes of non absorption of vitamin B_1.

11.6 Hypomagnesemia

Adult's goats, mainly when grazing growing pastures (less Mg contents), in final Winter/Spring, or when fertilized (high levels of potassium and nitrogen) or also in kids with fast growth fed with milk replacers can develop hypomagnesemia (blood Mg levels <1.1 mg/dL; <0.6 mmol/L). The lack of Mg exchanges neuromuscular transmission and, consequently, the muscle excitability. Goats show mainly periodic tetanic contractions and convulsions, especially when stimulated, leading to death during one of these episodes (Stelletta et al. 2008).

Mg is mainly absorbed in rumen and any cause decreasing persistently its absorption or the high milk production, increase hypomagnesemia incidence. So, this disorder was also called grass tetany, stall tetany, lactation tetany, milk tetany or transport tetany. Prevention is based in (unpalatable) Mg salts (e.g., magnesium oxide) dietary supplementation until 0.6% of DM, mainly during risk periods (Martens and Schweigel 2000; Stelletta et al. 2008).

11.7 Selenium and Vitamin E Deficiencies

Selenium and vitamin E deficiencies cause a nutritional/metabolic disease named white muscle disease or nutritional muscular dystrophy, which mainly affects to kids with fast growth in arid and semiarid regions, where soil/forage present low levels of the mineral/vitamin. In goats presenting this disorder, serum values of Se and Vitamin E are under 0.08 mg/L (0.9 mmol/L) and 1.0 mg/L, respectively (Bickhardt et al. 1999; McComb et al. 2010), and are due to low intact of both nutrients. Se and Vitamina E are responsive for antioxidant processes in tissues, limiting muscular skeletal and cardiac dystrophy (Fig. 11.4), and promoting integrity and production of muscle fibers. Kids appears to be more sensitive than lambs to vitamin E deficiency under low SE intake ambiance (Liesegang et al. 2008), and both nutrients improve immune status (Malá et al. 2009; Shokrollahi et al. 2013).

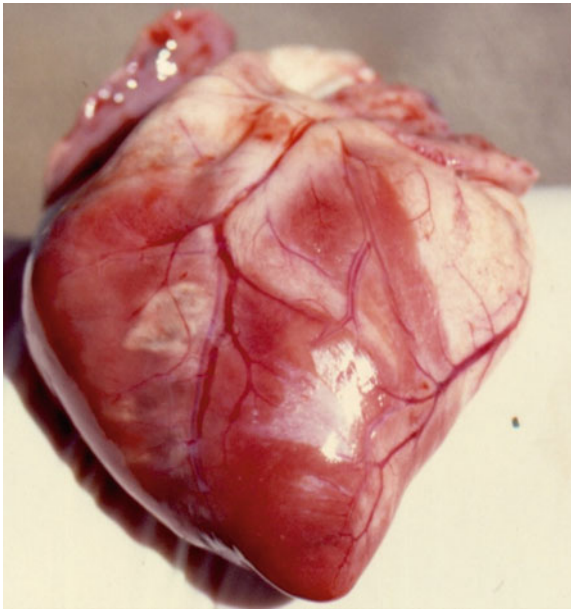

Fig. 11.4 Mascrocopic aspect of a young male kid's heart affected by nutritional muscular dystrophy showing typical pale and discolorated areas. The kid suffered sudden death after moderate exercise (provided by the authors)

Se supplementation (combinated with iodine) can improve kids' growth and inclusive Se (Aghwan et al. 2016) and NEFA (Aghwan et al. 2014) meat concentration (source for human population), but selenosis risk should be avoided. A positive effect of Se and vitamin E on milk yield and composition in lactating goats has also been reported (Tufarelli and Laudadio 2011). Moreover, Se supplementation seems to improve the fetal development in pregnant goats (Sevcikova et al. 2011) and also affects spermatogens in young bucks (Ganabadi et al. 2010).

A major question regarding Se and Vit. E management in farms would be that the supplementation of these nutrients are more valuable in Se deficient areas, i.e., the response to dietary supplementation is more significant when goats are in effective Se homeostatic unbalancement; and can vitamin E interact with Se more deeply in Se deficiency environment. Some studies supporting this hypothesis has been reported (Sánchez et al. 2007; Liesegang et al. 2008).

Regarding all aspects reported above, these trace elements joint to l vitamin E play an important role in the normal metabolism of kids and goats, not only promote their welfare and resistance to disease, but also can contribute for an adequate production performance.

11.8 Production Diseases in High-Producing Dairy Goat

Under pastoralism, the ruminal pH fluid in low-producing dairy goats is usually higher than 6 due to low concentrate/fiber ratio in feed intake. So, subacute ruminal acidosis and low milk fat syndrome are not expected to occur in these goats. However, the increase in milk yield production is because of genetic selection programs that needs to be accomplished with nutrients and energy intakes, not only to maximize lactation potential, but also to minimize lactational ketosis and hepatic lipidosis. This can be achieved improving the density energy in terms of DM, i.e., increasing the concentrate/fiber ratio (1.5; 60% concentrate) in diet.

A major problem of this nutritional management is the decrease of ruminal pH for levels <5.8 for longer than 5–6 h per day, i.e., subacute ruminal acidosis (Jia et al. 2014; Huo et al. 2014), which alters local fauna (Liu et al. 2015), volatile fatty acid production (Huo et al. 2013; Liu et al. 2015), local bacterial digestion with toxic protein formation, e.g., histidine (Hollmann et al. 2013), as well as chemical (pH) inflammation of rumen wall (rumenitis). This process is very well know in dairy cows and is related with ruminal parakeratosis (ruminal *papillae* atrophy), laminitis, liver abscesses and pulmonary bacterial emboli (superior vena cava syndrome), as well as ketosis (in a more advanced phase) and low milk fat syndrome (Kleen et al. 2013; Abdela 2016).

On one hand, diets with high carbohydrates content (energy) are needed to cover lactational requirements, avoiding ketosis and its consequences. On the other hand, these high energetic density diets can provoke disorders previously reported. To achieve a balance of these two sides, several procedures should be taken into account also regarding feed management practices, e.g., grouping goats by production level, improving fresh diet accessibility, using total mixed ration (minimizing feed selectivity behavior) or pelleted diets (due to goat selectivity for small particle size).

Low milk fat syndrome is classically related with ruminal acidosis and volatile fatty acid profile alteration, i.e., ↑propionate:↓acetate:↓butyrate ratio (Bauman and Griinari 2003; Urrutia and Harvatine 2017). In fact, ruminal acidosis decreases fat and protein milk contents at long-term in goats (Dong et al. 2013). Even, the etiopathophysiology of this syndrome remains poor understandable. Ruminal biohydroxigenation of polyunsaturated fatty acids to intermediate fatty acids, e.g., at least trans-10 and Cis-12 conjugated linoleic acids (Ventto et al. 2017), seems to play a significant role. In goats, this conjugated linoleic acids methyl esters seems to be dose-effect dependent in reduction of milk fat secretion (Fernandes et al. 2014) but improving energy balance (Baldin et al. 2014). However, probably the regulation of fat synthesis in mammary gland is also involved in the low milk fat syndrome occurence (Suárez-Vega et al. 2017; Ventto et al. 2017).

No effective prevention has been found until today to limit conjugated linoleic acids methyl esters produced in rumen, keeping the production levels. Best practices for nutritional, feed and health managements evaluating feed intakes, milk yield and contents, BCS, metabolic profiles, ruminal and urinary pH and the health status of individuals are strongly recommended.

11.9 Concluding Remarks

Nutritional and metabolic disorders are closely related modifying the homeostasis with negative impact in production, reproduction, health and welfare of goats. These animals are exceptional selective browsers/grazers, which allow the best use of biomass and nutrients intake in harsh environments. In these conditions, the plants diversity seems to be the best option to minimize the potential lack of energy, mineral and vitamins. As prevention of nutritional deficiencies, diet should be supplemented regarding epidemiology disorders in each region of the world.

Goat genetic improvement for milk yield and composition need to be complemented by nutritional and feed management programs. Similar to dairy cows, but with several particularities mainly related with feeding behavior, metabolism and diseases' ethiophisiopathology, goats present several disorders called "production diseases". Even a major factor can be originally involved, the interrelationship of several body systems, which can be affected by several risk factors. Consequently, a holistic approach is needed to control or even prevent nutritional and metabolic disorders.

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Chapter 12
Goat Meat Production in Resource-Constrained Environments and Methods to Improve Quality and Yield

Edward C. Webb and Pamela Pophiwa

Abstract Livestock production in South Africa occurs in a resource-constrained environment, due to the arid and semiarid nature of the regions where livestock are kept, as well as water scarcity and nutrient deficiencies. The improved Boer goat is one of the success stories of this harsh environment. Boer goats achieved international acclaim for their optimum combination of adaptability, growth, efficiency and carcass characteristics. Despite advances in breeding, feeding and production methods, goat meat remained a relatively unimportant source of meat in South Africa. However, the marketing of goat meat as chevon in the 1980s and research that highlighted the health-promoting and sensory attributes of chevon increased its popularity. The notion that meat from goats and sheep differ and that chevon represents a unique source of red meat improved consumer perceptions of goat meat. It was established that goat carcasses generally have high ultimate pH values and a low glycolytic potential, which necessitates the use of technologies such as electrical stimulation and delayed chilling of carcasses to better manage the conversion of muscle to meat, prevent cold shortening and improve meat quality. These technologies provide effective methods to address consumer concerns regarding stringy and tough goat meat and should be included as critical parts of the normal slaughter procedures at abattoirs. Research has now addressed most criticisms about goat meat and the indications are that this healthy source of red meat should gain popularity both locally and abroad. Consumer confidence in chevon is essential in order to meet the increasing demands for high-quality animal source proteins, especially in resource-constrained environments.

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12.1 Introduction

It is accepted that goats have served as a source of human nutrition, since the beginning of human civilization and they are now widely distributed around the world (Webb et al. 2005). Goat meat production is a deliberate process that ranges from conception to consumption, with the main focus of supplying consumers with a product that is wholesome, nutritious, and palatable (Casey and Webb 2010).

Approximately 88% of the world goat population is located in Africa and Asia, of which more than 80% inhabits the tropics and subtropics (Alexandre and Mandonnet 2005). In South Africa, about 70% of goat meat production occurs in the semiarid and arid regions (Lebbie and Ramsay 1999), which are aptly described as resource-constrained environments. In fact, most livestock production which occurs at latitudes between 30° North and 30° South of the equator (tropics and subtropics) are generally characterized by environmental constraints such as high ambient temperatures, significant temperature fluctuations, high humidity, qualitative- and quantitative-nutrient deficiencies, frequent challenges of internal and external parasite infestations, and short photoperiod impulse (low difference in duration of day and night). Moreover, in many countries in this zone, there are often a number of added challenges such as small stock diseases, predation, and stock theft.

Research contributions and scientific knowledge on meat goat production is negligible compared to that of other species of livestock (Shrestha and Fahmy 2007a). South Africa has gained international recognition for its research on and development of the Boer goat breed. This breed emanated from a need to improve the common Boer goats available in South Africa during the early 1900s, especially in terms of growth performance, feed efficiency, carcass characteristics, and hardiness in the semiarid and arid regions of the subcontinent.

Goats were popular because they could be used in farming with grazers like cattle in shrub and bushveld areas without increasing the stocking rates markedly. Their browsing and grazing characteristics make them more versatile than other livestock in extensive production systems. In fact, their ability to utilize browse was employed to combat bush encroachment in predominantly Savannah and bushveld areas, although goats were also criticized for contributing to overgrazing and bush encroachment in resource-constrained environments. In addition, it was soon realized that the value of livestock for meat production lies in the acceptability of the carcass in the market (Van Niekerk and Casey 1988).

The purpose of this chapter was to provide an overview of recent studies on meat goat production in South Africa and methods to improve goat carcass and meat quality.

12.2 Improved Goat Meat Production in South Africa: The Case of the Boer Goat Breed

In the beginning of 30s of the twentieth century, the common Boer goat was identified as an ideal genotype for improvement, since it was described as a compact, well-proportioned, and short-haired breed of goat (Van Rensburg 1938). Breeders commenced with breeding and selection of a faster growing, more fertile, and hardy goat, with improved carcass and meat characteristics (Steyl 1968). Skinner (1972) later reported on the excellent progress that was made with the new "improved Boer goat", which had much better potential for intensive animal production in semiarid parts of South Africa. Similar research occurred during the same period on East African goats, which demonstrated the huge potential of these hardy small ruminants in terms of efficient meat production (Devendra and Burns 1983). The local livestock industry soon discovered their huge potential in terms of growth traits, excellent carcass, and meat characteristics and high-value byproducts such as quality skins.

The improved Boer goat gained popularity nationally and internationally due to their high fertility, fecundity, and ability to breed in harsh environments, with little supplemental feeding. It was shown that Boer goats have a peak in sexual activity in Autumn, but out of season breeding is not uncommon and twins (50%) or triplets (6.6%) are often born (Skinner 1972). Much research was conducted since the development of the improved Boer goat in terms of growth in different productions systems, reproduction, nutrient requirements, carcass and meat characteristics, and parasite resistance (Steyl 1968; Van Niekerk and Casey 1988; Penzhorn and Krecek 1997; Malan 2000; Dhanda et al. 2003; Webb et al. 2005; Simela et al. 2011; Webb 2014).

Although Boer goats undoubtedly represent one of the most prolific and hardiest types of small ruminants, their carcass and meat characteristics have been topics of major concern to goat breeders and consumers.

12.3 Development of the Improved Boer Goat

The improved Boer goat was developed in the 1950s by a small number of farmers in the Somerset East district of the Eastern Cape in South Africa. It is generally accepted that the *circa* 570 goat breeds in the world were bred and developed from the Bezoar, Savannah, and Nubian goat types (Shrestha and Fahmy 2005). The genesis of the Boer goat is unique since its development did not follow the normal combination of two or more pure breeds (Malan 2000; Shrestha and Fahmy 2007b), but prototypes were selected from a number of existing goat breeds and types in South Africa to comply with the requirements of a functional and prolific goat that yields outstanding carcasses and meat which compares favorably with mutton and lamb.

Two other varieties of Boer goats occurred in South Africa. One variety had long hair, a heavy head with horns, strong shoulders and, according to Van Rensburg (1938), the skin and flesh were coarse. The other variety was a long-eared and polled breed, which was apparently derived from imported milk goats. Indigenous goats usually exhibit a wide variation in their size, coat color, and other phenotypic traits such as horns and ears, and they serve as a valuable genetic resource because of their ability to adapt to harsh climatic conditions and to efficiently utilize limited and poor quality feed (Webb and Mamabolo 2004).

Unimproved Boer goats were criticized for their poor carcass quality, coarse-grained meat and frequent complaints of unpleasant flavor, especially if the goats were not slaughtered at a young age (Steyl 1968). Prior to the establishment of the improved Boer goat in 1956, the leather trade ensured the survival of small numbers of the different Boer goat varieties. A summary of carcass weights and dressing percentages at typical slaughter weights of different goat breeds and goat crossbreeds as reported by different authors are presented in Table 12.1. The improved Boer goat is a remarkable breed that surpassed all expectations (Figs. 12.1 and 12.2). It excelled in the biologically important traits associated with adaptability, hardiness, growth, and yielded carcasses of high quality and meat that was generally more appealing to discerning consumers. However, better immunity against tick-borne diseases and internal parasite resistance remain problematic (Penzhorn and Krecek 1997; Sebei et al. 2004a, b).

In terms of intensive goat meat production, improved Boer goats demonstrated great potential (Skinner 1972), and more recent research confirmed the huge potential of improved Boer goats to yield heavier carcasses with carcass yields often exceeding 50% (Van Niekerk and Casey 1988; Dhanda et al. 2003; Webb et al. 2005; Simela et al. 2011; Webb 2014; Pophiwa et al. 2016).

Table 12.1 Slaughter weight, carcass weight and dressing percentage of different goat breeds

Breed or genotype	Slaughter weight (kg)	Carcass weight (kg)	Dressing (%)	References
Boer × Angora	26.0 (200 days)[a]	10.9	51.0	Dhanda et al. (2003)
Boer × Feral	25.5 (174 days)	11.5	54.0	
Boer × Saanen	27.7 (154 days)	16.9	51.7	
Saanen × Angora	26.1 (176 days)	10.9	51.4	
Saanen × Feral	26.8 (164 days)	11.8	53.2	
South African indigenous goats	27.8 (0 teeth)	11.8	42.2	Simela et al. (2011)
	33.1 (2 teeth)	13.7	41.0	
	36.6 (4–6 teeth)	15.2	41.4	
	42.7 (8 teeth)	16.9	39.0	
Improved Boer goats	35–40	16–22	46–51	Webb (unpublished)
	39.8	18.9	47.5	Pophiwa et al. (2016)

[a]Values in parentheses indicate the age of goat

Fig. 12.1 Improved Boer goat buch from South Africa (provided courtesy of Nico Botha Boer Goat stud, Britstown, Northern Cape, South Africa)

Fig. 12.2 Improved Boer goat does from South Africa (provided courtesy of Nico Botha Boer Goat stud, Britstown, Northermn Cape, South Africa)

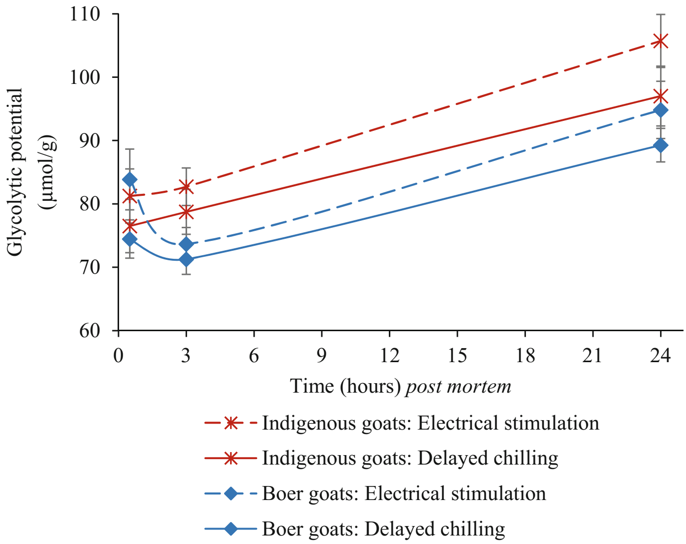

Fig. 12.3 Glycolytic potential (µmol/g) of South African indigenous (Indigenous goats) and improved Boer goats (Boer goats) calculated at 30 min, 3 and 24 h post mortem in *m. longissimus dorsi* after low-voltage electrical stimulation or delayed chilling of carcasses. Vertical bars indicate standard error of means. red and blue lines (♦,X) ~Differences in glycolytic potential between breeds (red and blue lines) were significant ($P < 0.05$) at 3 and 24 h *postmortem*, but no differences were observed between treatments (dotted and solid lines.)

The sensory and nutritional properties of goat meat at the point of consumption are the culmination of sequential influencing factors, which can be managed considerably by producers, marketers, and processors (Casey and Webb 2010). Webb et al. (2005) have shown that the popularity and usage of meat are influenced mostly by the culture of a community, which in itself is a very complex subject. The criteria and specific factors that usually affect carcass and meat quality are summarized in Table 12.2.

Unfortunately, complaints about the quality and sensory properties of goat meat remained problematic and it failed to gain more popularity in South Africa. Moreover, goat meat remained a product of choice for selected cultural groups, especially associated with certain religious or cultural activities, despite the fact that it is a healthy and lean red meat with virtually no known religious or cultural taboos (Webb et al. 2005).

Table 12.2 The criteria and factors affecting carcass and meat quality in goats

Criteria	Factors affecting meat quality
Carcass yield and composition	Ratio of fat to lean Muscle size and shape
Carcass conformation and quality	Color and water-holding capacity of lean Fat texture and color Marbling (intramuscular fat) Chemical composition of lean
Sensory attributes	Aroma Flavor Juiciness Texture and tenderness
Nutritional value and wholesomeness	Nutrient content Chemical safety Microbial safety Animal husbandry system

12.4 Challenges Associated with Carcass and Meat Quality of Boer Goats

One of the most influential studies on goat meat production in South Africa, subsequent to the initial study focusing on more intensive goat meat production from South African indigenous and Boer goats (Skinner 1972), was conducted by Casey in the early 1980s (Casey 1982). This study aligned goat meat with the internationally renowned product known as "chevon". Subsequent studies demonstrated the huge potential of improved Boer goats in terms of growth results (Van Niekerk and Casey 1988) and healthy nutrient content, especially in terms of favorable FA composition of goat meat (Casey and Van Niekerk 1985). The nutrient composition of goat meat is presented in Table 12.3, which confirms its favorable protein and relatively low-fat content (Webb et al. 2005). The latter research also set the scene for a number of subsequent studies that interrogated the practices and scientific principles associated with chevon or "high quality" goat meat production in South Africa.

Initially, the challenge was to present goat meat as a wholesome and healthy alternative to other sources of red meat. This included reviews about goat meat quality (Webb et al. 2005) and comparisons between the nutrient composition and meat quality attributes of meat from Boer goats, which were compared to the indigenous

Table 12.3 The nutrient composition of selected South African goat breeds (adapted from Webb et al. 2005)

Goat	Moisture (%)	Protein (%)	Fat (%)	Ash (%)
Improved Boer	69.4	22.8	10.5	0.95
South African indigenous	69.8	24.3	7.9	0.97
Angora	64.2	29.1	4.4	1.0

Table 12.4 Differences between indigenous and improved Boer goats in terms of cross-sectional muscle fiber areas and percentages of fiber types in *m. longissimus dorsi*

	Breed	
	Indigenous goats ($\bar{x}$ ± S.E.M.)	Improved Boer goats ($\bar{x}$ ± S.E.M.)
Cross-sectional areas of muscle fiber types (×1000 μm^2)		
Red fibers	1.95 ± 0.11	2.38 ± 0.22
Intermediate fibers	2.67[a] ± 0.15	3.51[b] ± 0.31
White fibers	3.50 ± 0.24	4.48 ± 0.42
Percentages of muscle fiber types		
Red	50.9[a] ± 0.98	47.0[b] ± 1.22
Intermediate	22.4 ± 0.80	24.4 ± 0.78
White	26.7 ± 0.83	28.7 ± 0.93

Means within the same row with different letters ([a, b]) differ ($P < 0.05$)

counterparts and local breeds of mutton sheep such as Dorper and SA Mutton Merinos (Casey and Van Niekerk 1985). A summary of the differences in cross-sectional areas and percentages of different muscle fiber types between indigenous and improved Boer goats are presented in Table 12.4, which clearly illustrates the increase in cross-sectional areas and change in muscle fiber types in the Boer goat.

It is also important to acknowledge that meat from goats and sheep differ, mainly due to variations in tissue proportions and in the composition of subcutaneous and intramuscular fat. Goats have smaller carcasses than sheep, while the latter yield proportionally more dissectible fat and lean and less bone than goats. Consumers can generally distinguish the species-related goat and mutton flavors, hence the important recommendation that goats should be valued as a different species compared to sheep. It was also found that goats are often slaughtered at very old age, which may detract from its perceived organoleptic quality. A study by Simela et al. (2008) indicated that chevon from South African goats is acceptable to consumers as mutton, provided that the meat is from goats of about 2 years of age or younger.

12.5 Managing the Conversion of Muscle to Meat

Much research has been conducted on goat carcass and meat quality, but little attention has been paid to the biochemical changes taking place in the meat immediately *postmortem* (Simela et al. 2004a). These biochemical changes in skeletal muscle have a significant effect on the quality of the meat yielded from a carcass.

Recent research indicates that goat meat of poor quality is often associated with inappropriate *ante*-, *peri*- or *postmortem* handling procedures (Pophiwa et al. 2016). Proper *ante*- and *postmortem* animal and carcass management are essential in order to ensure best possible conversion of muscle to meat, for optimum goat meat quality.

The conversion of muscle to meat depends mostly on the extent and duration of the metabolism of intramuscular glucose and associated glycogenic precursors to lactic acid, followed by a complex interplay between muscle pH and temperature decline *postmortem*. The intrinsic and extrinsic factors that influence the rate and extent of *postmortem* glycolysis are presented in Table 12.5.

An important finding in terms of *postmortem* muscle metabolism is that goat carcasses generally exhibit a high ultimate pH (pHu), high initial lactate concentration and low glycolytic potential, which suggest that they suffered both chronic and acute stress during preslaughter handling (Simela et al. 2004a). A number of previous studies have reported similarly high pHu values (Table 12.6). The data

Table 12.5 Intrinsic and extrinsic factors affecting the rate and extent of *postmortem* glycolysis

Intrinsic factors	Extrinsic factors
Animal species	**Stress**
Genotype	**Preslaughter drug administration**
Age	*Environmental temperature*
Temperament	**Postmortem temperature**
Type of muscle	*Electrical stimulation*
Intramuscular location	*Postmortem comminution*
Pathology	*Postmortem salting* *Postmortem pressure* *Postmortem oxygen tension*

NB: Factors that are in **bold text** affect **both** the rate and extent of glycolysis; in normal text affect the extent only; *italicized* affect the rate only (Adapted from Lawrie 1998)

Table 12.6 Summary of ultimate pH values reported for chevon of several goat breeds

Type of goat	Muscle	pHu	References
Saanen females	Not specified	5.88	Hogg et al. (1989)
Saanen males		5.90	
Feral males		5.55	
Unspecified breed castrates	*Iliopsoas*	6.01	Hogg et al. (1992)
Unspecified breed Females		6.00	
Boer goat	*Longissimus*	6.04	Swan et al. (1998)
Cashmere		5.70	
Boer × Cashmere		5.78	
Bucks of various breeds	*Longissimus thoracis*	5.6–5.8	Dhanda et al. (1999)
Boer crossbreeds	*Longissimus*	5.8–6.2	Husain et al. (2000)

presented indicate the generally high pHu values recorded for a variety of goat breeds by different researchers, which indicates the generally low glycolytic potential of goat meat.

Results suggest that high ultimate pH values observed in goat carcasses is not an intrinsic characteristic of chevon, but rather due to stressful *peri-mortem* handling of goats which results in low concentrations of glucose-6-phosphate. Data from Simela et al. (2004a, b) and that of Pophiwa et al. (2016) have demonstrated that goats generally have a low glycolytic potential as illustrated in Fig. 12.3. The latter has important implications on the *peri-* and *ante-mortem* management of goats, by reducing stress during these phases and employing technologies to improve *post-mortem* muscle biochemistry to improve the conversion of muscle to meat.

12.6 Effects of Electrical Stimulation and Delayed Chilling on Goat Meat Quality

Both the rate and extent of *postmortem* glycolysis affect the development of meat quality (Scheffler and Gerrard 2007). During the conversion of muscle to meat, pH usually decreases gradually from *circa* 7.4 to ultimate values of between 5.4 and 5.6 (Young et al. 2004). Previous studies indicate that either too fast or slow glycolytic rates have detrimental effects on meat quality (Ryu and Kim 2005). In addition, the combination of pH and temperature at the onset of *rigor mortis* is crucial for optimal meat tenderness (Hannula and Puolanne 2004).

Ideally, pH should decrease to *circa* 6 while carcass temperature is between 14 and 19 °C (Locker and Hagyard 1963; Hopkins et al. 2011) to ensure optimal conversion of muscle to meat. Temperatures below 12 °C or above 35 °C, however, can cause excessive sarcomere shortening, with adverse effects on meat tenderness (Thompson 2002).

Goat meat tends to be darker and less tender than lamb/mutton (Babiker et al. 1990; Sen et al. 2004). Dark meat is typical of muscles exhibiting slow glycolytic rates (Ryu and Kim 2005). On the other hand, decreased goat meat tenderness is usually ascribed to excessive sarcomere shortening during normal chilling conditions (Simela et al. 2004a; Kadim et al. 2006; Gadiyaram et al. 2008). Goat carcasses are generally small and have a thin subcutaneous fat layer. These characteristics permit rapid dissipation of heat early *postmortem*, which may lead to cold shortening and subsequent muscle toughening (Webb et al. 2005). Control of both pH and temperature declines *postmortem* is, therefore, crucial in order to achieve goat meat of optimal quality.

Postmortem electrical stimulation has been shown to improve meat quality in many species including goats (King et al. 2004; Gadiyaram et al. 2008). Muscle contraction during electrical stimulation accelerates the rate of pH decline, allowing carcasses to be rapidly chilled without the risk of cold shortening (Fabiansson and Reutersward 1984). Some researchers have indicated that electrical stimulation can

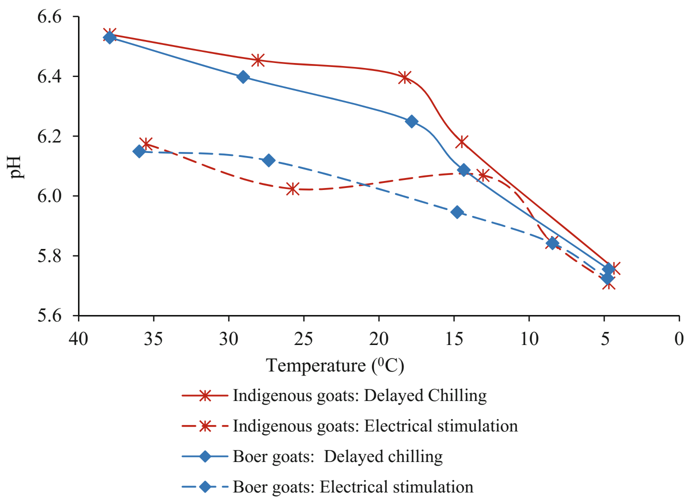

Fig. 12.4 Effects of low-voltage electrical stimulation and delayed chilling of carcasses from indigenous South African and improved Boer goats on pH-temperature profiles as measured in the *m. longissimus dorsi* red and blue lines (♦,X) ~Differences in pH-temperature profiles were observed between treatments (dotted and solid lines) from 30 min to 6 h *postmortem,* but no differences were observed after 6 h postmortem or between breeds (red and blue lines)

also improve goat meat color (King et al. 2004). Therefore, low-voltage electrical stimulation has been employed as an "ideal" strategy for improving goat meat quality, and the effects are illustrated in Fig. 12.4. Both electrical stimulation and delayed chilling have beneficial effects on goat carcasses, but electrical stimulation is preferential (Pophiwa et al. 2016).

Low-voltage electrical stimulation and delayed chilling of goat carcasses have also demonstrated beneficial effects on glucose-6-phosphate concentrations, with subsequent improvements in the conversion of muscle to meat and, thus, meat quality (Fig. 12.5). The use of either electrical stimulation and/or delayed chilling of goat carcasses markedly decreases the risk of cold shortening, while heat shortening does not seem to be a major risk in this species.

The major disadvantage of electrical stimulation is that it is expensive to install and maintain, therefore may not be readily adopted by small-scale abattoirs. In such situations, delayed chilling, which has also been shown to prevent cold shortening and improve meat tenderness, may be considered (Fernández and Vieira 2012).

Delayed chilling involves holding carcasses at elevated temperatures (above 10 °C), until the onset of *rigor mortis* (Hannula and Puolanne 2004; Savell et al. 2005). At such elevated temperatures, the sarcoplasmic reticulum can recapture the released calcium ions and muscles enter into *rigor mortis* in a relaxed state, resulting in optimal meat tenderness (Cornforth et al. 1980). The beneficial effects of electrical stimulation and delayed chilling on the concentration of intramuscular glucose-6-phosphate (G-6-P) are demonstrated in Fig. 12.5, indicating the better

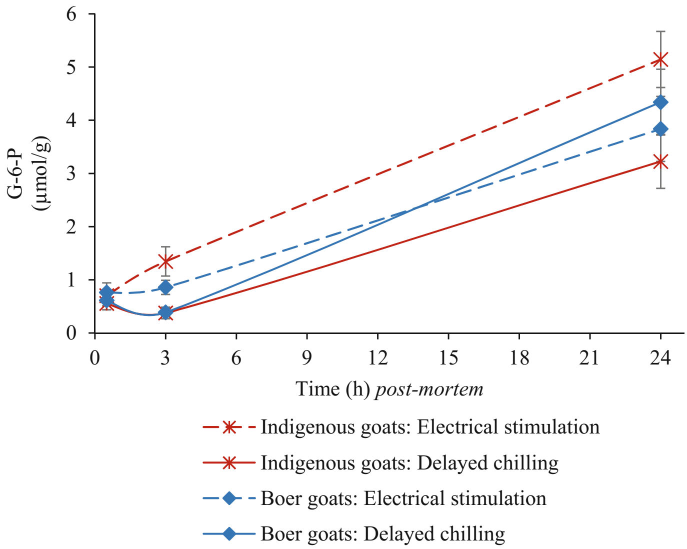

Fig. 12.5 Glucose-6-phosphate (G-6-P) concentration (µmol/g), at 30 min, 3 and 24 h post mortem in *m. longissimus dorsi* of indigenous South African and improved Boer goats after applying electrical stimulation or delayed chilling of carcasses. Vertical bars indicate standard error of means red and blue lines (♦,X) ~Differences in G-6-P between treatments (dotted and solid lines) differed at 3 h *postmortem* ($P < 0.05$), but no differences were observed between breeds (red and blue lines)

response in terms of G-6-P concentrations subsequent to the application of these methodologies.

Shear force values of meat from improved Boer goats were significantly lower (4.2 ± 0.2 kg; ± S.E.M.) compared to that obtained for indigenous goats (4.5 ± 0.3 kg; $P < 0.05$), which illustrate the improvements in meat quality due to genetic selection. Meat from Boer goats was more tender than that from indigenous goats, which is important since the latter was previously criticized for producing stringy meat.

Electrical stimulation of goat carcasses also resulted in a consistent decrease in Warner Bratzler shear force values, which provides an indication of improved meat tenderness. Shear force values showed a small numerical decreased from 4.4 ± 0.2 kg for unstimulated carcasses to 4.1 ± 0.2 kg for electrically stimulated carcasses. Although the shear force values obtained were well within the acceptable range for tender meat, the decrease in shear force values confirm the potential beneficial effects of employing technologies such as electrical stimulation on the quality of goat meat, which addresses one of the remaining complaints regarding goat meat, namely that it tends to be stringy and tough.

12.7 Conclusions

The improved Boer goat is a highly prolific breed of goat that exhibits an optimum combination of sought after attributes in terms of adaptability, growth, efficiency, carcass characteristics, and meat quality. Despite improvements in goat breeding, feeding and production systems, goat meat failed to gain more popularity as an important source of red meat in South Africa.

During the 1980s, the marketing of goat meat as chevon and research directed at emphasizing its beneficial nutritional, sensory and health-promoting attributes, resulted in more demand for this meat. It is also essential to acknowledge that meat from goats and sheep differ, and that chevon represents a unique source of red meat. The confirmation of the generally high ultimate pH values and low glycolytic potential of goat meat, resulted in the shift in focus to the use of technologies such as electrical stimulation of carcasses and delayed chilling, to better manage the conversion of muscle to meat, and therefore goat meat quality.

Both electrical stimulation and delayed chilling *postmortem* can be effectively applied to prevent cold shortening of goat carcasses. These technologies provide effective methods to address consumer concerns regarding stringy and tough goat meat, and should be included as critical parts of the normal slaughter procedures at abattoirs to ensure optimal conversion of muscle to meat, and therefore increase consumer preference for this vitally important source of animal protein in resource-constrained environments.

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Part IV
Health Management and Public Health

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Chapter 13
Major Infectious Diseases with Impact on Goat Production in North African Countries

Moustafa Kardjadj and Meriem H. Ben-Mahdi

Abstract Goat industry provides a vital food source (meat and milk) of many North African inhabitants. The goat populations in North Africa are more than 17 million heads, and most of them are reared under traditional husbandry system. In spite of the advantages of goats rearing in the region, diseases can substantially affect the optimal and cost-effective production. In this chapter, we describe the major infectious diseases with impact on goat production in North African countries (Morocco, Algeria, Tunisia, Libya and Egypt) and the control measures adopted in each country. The main diseases threatening the goat industry are peste des petits ruminants, bluetongue, foot-and-mouth disease, sheep/goats pox, brucellosis and Rift Valley fever. The current epidemiological situation of those goat diseases in the region can be considered as very dramatic. Therefore, the implementation of a regional control approach is needed to prevent and control these devastating diseases.

13.1 Introduction

According to the Food and Agriculture Organization (FAO), an estimated 95% of the goat population is concentrated in developing countries (FAO 2014). These animals play a significant economic role in many rural areas of the world, because they adapt easily to all production systems, under most climatic conditions and convert very efficiently their feed into highly nutritious milk and meat that could cover the nutritional needs of the inhabitants in developing countries (Morand-Fehr et al. 2004; Boyazoglu et al. 2005).

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Because of its geographical location and its borders with Middle Eastern and Sahelian countries, where major infectious diseases are present, the North African region is vulnerable to them, including peste des petites ruminants (PPR), bluetongue (BT), foot-and-mouth disease (FMD), sheep/goats pox, brucellosis and Rift Valley fever (RVF), which affect livestock production in these countries (OIE 2016).

Livestock is one of the most important components of agriculture in North African countries. Its contribution to the agricultural gross domestic product (GDP) ranges from 20 to 25%. It employs more than 20% of the active rural population and provides products such as milk, meat, wool and skins to other sectors (agri-food and artisanal industries). Goats have an important economic and social role; their estimated contribution to the region GDP varies each year from 1 to 3% (FAO 2014).

In this chapter, we describe the major infectious diseases with impact on the goat's production in North African countries (Morocco, Algeria, Tunisia, Libya and Egypt) as well as the adopted control measure of these diseases according to the available literature.

13.2 Goat Population in North Africa Region

Goat population is one of the main sources of meat and milk production in North African countries that plays a vital role in food security (Rancourt et al. 2006). The goat populations in North Africa is estimated to be more than 17 million goats (Table 13.1). Although intensive husbandry structure has recently been introduced, the majority of the goat herds in the region are reared under traditional extensive system (FAO 2014).

In spite of the advantages of goats rearing in the region, diseases pose significant challenges to ideal and profitable production in those countries (Boyazoglu et al. 2005; Canali 2006). Furthermore, the local goat population in North Africa is characterized by its heterogeneity because of the mixing of different breeds (Table 13.1). This population is considered as rustic and with poor productive

Table 13.1 Goat population and main breeds reared in North African countries

Country	Goat census (heads)	Main goat breeds
Algeria	5,000,000	Arabia, Berber, Kabyle, Makatia, Mzabite, Sahelian, Tuareg
Egypt	4,000,000	Baladi, Barki, Saidi, Sharkawi, Sinai, Wahati, Zaraibi
Libya	1,800,000	Mahali, Like Targhai, Tibawi
Morocco	5,000,000	Attaouia, Berber, Yahyaouia
Tunisia	1,500,000	Arabia, Nubienne, Maltaise

Source FAO (2014)

traits. Actually, it is difficult to distinguish pure breeds that could present specific qualities to be developed (FAO 2014).

13.3 Peste des Petits Ruminants

PPR is a highly contagious disease of small ruminants especially in goats (also see Chap. 20 of volume 1) (Banyard et al. 2010). It is caused by a virus belonging to the *Paramyxoviridae* family. The disease is characterized by high fever, stomatitis, purulent ocular and nasal discharges, pneumonia and diarrhea with severe dehydration often leading to death (Diallo et al. 2007). The morbidity and mortality rates can be as high as 90% depending on some intrinsic and extrinsic factors (Albina et al. 2013).

PPR is enzootic in all Africa (except the most southern part). Considering the significance of the small ruminant's industry in the socio-economic livelihood of the poor communities, PPR has been linked with food security achievement. Therefore, PPR has been classified as a notifiable disease by the World Organization for Animal Health (OIE) and as the next disease to be eradicated by the Food and Agriculture Organization (FAO) (Banyard et al. 2010; Albina et al. 2013). Although PPR virus (PPRV) exist as one serotype or strain, partial sequence analysis points towards the presence of four lineages (I, II, III and IV) (Kwiatek et al. 2011).

PPRV outbreaks occurred across the world have resulted in the spread of the disease into PPR free areas within the African continent (Kwiatek et al. 2011). The recent results from the FAO project «*Toward a harmonized strategy for the control of Peste des Petits Ruminants in North Africa TCP/RAB/3302*» provide profound perceptions into PPR epidemiological situation in Morocco, Algeria, Tunisia, Libya and Egypt updated up to 2012–2013. These results illustrated a 40–70% herd prevalence in these countries, except in Morocco, which adopted 4 years of mass vaccination program (the last campaign was in 2011) (EFSA 2015). On the other hand, the results of the molecular studies in Morocco, Egypt, Libya, Tunisia and Algeria showed that the lineage IV of PPRV is circulating throughout the region (Kwiatek et al. 2011; Sghaier et al. 2014; Kardjadj et al. 2015).

A homologous PPR vaccine is available since 1989; this vaccine confers protection against PPR for at least 3 years (Diallo et al. 2007). However, only in Morocco, PPR was well controlled at the national level through mass vaccination, thus providing very strong evidence that PPR control can be achieved in Northern Africa and other endemic territories. Moreover, after the vaccination campaigns in Morocco, the epidemiological situation was assessed. No viral circulation could be observed among young unvaccinated animals, and a good immune protection rate was achieved in vaccinated adults (FAO 2013). However, assiduous vigilance is still needed because there is a risk of PPR reoccurrence given the illegal cross-border livestock movements. Early detection of such reoccurrence is a necessary condition for a rapid response and effective management of possible outbreaks of PPR. This fragile PPR-free situation in Morocco highlights the importance of designing and actually implementing a regional PPR control strategy, relying on coordinated mass vaccination in affected countries, together with post-vaccination monitoring and efficient active surveillance measures. In particular, a better knowledge of legal and illegal livestock movements is of critical importance (EFSA 2015).

13.4 Foot-and-Mouth Disease

FMD is a highly contagious disease in ruminants including goats. It is caused by FMD virus (FMDV), that belong to the *Picornaviridae* family. The virus exists as seven immunologically distinct serotypes, viz. O, A, C, Asia 1, Southern African Territories (SAT) 1, SAT 2 and SAT 3. FMD is constantly present in many developing countries with three predominate serotypes (O, A and SAT 1) (Rweyemamu et al. 2008).

FMD is characterized by fever and blister-like sores on the tongue and lips, in the mouth, on the teats and between the hooves. The disease causes severe production losses and while the majority of affected animals recover, the disease often leaves them weakened and debilitated; vaccination or recovery from infection with one serotype will not protect against subsequent infection with another serotype (Belsham 2005). Control of FMD is difficult due to the emergence of new strains (Domingo et al. 2005). Phylogenetic studies of the VP1-coding region have been used to define genotypes, which occur in defined geographic areas (topotypes) for each serotype (Knowles and Samuel 2003).

Historically, four serotypes have circulated in North Africa (O, A, SAT 2 and C) with type O being the most prevalent serotype, followed by serotype A (WRLFMD 2016). FMD in small ruminants is generally silent; however, the role of small ruminants in the epidemiology of FMD in African countries is well documented. The small ruminants contaminate river water, ponds, pastures, the shrubs and other environmental elements (Rweyemamu et al. 2008). For example, in 1989, in a Tunisian FMD free area, a cattle was infected after importing sheep and goats from the Middle East. Subsequently, the disease spread into FMD free territories of Algeria and Morocco (Knowles and Samuel 2003). Furthermore, in 1999 a West-African topotype (O/CIV/8/99) was isolated in cattle in Algeria, which spread to Tunisia and Morocco causing severe outbreaks in sheep and goats as well as in cattle (Samuel et al. 1999). On the other hand, the FMD epidemiological situation in Egypt and Libya is different compared to Tunisia, Algeria and Morocco (Samuel et al. 1999), due to the fact that, since 2000, FMD is considered endemic in Egypt and Libya; where several outbreaks of FMD have been reported due to serotypes A, O and SAT (OIE 2016).

The last FMD episode in the North African countries was in 2014–2015; when the topotype O/ME-SA/Ind 2001d spread from Saudi Arabia to Egypt, Libya, Tunisia, Algeria and Morocco. This FMD episode caused huge economic losses in cattle, sheep and goat industries in these countries (Kardjadj 2016).

Currently, the rapid spread of SAT2 and A in Libya and Egypt establishes the need for a robust surveillance system to detect and respond effectively to newly emerged strain in the region (Ahmed et al. 2012; Ryen et al. 2015). Even if, Algeria, Tunisia, Morocco and Egypt have contingency plans for immediate vaccines procurement; the unstable political situation in Libya invariably put their neighbours at constant risk as result of free movement of animals across borders (WRLFMD 2016). Furthermore, the livestock population in Algeria and Morocco is highly susceptible to SAT2, and effective vaccines are only used in Tunisia and Egypt (Kardjadj 2016). In Libya, the routine implementation of vaccination programs has been severely affected by its current unstable political situation. It is expected that serotypes SAT2 and A will spread extensively and will affect seriously to livestock in the region (Hall et al. 2013; Kardjadj 2016).

Control and preventive measures for FMD are similar to other transboundary animal diseases, which would include surveillance, animal movement control, vaccination, quarantine and fair economic compensation. The FMD epidemiological status in the region required intensive monitoring of the circulating FMD strain, rapid typing of the isolated FMD strain at OIE or FAO Reference Centres and contingency plans for immediate vaccines procurement (Kardjadj 2016).

13.5 Bluetongue

BT is a viral disease of cattle, sheep and goats characterized by inflammation of mucous membranes, oedema and haemorrhages which can be responsible for up to 75% mortality in livestock (Maclachlan 2010). BT virus (BTV) is transmitted by several species of *Culicoides*, critical for the geographical range of the disease (Tabachnick 2004). BTV is the prototype of the genus *Orbivirus*, within the family *Reoviridae*; and of which 26 distinct BTV serotypes have been identified (Maan et al. 2011). The disease severely affects sheep, cattle and goats, being these latter considered as the main bluetongue reservoir (Maclachlan 2010).

In 1956, and for the first time in North Africa BT was reported in Morocco, although no clinical cases were reported until 2004 when the second epidemic caused by a BTV-4 was declared (Mellor et al. 2008). In 2006, a new serotype (BTV-1) originated from Algeria reemerged and caused the third epidemic in Morocco (Cêtre-Sossah et al. 2011). Egypt was affected by BT several times: the reported serotypes were BTV-1, 2, 4, 10, 12 and 16 (Mellor et al. 2008). Bluetongue is generally mild in indigenous sheep of Egypt and Libya since the classical symptoms of the disease are not commonly seen (Mellor et al. 2008).

BT was reported for the first time in Tunisia in 1999–2000 due to serotype 2; molecular studies comparing the Tunisian strain to those isolated in Corsica the same years showed 99.4% homology between them. Subsequently, the disease spread into the northeastern part of Algeria between July and September 2000 and, then, the virus spread to other parts of the country (Hamida 2000). In July 2006, serotype 1 of BTV was reported in central Algeria; this strain spread into other North African countries (Tunisia, Libya and Morocco) and South European countries (Spain, Italy, Portugal and France). This wide movement of BTV may have been caused by windborne movement of adult *Culicoides* (Cêtre-Sossah et al. 2011).

13.6 Sheep Pox and Goat Pox

Sheep pox and goat pox (also see Chap. 20 of volume 1) are considered to be a single disease by the OIE, referred to here as Sheep Pox and Goat Pox (SPGP). The two diseases are clinically indistinguishable. Strains of sheep pox virus (SPPV) and goat pox virus (GTPV) cannot be differentiated serologically, although distinct host preferences exist with most strains causing more severe disease in the homologous host (Bhanuprakash et al. 2006; Diallo and Viljoen 2007). SPPV and GTPV belong to the Poxviridae family (Diallo and Viljoen 2007). Sheep pox and goat pox in enzootic region are related with substantial production losses in milk, meet and wool; furthermore, SPGP increased the abortion herd rates and the mortality rates among young lambs (Yeruham et al. 2007).

SPGP are endemic in Africa (except for southern Africa), Asia, and the Middle East (OIE 2016). Although infection with SPGP virus in North African countries was previously described, and an annual sheep vaccination was conducted since the 80s (Achour and Bouguedour 1999), the disease is still responsible for substantial economic losses in small ruminants breeding. Clinically, the classical SPGP vesicular form is usually observed in these countries and characterized by the appearance of skin lesions on the entire body surface evolving from macules, to papules, vesicles or vesiculo-pustules and crusts at the end of disease evolution (OIE 2016).

13.7 Brucellosis

Small ruminant's brucellosis due to *Brucella melitensis* is a significant zoonosis with a serious threat to human health (Seleem et al. 2010). The epidemiological situation of brucellosis worldwide is regularly shifting, with the disease emergence in new areas (OIE 2016). *Brucella melitensis* has long been associated with the Mediterranean littoral. The public health and economic impact of brucellosis remain of particular concern in North African countries due to the danger that infected animals suppose for humans and other animals. The economic losses associated with the affected animals forced national veterinary services in the affected countries to encourage the improvement of animal husbandry systems (Benkirane 2006).

Thus, all endemic countries have struggled to control animal brucellosis using different strategies, which have led to various levels of success (Seleem et al. 2010). In the North African region, and despite its acknowledgment as a significant health hazard and the availability of proven control means, it continues to occur with a relatively high prevalence. Benkirane (2006) stated that the main reasons for brucellosis persistence in the region are:

- the adopted extensive type of husbandry;
- the lack in logistic and human resources to control the disease;
- the absence of a clear political control program.

The Algerian state adopted in 2006 a new prophylactic approach, to control brucellosis by vaccinating sheep and goats in steppe region with the Rev-1 vaccine (Kardjadj and Ben-Mahdi 2014). As a result, the herd prevalence in 2014 was decreased to 3.33% in the region compared to 5.7% prevalence reported in 2002 (Kardjadj and Ben-Mahdi 2014; Kardjadj et al. 2016).

Brucellosis was well controlled in Algeria's steppe region through vaccination, thus provide a very strong evidence that Brucellosis control can be achieved in Northern Africa. Moreover, after the vaccination campaigns in Algeria, Kardjadj et al. (2016) revealed no significant association between abortion history and brucellosis infection in Algerian small ruminants' herds.

13.8 Rift Valley Fever

RVF is an acute arthropod-borne disease affecting a wide range of animals, ranging from rodents to camels. However, small ruminants and especially goats are the most economically significant hosts, in which high abortions and neonatal mortality rate occur (Davies and Martin 2003). The growing worldwide significance of RVF is evidently confirmed by its geographical spreading out. The existence of a varied range of host and vector species along with the unique epidemiological characteristics of RVF has led to the appearance of new foci in previously RVF free Africa (Clements et al. 2007).

The first RVF outbreak in Egypt was recorded at Belbies city in Sharqiya Province in 1977 (Mahmoud et al. 1989). In 1994, RVF virus was isolated from 139 (31.7%) goats and 84 (57.1%) sheep in Kafr El Sheikh and Behira Provinces. Unfortunately, the locally produced RVF vaccine was ineffective (Abd-El-Rahim et al. 1999). In 2003, further outbreaks were encountered in various localities of Egypt (Hanafi et al. 2011).

In 2010, Di Nardo et al. (2014) reported the presence of IgG antibodies against the RVF virus in Sahrawi refugee camps in Tindouf district, at the southwestern border of Algeria with Western Sahara, Mauritania and Morocco. These camps practice high meat consumption, and to cover the high demand of meat of the refugee people a conspicuous livestock trade has been developed from Mauritania, Algeria and Mali to the refugee camps. These livestock are vended in the refugee camps market areas, where they are incorporated into pre-existing herds (Di Nardo et al. 2014). This type of animal movement constitutes a serious RVF spreading threat to other free North African countries.

13.9 Abortive Diseases

Abortive goat diseases have a negative influence on livestock production, animal health and rural communities since the majority of the goat population are reared by the rural poor families as a means of alleviating poverty (Boyazoglu et al. 2005; Canali 2006), which occur in North Africa as well.

The husbandry and communal grazing system practiced in the North African region enables the spread of many infectious abortive agents such as *Chlamydia abortus*, *Campylobacter* spp., *Toxoplasma gondii*, *Listeria* spp., *Coxiella burnetii* and *Brucella melitensis* (Entrican 2009; Van den Brom et al. 2012; Lafi et al. 2014; Ababneh et al. 2014). Therefore, improved diagnostic capacity, suitable control strategies and regular monitoring system are required (Van Engelen et al. 2014).

13.10 Concluding Remarks

The health status of the goat population in North African countries can be considered as very dramatic. Thus, the application of a regional control approach is needed. Regional strategies to control animal diseases are focused to prevent, control and/or eradicate the major infectious diseases with impact on livestock production in the region.

It seems impossible for a single North African country to fully control an animal disease only at a national level, due to the communal border shared with other countries in the region. North African countries share, thus, many animal diseases. The main diseases present or potentially threatening the goat industry in the North African region are PPR, FMD, BT, SPGP, brucellosis and RVF. Therefore, the establishment of early warning systems and proper implementation of control measures at the regional level of these diseases are highly recommended to prevent the socio-economic losses related to them.

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Chapter 14
Health and Welfare of Indigenous Goat Breeds from Dairy Farms in Greece

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Abstract We address the dairy production system, health indicators, and welfare status of the goat industry in Greece. Initially, we describe the dominant production systems with their major trends and challenges for Greek goat herds' sustainability and we characterize the most prevalent indigenous goat breeds. Afterward, we emphasize on health and welfare implications in low-input farming systems as they are determined by environmental exposure, housing and husbandry conditions, and the behavior of goats reared under these systems. Then, we summarize the most significant infectious and parasitic diseases and we describe them. We underline the significance of paratuberculosis, colibacillosis, contagious agalactia, clostridial diseases, pasteurellosis, scrapie and major endoparasites (trematodes, cestodes, and nematodes) and ectoparasites (flies, mange, ticks, and fleas). In the next section, we discuss the most suitable animal-based indicators to assess health and welfare status in goat farms and we present the results from a prospective epidemiological study regarding the prevalence and the incidence of the main health and welfare problems, on individual goat level in low-input goat herds. We conclude that among the factors undermining health and welfare status in goat herds in Greece, the most challenging ones include climatic change, weather exposition, inadequate feeding and water supply, inappropriate infrastructures and housing, infectious and parasitic diseases, as well as lack of farmers' education and training on aspects regarding preventive medicine, herd health management, and human–animal relationship.

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14.1 Introduction: Dairy Goat Sector Census in Greece

Historically, goat farming is one of the earliest agricultural activities in Greece. It evolved concurrently with rural communities from ancient to modern times, providing a significant source of income for families in these communities (Zioganas et al. 2001; Theodoridis et al. 2012; Gelasakis et al. 2017). The socioeconomic aspects of goat farming in less favored and in remote areas, such as mountainous, semi-mountainous areas, and islands of Greece, remain important (Arsenos et al. 2014). The ability of goats to adapt under harsh environmental conditions utilizing distant or inaccessible pastures and plants, which are not suitable for alternative uses, renders goat farming a sustainable solution in these areas. Moreover, it is consistent with the traditional, low-input management systems, where goats meet their nutritional demands mainly from grazing natural pasturelands (grasslands, woodlands, and shrublands). Such systems are dominant in provinces where rural economy is poorly diversified and employment opportunities are limited, offering an eligible professional activity for local population (Tzouramani et al. 2011).

Greece has the largest national goat population in the EU counting about 4.2 million dairy goats that produce about 407,000 tons of milk. Milk yield per doe is low (<100 kg of milk/doe/year) which is consistent with the limited inputs used by the implemented traditional management systems. Most of the milk produced is used by dairies to produce traditional products (e.g., feta), whereas milk is also used for yogurt production or as pasteurized raw milk for consumption. Small-scale farm cheese production is also present.

This chapter addresses the dairy production system, health indicators, and welfare of the goat industry in Greece.

14.2 Production Systems—Trends and Challenges for Production Sustainability

In Greece, during the last decade, goat farming has changed as a result of high demands for milk from dairies. Goat farming systems were recently described and classified, in order to produce a meaningful insight of the current situation of the sector as well as an objective and representative typology. The description and typology of goat farming systems was part of the European project SOLID (Sustainable Organic and Low-Input Dairying). For this reason, an in-depth data recording protocol of farm characteristics and management practices was used, followed by a multivariable statistical analysis (Gelasakis et al. 2017). The study revealed the most suitable variables for goat farming systems classification, i.e., goat herd size, age of kids at weaning, age at first mating, does to bucks ratio, bucks' replacement rate, doelings to does ratio, cultivated land per livestock unit, irrigated land used, years of farmer's experience and infrastructure. Using these variables as descriptors of farming systems, a typology was produced; production systems ranged from semi-extensive low-input and traditional farms to large, semi-intensive, high-producing, and investing farms. Hence, the intensity of farms has been objectively distinguished beyond traditional classification variables such as grazing schemes and herd size.

Irrespective of the observed variability in inputs of existed farming systems, low-input farms are still the dominant ones. These farms are usually located in marginal areas and characterized by restricted investments in infrastructure, land, and feeds. They raise indigenous breeds of goats or their crossbreds with improved high-yielding breeds, which are well adapted to grazing in remote pastures, mainly shrublands and woodlands, all year round. The sustainability of these farms depends on the planning of grazing management and stocking rate, on targeted preventive measures and herd health management, whereas subsidies are significant to complement farmer's income. Meat production is a significant source of income in those farms, contrary to the notion that is just a by-product of milk production. Meat production is a challenging issue considering that carcass cuts, processing, and packaging have not been explored yet. Also, goat farm owners tend to recognize the significance of more intensive management and supplementary feeding for increased milk production. While they intensify their production system, they select either to expand, in order to reclaim their investments on labor and equipment, according to the principles of economies of scale or to invest on efficient feeding and management strategies to increase productivity and reduce production cost (Gelasakis et al. 2017).

The implementation of genetic selection programs is not the norm in low-input systems in Greece, as the criteria to be used for the determination of the most resilient animals in these systems have not been clearly defined yet. In some cases, genetic selection programs have been occasionally applied, but this has been on a limited scale and under the coordination of local cooperatives aiming only on the improvement of milk yield.

14.3 Goat Breeds Characterization

14.3.1 Skopelos Goats

Skopelos breed originates from the homonymous island. It is a medium- to large-sized breed with adult females weighting ca. 50–60 kg. Skopelos goats are brown with short to medium hair length (Fig. 14.1). They have horns, middle-sized erect ears, and straight nose. They are well adapted to dry and hot climates and appropriate for extensive and semi-extensive farming systems, as they can efficiently utilize poor pastures for milk production. Depending on the implemented system, average annual milk yield may vary from 200 to 400 kg per 240-day lactation and the prolificacy from 1.2 to 1.6 kids per doe.

Fig. 14.1 Skopelos breed goats browsing in shrublands on the island of Skopelos (provided by A. Gelasakis)

14.3.2 Eghoria Goats

Eghoria Goat is found across Greece both in the mainland and in the islands. It is medium-sized with adult females weighting 35–45 kg. Goats of Eghoria breed may be black, brown, and white or combinations of them with medium to long hair length (Fig. 14.2). They usually have horns and have middle-sized erect ears and straight nose. They are well adapted to dry and hot climates and appropriate for extensive and semi-extensive farming systems moving long distances in mountainous areas and utilizing poor pastures for milk production. The average annual milk yield may vary from 100 to 250 kg per 200-day lactation and the prolificacy from 1.1 to 1.4 kids per doe.

14.3.3 Foreign Breeds

Aside from the two indigenous Greek breeds, farmers commonly use other imported breeds to improve the productive potential of their herds. The main breeds used in crossbreeding schemes are Saanen, Alpine, Damascus, Anglonubian, and Murciano-Granadina.

Despite the use of high-producing breeds for genetic improvement of the indigenous goat population, in most of the cases, farmers do not adjust management

Fig. 14.2 A goat of Eghoria breed few minutes post-kidding in a herd located close to Volvi lake at Northern Greece (provided by A. Gelasakis)

practices according to the specific needs of these breeds. Therefore, farmers lose much of the productive capacity of these breeds and their crossbreds, which seems to be limited by the restricted available resources (Gelasakis et al. 2017). Matching management to the potential of goats' genotype is not a common practice in low-input systems, where the notion is that crossbreeding can result in more productive goats, irrespective of the restrictions on the available resources deriving from the given farming system. Hence, it is suggested that farmers could improve production if they matched management to the potential of their goats' genotype.

In general, indigenous breeds' farming systems and their challenges regarding goats' health and welfare can be perfectly described and assessed by extrapolating data from the existing situation in low-input goat farming systems.

14.4 Health and Welfare in Low-Input Goat Farming Systems

A healthy animal is considered as an animal with no disease. In addition, the concept of welfare is perceived as the animal's well-being status during its efforts to cope with a constantly changing environment (Broom 1991). Low-input systems are generally considered to be less invasive and welfare-friendly systems, due to the low duration of housing, the free-range grazing potential and the minimal behavioral restrictions during grazing (Sevi et al. 2009). However, this is rather an unexploited hypothesis in the case of Greek low-input goat farms, which is supported mainly by subjective considerations, as health and welfare status of goats raised under these systems has not been recorded and assessed systematically yet (Turner and Dwyer 2007).

Climatic change, adverse weather conditions, inadequate feeding and water supply, inappropriate infrastructures and housing are known to undermine the health and welfare status for goats reared under low-input systems (Sevi et al. 2009). Other factors, associated with adverse health and welfare, include lack of expertize and training of farmers on aspects regarding preventive medicine, herd health management, and human–animal relationship. Qualified expert advisors are rarely consulting these farms and hence, a structured and documented approach to monitoring health status, prevention and treatment of diseases is rarely available.

14.4.1 Environmental Exposure

Low-input systems are less invasive, but highly dependent on climatic conditions and unpredictable environmental factors. Despite the adaptability of indigenous goats to the climate of Greece, they may still suffer from heat stress in summer and from low temperatures during rainy and windy weather in winter. Hence, although they have a broad thermal comfort zone, increased or decreased environmental temperatures cause physiological and behavioral changes on goats, in order to adjust the body heat loss and achieve an effective thermoregulation (Silanikove 2000; Battini et al. 2014).

In low-input farms, inadequate feeding may cause a significant decrease on animals' health and welfare status. Goats in these farms are highly dependent on the utilization of natural resources to meet their nutritional demands (Fig. 14.3). However, the variability of these resources, in the available pastures and inadequate supplementary feeding are followed by temporary feeding restrictions and nutritional stress during specific seasons across the year. In some cases, these feeding restrictions coincide with periods of increased nutritional demands (e.g., mating and kidding seasons, last third of gestation and first months of lactation) and adverse weather conditions (demands for thermoregulation) leading to significant health and welfare implications.

In particular, seasonal fluctuations of pasture quantity and quality, overgrazing, insufficient complementary feeding inside the shelter, and parasitism can cause nutrient deficiencies in grazing goats, associated with decreased body condition score and various clinical manifestations. During summer, pastures are poor and less palatable, as the transition of plants to their reproductive phase is characterized by a reduction in the quality of the forage and increased fibrous content (Cannas and Pulina 2008); hence, the quality of the available biomass at the feeding sites can be

Fig. 14.3 Crossbred indigenous goats grazing and browsing at shrublands at the mountains of Drama (provided by A. Gelasakis)

inadequate to meet goats' nutritional demands. During winter, grazing is restricted and goats remain housed to avoid exposition to adverse weather (i.e., low temperature, rain, wind, and snow). This is the norm in most of low-input goat herds which are mainly located in high altitudes. To compensate for the restrictions of the available feeding resources and nutrient deficiencies, farmers select either to increase daily grazing distance and duration, in order to reach remote non-grazed richer pastures (in summer), or to provide supplementary feeds, in cases where accessibility of pasture land is difficult or the available biomass within it is limited (in summer and winter).

In any case, modifications on feeding are based on subjective considerations rather than on systemic monitoring of the body condition score of animals (Vieira et al. 2015). Indeed, goat farmers usually feed higher quantities of concentrates compared to roughages as supplementary feeds. This practice disrupts the rate of dry matter which is provided by roughages ($\leq 60\%$) and predisposes to ruminal acidosis, bloat, and clostridial diseases.

Moreover, in many low-input farms, during dry season, the access to water supplies is restricted which causes the dehydration of goats and, subsequently, the reduction of feed intake and metabolic rate. Hence, during the hottest months of the summer, the combination of inadequate water supply, heat stress, and reduced feeding during grazing, cause changes on rumen's fermentation and decreased metabolic rate which are definitely inconsistent with goats' welfare (Silanikove 2000).

14.4.2 Housing and Husbandry Conditions

A lower than needed feeding space and drinking place per goat, within the shelter, is commonly observed when investigating herds for queuing at feeding and drinking (Battini et al. 2014). In other cases, feeding and watering of animals are not performed on a sheltered environment to overcome harsh environmental conditions.

In low-input systems, goat herds remain housed only during night and when grazing is impossible due to bad weather conditions. In the majority of cases, the traditional shelters are not appropriately designed and constructed and do not provide sufficient area and volume for housing the goats (Fig. 14.4). In these cases, insufficient area causes competition for feeding and decreased resting time, inadequate grouping of animals for management purposes, increased moisture, manure accumulation, air-borne microorganisms concentration, and an overall decreased hygiene status (Sevi et al. 2009). Housing conditions deteriorate further because most of these shelters are not well ventilated and enlightened.

The use of dry and clean bedding material throughout the year is not the norm inside these shelters and is generally restricted only during wet season; even then, it is highly inadequate, as it is considered to significantly increase production cost. This causes the animals to stand and lie in mud and manure during wet season, or to inhale dust from dried manure during dry season.

Furthermore, inappropriate construction of traditional premises results in inadequate ventilation in the shelter and inconvenient (by hand) and generally infrequent manure removal. High stocking density and inadequate ventilation and hygiene in the shelter, cause dampness and increased dust, ammonia and air-borne microorganisms concentration in it. They also cause decreased resting time and ruminating activity, particularly when goats remain housed for a long time.

14.4.3 Behavior of Goats

Insufficient feeding and watering, restricted grazing, as well as inappropriate resting areas and moving areas, housing conditions and livestock management practices can cause alterations on both goats' behavior and the social interaction between them and with humans (Muri et al. 2013). These situations cause significant stress on animals, favor their agonistic and aggressive behavior, and decrease their well-being status (Battini et al. 2014) (Fig. 14.5). In low-input systems, excessive handling, regrouping, and relocation of goats are not frequent. Hence, the stress caused by these practices is generally low (Patt et al. 2013).

Fig. 14.4 A traditional goat shelter at the region of Chalkidiki. It has been cleaned and prepared for kidding season. The area and volume of these shelters are usually restricted and the ventilation and bedding material inadequate (provided by A. Gelasakis)

14.5 Infectious and Parasitic Diseases of Interest in Goat Farms in Greece

The most significant health problems in low-input goat farms in Greece are associated with transmissible infectious and parasitic diseases as following described.

14.5.1 Infectious Diseases

14.5.1.1 Paratuberculosis (Johne's Disease)

Paratuberculosis is a significant cause of reduced milk production, involuntary culling of adult goats, and increased replacement rate in low-input herds (Nielsen and Toft 2009) (also see Chap. 15 of volume 1). Although vaccination at an early age is considered an effective preventive measure against the disease, it is rarely performed by goat farmers as considered to be expensive. Epidemiology of the disease is not well established in low-input systems because the disease remains

Fig. 14.5 Agonistic behavior of Skopelos goats associated with the restricted feeding space and allowance in a farm on the island of Alonnisos (provided by A. Gelasakis)

grossly underdiagnosed or underreported by the farmers. However, in some areas with high stocking rates, paratuberculosis is considered the main cause of involuntary culling of adult goats.

14.5.1.2 Colibacillosis

Colibacillosis is one of the commonest problems, in goat kids within 3–7 days of age (Muñoz et al. 1996). It is the commonest and the most significant cause of diarrhea and losses in newborn kids, particularly in cases where kidding season initiates during winter. The mortality rate may be high (up to 80%) associated with inadequate consumption or low quality of colostrum, inappropriate housing, hygiene, and adverse weather conditions. Adequate feeding during the last third of gestation, colostrum management, and appropriate hygiene and housing could reduce the losses but most of the farmers are not willing to improve them or do not have the necessary infrastructures to do so. Currently, there are no available vaccines for use in goats.

14.5.1.3 Contagious Agalactia

Contagious agalactia is one of the most significant infectious diseases in low-input goat farming systems in Greece. It is commonly diagnosed in grazing herds where the causative agent (*Mycoplasma agalactiae*) is transmitted through communal grazing and water troughs. The symptoms which are recognizable by the farmers are the commonest symptoms of the disease, namely arthritis, mastitis, and keratoconjuctivitis (Corrales et al. 2007). The morbidity rate is high in newly infected herds but the mortality rate is usually low. However, the occurrence of chronic carriers and the detrimental effects on milk's quantity and quality result in a remarkable involuntary culling of infected goats and increased replacement rate and cost. Despite the significance of the disease for the sustainability of the farms, a carefully designed vaccination schedule for the prevention and the control of the disease is advised but it is not routinely followed in the majority of cases.

14.5.1.4 Clostridial Diseases

They are common in goat herds where frequent changes on feeding regimes, according to the available natural resources, are observed (Sumithra et al. 2013). Due to the unpredictable occurrence of the clostridial diseases and farmers' awareness regarding the increased losses associated with them, vaccination against clostridial diseases is the most commonly practiced vaccination in low-input goat herds in Greece.

14.5.1.5 Pasteurellosis

It is prevalent where goats remain permanently housed in a high stocking density with inappropriate ventilation and hygiene conditions. In low-input systems, pasteurellosis is usually observed during winter and complicates other respiratory diseases such as *Mycoplasma* spp. pneumonia. Numerous predisposing factors have been reported with climate and stress-related ones being the most significant (Brogden et al. 1998).

14.5.1.6 Scrapie

Although scrapie is less common in goat herds compared to sheep flocks, it has been reported in the mainland of Greece (Fragkiadaki et al. 2011), whereas no cases of the disease have been found on the islands. Currently, there is an eradication program in place, including culling of the infected goats and surveillance of the affected herds to reduce the infectious load. No selection programs for resistance against scrapie are currently available, although selecting for resistance seems to be effective in controlling the disease.

14.5.2 Parasitic Diseases

14.5.2.1 Endoparasites

Grazing in natural pastures favors the development of parasitic infections. Parasitism by endoparasites can cause alterations on goats' behavioral patterns (i.e., reduced activity during grazing and dry matter intake, and restlessness) and a reduction on feeding efficiency with significant implications on weight gain and milk yield.

For the control of endoparasites, routine preventive use of anthelmintics is the norm. However, underdosing of anthelmintics and inappropriate rotation of their active ingredients are commonly observed, resulting in an increase on anthelmintic resistance. Rotational grazing may exceptionally be applied but only in cases where the available pastures are naturally segmented; artificial segmentation of land using electrical fencing is not practiced as considered to be non-applicable in shrublands. However, in shrublands, the consumption of plants such as kermes oak (*Quercus coccifera* L.) which usually is the predominant vegetation and it is rich in condensed tannins has beneficial effects against nematodes (Manolaraki et al. 2010). Other complementary methods to reduce parasite burdens while minimizing the use of anthelmintics, such as grazing in clean pastures, rotational grazing of different animal species on the same pastures, and fecal egg counts are rarely applied. The use of homeopathic treatments and genetic selection for resistance against endoparasites are not practiced.

The most prevalent endoparasites in indigenous goats are following summarized:

(1) ***Trematodes***. The incidence of goats' parasitic infections with Trematodes (*Dicrocoelium dendriticum*, *Fasciola hepatica,* and *Paramphistomum* spp.) is low. However, it can be high when goats graze in humid areas with water ponds, which offer the ideal environment for the intermediate hosts (e.g., snails). In particular, on low-input goat farms located in high lands, parasitic infection with Trematodes are not common due to the prevailing browsing behavior during grazing in shrublands, or remain underdiagnosed until severe symptoms are evident;
(2) ***Cestodes***. *Echinococcus granulosus, Moniezia* spp*., Taenia hydatigena,* and *Taenia multiceps* are the major Cestodes found in low-input goat farms. Goats, as intermediate hosts, are infected by consuming parasitic eggs excreted by definitive hosts. Guardian dogs, herding dogs, and other canids, play a significant role as definitive hosts and they are infected by ingesting viscera of infected goats containing hydatid cysts (Sotiraki and Rinaldi 2016);
(3) ***Nematodes***. *Teladorsagia* spp., *Haemonchus* sp. , and *Trichostrongylus* spp. are the most prevalent nematodes found in goats reared under low-input systems, followed by *Cooperia* spp., *Chabertia ovina*, *Oesophagostomum* spp., and *Bunostomum* spp. The most prevalent Nematode species may differ, depending on the specific location across Greece (Papadopoulos et al. 2003). In any case, the prevalence of gastrointestinal parasitism by Nematodes is lower when compared to sheep. This is explained by their browsing behavior which is

associated with a reduced exposure to infected nematode larvae (L3). However, the benefit of lower exposure due to browsing has led to a different evolutionary process regarding defense mechanisms against gastrointestinal nematodes and a less effective immune response when compared to sheep (Hoste et al. 2011).

14.5.2.2 Ectoparasites

The most common ectoparasites found in low-input goat herds are flies, mange, ticks, and fleas.

(1) ***Flies***. Myiasis is seasonal and observed during spring and summer. It is common in low-input systems and the most common causative agents are the parasitic larvae of *Oestrous ovis*, *Przhevalskiana silenus*, and *Wohlfartia magnifica* which penetrate in the nostrils, the subcutaneous tissue, and the wounds or natural orifices of goats' body, respectively (Sotiraki and Hall 2012) (Fig. 14.6). *Lucilia sericata* can also cause traumatic myiasis, although it is a facultative parasite (Sotiraki and Hall 2012). Flies cause significant and chronic irritation and they degrade goats' welfare status. Under field conditions, macrocyclic lactones are used during dry period, at the last third of gestation, mainly for the treatment but also for the prevention of myiasis in areas with severe problems;

(2) ***Mange***. The commonest mites associated with mange are *Chorioptes caprae* (lesion of alopecia and crusts in legs, udder, and base of the tail), *Demodex caprae* (lesions in face and neck), *Psoroptes* spp. (lesions in ears, neck, shoulders, and back) *Sarcoptes scabiei* (lesions in face, ears, and groin) (Sotiraki and Rinaldi 2016). The materials used in the shelters (i.e., woody palettes) and the inefficient disinfections within the shelter favor the contamination of the environment and the spread of the mites. Similarly, to control of myiasis, systemic treatment is mainly practiced during dry period to avoid withdrawing of milk. Antiparasitic baths against ectoparasites are not practiced;

(3) ***Ticks***. Both "hard" (Ixodidae) and "soft" (Argasidae) ticks show a seasonality regarding their transmission; spring and autumn are the seasons with the highest infection rates but this may vary according to the specific environmental factors (i.e., type of pasture land) and the climate of each region. According to Chaligiannis et al. (2014), *Rhipicephalus sanguineus*, *Rhipicephalus bursa*, and *Rhipicephalus turanicus* are the most prevalent ticks in goat herds in Greece, although several other species have been observed. In any case, infected pastures play a critical role in the transmission of ticks, particularly in cases where rotational grazing or other control strategies are not adopted. Ticks are vectors of some significant pathogens with the most important of them for goat herds in Greece being *Babesia* spp., *Theileria* spp., *Anaplasma* spp., and *Coxiella burnetii* which can lead to serious clinical diseases in the infected goats;

(4) ***Fleas***. The infestation of herds initiates from the external environment and peaks during summer. *Ctenocephalides felis*, *Ctenocephalides canis*, and *Pulex irritans* are the most prevalent species in goats. Inappropriate facilities, manure

Fig. 14.6 Infection by *Wohlfahrtia magnifica* maggots at female's genitalia (provided by A. Gelasakis)

accumulation, and generally low hygiene status favor infestation and multiplication of fleas. Fleas cause intense pruritis and secondary traumatic lesions, whereas they are vectors of virus and bacteria which can be easily transmitted due to fleas' feeding behavior. Insecticides in the form of pour-on preparations are frequently used on goats. However, they are not effective, when they are not combined with insect growth regulators for treating both the animals of the herd and the environment against larvae, simultaneously (Sotiraki and Rinaldi 2016).

14.6 Animal-Based Indicators to Estimate Health and Welfare Status in Goat Farms

Direct animal-based indicators can be used to provide sufficient direct or indirect information regarding health and welfare status of goats (Muri et al. 2013). An assessment protocol has been suggested by Anzuino et al. (2010) based on indicators that are representative of the basic elements which can compromise goats' welfare. Among these indicators, the most significant ones for low-input systems are following described.

(1) ***Mastitis***. Mastitis, either in its clinical or its subclinical form, is considered one of the major problems in dairy goat herds, because it is associated with decreased milk yield, inappropriate milk quality, and hygiene, as well as, increased veterinary and replacement costs (Koop et al. 2010; Gelasakis et al. 2016). In Greek low-input goat herds, hand-milking is the norm (Fig. 14.7). In these herds, intramammary infections caused by several pathogens have been found to be associated with subclinical mastitis. In a recent study, we collected and microbiologically examined 755 milk samples from indigenous goats, reared under low-input systems, with increased somatic cells and bacterial counts in their milk (Gelasakis et al. 2016). We found 555 samples with positive cultures and isolated 661 pathogens. Most of them were Gram-positive bacteria, with coagulase-negative staphylococci (CNS) being the group encompassing most of the pathogens (50.2%), followed by coagulase-positive staphylococci (CPS, 34.5%) and *Streptococcus/Enterococcus* spp. group (5.3%). Gram-negative bacteria constituted *ca.* 6.0% of the isolated pathogens (Gelasakis et al. 2016). In the same study, the incidence and cumulative incidence of subclinical mastitis for two successive milking periods were 69.5 and 96.4 new subclinical mastitis cases per 1000 goat-months and 24.1 and 31.7%, for the first and the second milking period, respectively (Gelasakis et al. 2016).

Clinical mastitis can cause pain and discomfort and can modify the behavior of goats. Prevention of intramammary infections (IMI) plays a key role for the control of mastitis either in its clinical or subclinical form. Most of the goat farmers are not aware of the principles of the holistic approach for the prevention of IMI and they reject preventive medication as being expensive. Under low-input systems, the prevention needs to be focused on high hygiene standards (appropriate stocking density, clean bedding material, adequate ventilation, frequent manure removal, and disinfection) and husbandry measures (separation of infected goats, early weaning and gradual cessation of lactation strategies, drying-off treatment, and vaccination), efficient milking procedures, appropriate feeding, and genetic selection for resistance against mastitis. As already mentioned, in the vast majority of low-input goat herds in Greece, hand-milking is implemented. Hence, although machine-milking management and related factors may significantly affect udder health status and goats' welfare, their analytic description is beyond the scope of this chapter;

(2) ***Udder and teat abnormalities***. Udder and teat conformation, abnormalities and lesions can be easily observed and palpated in low-input herds during milking. Clinical and subclinical mastitis, udder asymmetry, fibrosis, and abscesses are relatively common findings, indicating a high prevalence of chronic IMI (Fig. 14.8). Pendulous and inappropriately shaped udders are also observed and associated with inefficient milking and predisposition to IMI;
(3) ***Lameness***. Lameness is a significant indicator of pain in goats (O'Callaghan et al. 2003). Lameness due to arthritis is mainly associated with contagious agalactia infection (*M. agalactiae*), whereas there are no records regarding the prevalence of caprine arthritis encephalitis and the disease seems to be underdiagnosed in Greek goat herds (Fig. 14.9). Moreover, foot lameness is not

Fig. 14.7 Hand-milking of goats in a traditional low-input farm. In many cases, basic infrastructures such as electricity are not available in low-input farms and machine-milking is not considered a feasible option (provided by A. Gelasakis)

Fig. 14.8 Abscess at the mammary lymph node of an adult Skopelos goat (provided by A. Gelasakis)

considered very common in goats reared under the low-input goat systems with the exception of infectious footrot. Grazing in common pastures with goats infected by infectious footrot may predispose to the infection of an uninfected herd, which can be easily exposed to *Dichelobacter nodosus* and *Fusobacterium necrophorum*, i.e., the causative agents of the infectious footrot (Winter 2011).

Overgrown hooves and foot lameness other than injuries or foreign bodies are rarely observed during dry grazing season. During this season, daily grazing on a rough terrain causes the natural wear and mechanical cleaning of the hooves; for this reason, hoof-trimming is rarely needed. However, overgrown hooves may be observed during winter and wet season when goats spend most of their time housed or grazing on soft and wet soil. During winter, inappropriate nutrition, increased moisture and manure accumulation, inadequate flooring and hygiene in the shelter, and infrequent claw-trimming predispose to foot lameness.

In these systems, consequences of lameness are severe because lame animals cannot follow the herd during grazing, they do not graze efficiently to meet their nutritional demands and, consequently, they produce less milk and meat. Although farmers recognize the detrimental effects of lameness on animal's welfare, in most of the cases, a late treatment is attempted, including claw-trimming, foot bathing, and administration of injectable antibiotics;

(4) ***Abscesses***. Existence of abscesses is an indicator of health and welfare status in a herd, related to the hygiene status in the shelter, the concentration of pathogens in it, and inappropriate animal husbandry practices and prevention

Fig. 14.9 Arthritis due to caprine arthritis encephalitis disease in a crossbred Saanen x Damascus adult goat (provided by A. Gelasakis)

(Battini et al. 2014). Caseous lymphadenitis is caused by the contamination of open wounds or the inhalation of the bacterium *Corynebacterium pseudotuberculosis* (Williamson 2001). Transmission of the bacterium between farms is caused by the introduction of animals from infected herds or by shared facilities between infected and uninfected herds. Vaccination with infected needles, inadequate hygiene of the equipment used during castration, contaminated environment (e.g., bedding, wires, and nails), browsing in shrublands, and fighting behavior among the goats, facilitate the occurrence of open wounds and the inoculation of the bacterium in low-input goat herds.

There are several other causative agents associated with the occurrence of abscesses on individual animals when penetrating wounds on different parts of goats' body. These agents may include bacteria such as *Staphylococcus* spp., *Streptococcus* spp., and *Actinomyces pyogenes*. Abscesses at the site of injections may also be observed after vaccination either due to the use of contaminated needles or associated with inappropriate injection techniques; in the latter case, swellings produced at the site of injections are usually sterile as a reaction to vaccines' adjuvants. Tooth root abscesses may be present either at the upper or the lower jaw, in many cases affecting the bones of the jaws. These abscesses usually discharge into the mouth or skull's sinuses and the outer part of the mandible, respectively;

(5) ***Ear tears***. Ear tears are quite common for goats browsing at shrublands and woodlands; in this case, ear tags are entangled in the shrubs' and trees' branches which causes them to be ripped from the ears. Ear tags may also be entangled in the feeding troughs. In general, ear damages may lead to hematomas and can be complicated by myiasis;
(6) ***Skin lesions—hair coat condition***. Skin lesions may be the result of injuries or ectoparasite manifestation (i.e., mange, ticks, flies, fleas, and lice) (Smith and Sherman 2009). In general, decreased nutritional and health status predispose to bad hair coat condition, with rough or scurfy hair and hair loss being practical and valid indicators of poor health status (Battini et al. 2014, 2015);
(7) ***Horns***. Although most of the indigenous goats are horned, in many flocks, there are naturally occurring hornless goats; hornless goats due to disbudding or dehorning are not commonly found, as these practices are not common in the vast majority of low-input goat herds. Keeping the horned and hornless goats separately and generally grouping of goats is not a feasible option for the farmers in these herds because it is considered to complicate grazing management and demands more labor. Horned goats may exhibit agonistic behavior and can cause traumatic severe injuries and social stress at hornless ones (Loretz et al. 2004). Partial and atrophic horns may also have welfare implications as they are susceptible to injuries and it is easier to be broken; in some other cases, their abnormal morphology and growth may cause injuries on the top of the head, sinusitis, brain abscesses, or tetanus (Plummer and Schleining 2013);

(8) ***Diarrhea***. Several causes are associated with the occurrence of diarrhea in goat kids and in adult goats in Greek low-input systems. Pathogens including *Escherichia coli*, C*lostridium perfrigens*, *Cryptosporidium parvum*, *Eimeria* spp., and nematodes may be associated with diarrhea in goat kids (Muñoz et al. 1996). Acute and chronic ruminal acidosis, endoparasite infections, paratuberculosis, and mycotoxins can be associated with diarrhea in adult goats. Anal soiling reflects inappropriate feeding and nutrition or the occurrence of one of the forementioned diseases and is indicative of recent diarrhea;

(9) ***Neonatal morbidity and mortality***. A high neonatal morbidity and mortality are frequently reported in low-input goat farms. The major causes of goat kid losses are hypothermia and endemic infectious diseases such as colibacillosis, enterotoxaemia, and pasteurellosis. Mismothering, pre- and post-kidding maternal undernutrition, infections and injuries may be, also, associated with low quality of colostrum and kids' starvation which finally lead to increased mortality and morbidity rates (Mellor and Stafford 2004).

14.7 Health and Welfare Status of Individual Goats in Greek Herds

In a recent mixed-design epidemiological study (cross-sectional and prospective cohort study), we used direct observations and animal-based welfare indicators in order to assess health and well-being status of individual goats in low-input systems in Greece.

In this study, a total of 823 out of 4240 adult, female, milking goats from seven representative low-input dairy goat herds and three different breeds (Skopelos and Eghoria and Damascus goats) were randomly selected and followed over a milking period. Monitoring included recording of several health and welfare parameters by a single observer using a case-specific data recording sheet. Detailed individual observations were performed, following a modified version of the standard protocol of direct animal observation developed by Anzuino et al. (2010). In detail, data regarding injuries, skin lesions (hair loss or skin damage), abscesses, diarrhea, hernias, ocular defects (keratoconjuctivitis or injury), discharges (nasal and ocular), arthritis, overgrown claws, and lameness were collected from the body, head, and limbs inspection. Lameness was assessed using a 4-degree locomotion scale (0 = non-lame; 3 = not bearing weight on one or more legs). A detailed observation and palpation of the udder facilitated recording of asymmetry between the two halves, udder abscesses and clinical mastitis. Health and welfare parameters measured in the protocol and their description, are summarized in Table 14.1.

Results of the study: The median herd size and number of milking goats were 400 adult female goats [with interquartile range (IQR) 200–1200] and 380 milking goats (IQR 195–1000), respectively. The reported average milk yield ranged from

Table 14.1 Description of the health and welfare parameters assessed in the survey

	Parameter	Description
Head	Ear injury	Injury located on the ear including tear of ear tissue
	Horn injury	Deformed, damaged, or broken horn
	Nasal discharge	Discharge from the nose
	Skin lesion	Hair loss and/or any type of dermatitis in the head
	Pulpitis	Dental root inflammation with gum swelling
	Ocular discharge	Discharge from the eyes
	Blindness	Lack of visual perception in at least one of the eyes
Body	Injury	Injury located at any part of the body
	Abscess	Abscess located at any part of the body
	Diarrhea	Fresh fecal material on the tail or at the area around the anus
	Hernia	External protrusion of an organ through the wall of the cavity that normally contains it
Limbs	Arthritis	Inflammation or swelling of the lower limb joints
	Overgrown claws	At least one overgrown claw
	Lameness	Any departure of the normal gait
Udder	Asymmetry	One udder half is smaller than the other half
	Abscess	Hard and clearly circumscribed masses in the udder tissue
	Clinical mastitis	Udder inflammation followed by clinical signs

60 to 630 L/goat/year (median 260, IQR 180–550) and prolificacy from 1.4 to 1.8 kid/goat (median 1.6, IQR 1.5–1.7).

Table 14.2 shows the prevalence of the studied health and welfare parameters, as well as their variation across the farms. For the studied population, a high overall prevalence was found for udder asymmetry (median 18%, IQR 7.9–23.2%), overgrown claws (median 10.6%, IQR 8.7–44.2%), and skin lesions (median 5.3%, IQR 0.0 to 19.1%), whereas no cases of diarrhea or hernias were observed.

From the follow-up study, a data set comprised of 2998 goat-months was developed. Table 14.3 summarizes the number of new cases, incidence rates, and cumulative incidences of the studied health and welfare parameters when observed upon time. Udder asymmetry had the highest incidence rate, and cumulative incidence (about 123 new cases per 1000 goat-months and 43%), followed by overgrown claws and nasal discharge (about 70 and 56 new cases per 1000 goat-months and 27 and 20%, respectively). The lowest incidence rate and cumulative incidence were observed for hernias, pulpitis, and ocular discharge (0.3, 2.7, and 3.0 new cases per 1000 goat-months and 0.1, 1.0, and 1.1%, respectively).

Table 14.2 Prevalence (%) of the studied health and welfare parameters in 823 adult female goats

	Parameter	Number of goats (%)	Variation in parameters' prevalence (%) across the farms		
			Median	IQR	Maximum
Head	Ear injury	40 (4.9)	1.9	0.7–11.6	13.2
	Horn injury	19 (2.3)	1.9	1.4–3.3	4.0
	Nasal discharge	46 (5.6)	0.0	0.0–12.6	16.6
	Skin lesion	108 (13.1)	5.3	0.0–19.2	42.4
	Pulpitis	2 (0.2)	0.0	0.0–0.7	1.6
	Ocular discharge	7 (0.9)	0.0	0.0–1.4	4.0
	Blindness	6 (0.7)	0.0	0.0–1.4	2.0
Body	Injury	2 (0.2)	0.0	0.0–0.7	1.6
	Abscess	41 (5.0)	2.9	1.3–9.2	14.8
	Diarrhea	0 (0.0)	0.0	0.0–0.0	0.0
	Hernia	0 (0.0)	0.0	0.0–0.0	0.0
Limbs	Arthritis	6 (0.7)	0.0	0.0–0.0	5.8
	Overgrown claws	143 (17.4)	10.6	8.7–44.2	63.9
	Lameness	4 (0.5)	0.0	0.0–0.0	3.8
Udder	Asymmetry	137 (16.6)	18.0	7.9–23.2	35.1
	Abscess	18 (2.2)	2.8	0.7–3.3	5.8
	Clinical mastitis	1 (0.1)	0.0	0.0–0.0	0.7

IQR Interquartile range

Table 14.3 Number of new cases, incidence rates (/1000 goat-months), and cumulative incidences of the recorded health and welfare parameters

	Condition	Number of new cases	Incidence rate (/1000 goat-months)	Cumulative incidence (%)
Head	Ear injury	48	16.6	6.1
	Horn injury	23	7.7	2.9
	Nasal discharge	155	55.8	19.9
	Skin lesion	68	24.4	9.5
	Pulpitis	8	2.7	1.0
	Ocular discharge	9	3.0	1.1
	Blindness	13	4.4	1.6
Body	Injury	14	4.7	1.7
	Abscess	113	40.6	14.5
	Diarrhea	20	6.8	2.4
	Hernia	1	0.3	0.1
Limbs	Arthritis	20	6.8	2.4
	Overgrown claws	181	69.6	26.6

(continued)

Table 14.3 (continued)

	Condition	Number of new cases	Incidence rate (/1000 goat-months)	Cumulative incidence (%)
	Lameness	13	4.4	1.6
Udder	Asymmetry	295	123.3	43.0
	Abscess	54	18.8	6.7
	Clinical mastitis	12	4.0	1.5

14.8 Concluding Remarks

Although low-input farming systems are considered to be less invasive and more welfare-friendly systems, there are several environmental and management factors which may undermine health and welfare status of goats in them. Among these factors, the most challenging ones for Greek goat herds include climatic change, weather exposition, inadequate feeding and water supply, inappropriate infrastructures and housing, infectious and parasitic diseases, as well as lack of farmers' education and training on aspects regarding preventive medicine, herd health management, and human–animal relationship.

Specially designed, evidence-based monitoring systems need to be adopted and appropriate adjustments on farms' structure and characteristics need to be made in order to control the major health and welfare implications and ensure a life worth living for goats.

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Chapter 15
Diagnosis of Mycobacteriosis in Goats: Tuberculosis and Paratuberculosis

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Abstract Two main diseases are caused by mycobacterium in goats. Tuberculosis, caused by *Mycobacterium bovis* or *M. caprae*, produces severe respiratory distress in goats or remain in a subclinical state. Another important mycobacteriosis in goats is paratuberculosis or Johne's disease caused by *M. avium* subsp. *paratuberculosis* is characterized by chronic emaciation. In mycobacterial infections, clinical signs are insufficient to establish a diagnosis. Histopathological diagnosis of tuberculosis compatible lesions usually allows a presumptive diagnosis of the disease. The gold standard test for *Mycobacterium* spp. diagnosis is the microbiological culture but can take several weeks. During the past several years, many molecular methods have been developed for direct detection, species identification, and drug susceptibility testing of mycobacteria. Throughout this chapter, it will be reviewed the different methods of diagnosis of *Mycobacterium* spp. in goats. The main aim of this chapter is to describe the different methods of diagnosis with their advantages and disadvantages.

15.1 Introduction

Classic zoonotic diseases, such as tuberculosis, are controlled in many areas where modern systems of animal husbandry, disease control, and animal health care have been introduced. However, epidemiological studies indicate that tuberculosis in goats has a global distribution, and has been reported in several countries including, Sudan, Portugal, Spain, Italy, Nigeria, the United Kingdom, Algeria, or Ethiopia among others. In sheep, the number of studies reporting tuberculosis has also been

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increasing in the last decades (Pesciaroli et al. 2014). The infection can be transmitted through raw milk and unpasteurized dairy products but evidence of meat-borne transmission of these pathogens to humans from small ruminants is lacking, so this potential pathway of infection remains unproven (EFSA 2013; Müller et al. 2013). According to EFSA BIOHAZ Panel (2013), the risk of transmission of *Mycobacterium bovis* to humans by meat consumption is currently considered as negligible.

Regardless these aspects, most of the information on small ruminants' tuberculosis in several EU countries derives from recognition of tuberculosis-related lesions at the slaughterhouse and from laboratory reports. The ability of traditional *postmortem* inspection to detect lesions caused by mycobacteria is relevant in regions where they are present. *Postmortem* examination of infected animals reveal circumscribed pale yellow, white, caseous, or caseocalcareus lesions of various sizes, often encapsulated, especially in the lungs and mediastinal lymph nodes, or in the mesenteric lymph nodes (Quintas et al. 2010; Pesciaroli et al. 2014; Benavides et al. 2015).

A change to visual only inspection causes a significant reduction in the probability to detect cases of tuberculosis because it implies abandoning palpation. Surveillance of tuberculosis at the slaughterhouse for small ruminants should be improved and encouraged, as this is, in practice, the only surveillance system available (EFSA 2013).

Other important mycobacterial disease in small ruminants is paratuberculosis or Johne's disease. Ovine and caprine paratuberculosis involves chronic inflammatory lesions of the intestinal and lymphoid organs and is caused by *M. avium* subsp. *paratuberculosis* (MAP) (Windsor 2015; Bauman et al. 2016a). The disease has worldwide distribution and the most definitive diagnostic test for ovine and caprine paratuberculosis is *postmortem* evaluation with histopathological confirmation, seeking identification of characteristic pathological changes of depletion of fat reserves, thickening of the bowel wall, and enlargement of the gut-associated lymphatics, including the presence of so-called "lymphatic cords" on the serosal surface of the ileum and caecum (Windsor 2015).

The potential zoonotic link between paratuberculosis and human chronic enteritis, Crohn's disease is cause of concern (Hermon-Taylor et al. 2000; Juste 2012; Windsor 2015) as well as the association between MAP and the development of type I diabetes (Sechi et al. 2008; Niegowska et al. 2016). Human exposure to MAP from livestock could be via milk and meat products (Eltholth et al. 2009; Naser et al. 2014). For the latter, abattoirs are critical points to reduce MAP in meat and the risk of exposure to humans (Okura et al. 2011). If MAP is eventually confirmed as a zoonotic pathogen, it is expected that public confidence in products from bovine and potentially small ruminant dairy industries will very likely decline and efforts to diminish or remove the organism from the human food chain should be encouraged (Windsor 2015). However, at present, there is no agreed consensus on any aetiological role for MAP in Crohn's disease and no evidence that it presents a risk via consumption of meat or meat products (EFSA 2013).

While the EFSA opinions question the efficacy of traditional *postmortem* inspection for public health purposes, they emphasize the significance of the process for animal health purposes and particularly its use on farm (Collins and Huey 2015). A meat safety assurance system for small ruminants, combining a range of preventive measures and controls applied both on the farm and at the slaughterhouse and taking into consideration the entire process of production and processing involved in producing meat or meat products as food from farm animals is the most effective approach to control the main hazards in the context of meat inspection (EFSA 2013; Collins and Huey 2015).

This chapter addresses a critical review of mycobacterium laboratorial diagnosis, including advantages and disadvantages of each of them.

15.2 Clinical and Epidemiological Diagnosis

Clinical signs are insufficient to establish a diagnosis. Together with the epidemiological data, it will be possible to establish a suspicion of *Mycobacterium* spp. in the flock. Tuberculosis, caused by *M. bovis* or *M. caprae*, can cause severe respiratory symptoms in goats or remain in a subclinical state (Smith and Sherman 2009). However, its clinical evolution is predominantly chronic (Perea et al. 1999) with an incubation period ranging from a few weeks to a few months (Garcia and Gutiérrez 1996a, b). Thus, tuberculosis in this species presents a relatively rapid clinical evolution, characterized by a generalization phase with lymphohematogenous spread and the elimination, in its open forms, of large numbers of bacilli into the environment through cough, sputum, and feces (Perea et al. 1999).

The symptoms are nonspecific and depend on the affected organs. Some goats, even with extensive lesions, may have no symptoms (Matthews 2017). The disease becomes clinically evident in herds with 25–30% of affected animals, where they present chronic and progressive weight loss, with or without diarrhea, culminating with death (Garcia and Gutiérrez 1996a; Bezos et al. 2012). Other common symptoms are anemia, erect hair or hair loss, and decreased milk production (Bernabé et al. 1991a; Garcia and Gutiérrez 1996a; Perea et al. 1999). Some goats may even have solid nodular lesions in the mammary gland (Smith and Sherman 2009; Quintas et al. 2014). Mortality is variable (Perea et al. 1999), and in some cases it may reach 20–30% annually, with affected animals of all ages, although it is more frequent in young adults (Garcia and Gutiérrez 1996a).

Respiratory changes are inconstant and arise mainly in the late stages of the disease (Garcia and Gutiérrez 1996a, b; Perea et al. 1999). They have onset with a deep and productive chronic cough, with tachypnea, dyspnea and abnormal lung sounds (Plummer et al. 2012). The superficial lymph nodes may be enlarged and easily palpable (Matthews 2017). Increased regional lymph nodes may contribute to the onset of stridor, dysphagia, and tympanism (Plummer et al. 2012). In rare cases, fistulas, ulcers, and nodules may appear on the skin (Matthews 2017).

Garcia and Gutiérrez (1996a) refer to having the highest diagnostic value in the diagnosis of tuberculosis in goats when:

(a) High mortality is present in adult animals of all ages, without seasonality and distributed in a cadential way throughout the year;
(b) Sick animals present a chronic process that lasts from weeks to months, characterized by progressive weight loss and the presence of respiratory symptoms in the final phase of the disease.

In paratuberculosis, certain characteristics of MAP infection can guide the veterinarian to a presumptive diagnosis.

According to the authors' experience, the first suspicions of disease begin in the herd when some adult goats present a dramatic emaciation as a consequence of progressive weight loss during several weeks/months, normally without changes in appetite in this period, and with a marked diarrhea and depression in the terminal stages of the disease (Fig. 15.1). The clinical signs still include anemia, lethargy, flaky skin, rough hair coat, and intermandibular edema (Djønne 2010; Robbe-Austerman 2011). In the advanced state of the disease, the goats are immunologically depressed and can die due to inanition or secondary infections (Smith and Sherman 2009; Djønne 2010; Matthews 2017).

The observation of animals between 2 and 4 years of age, often females at *postpartum*, or a history of a recent introduction into a new herd or other episodes of stress, affected by a progressive slimming syndrome with intermittent or continuous diarrhea in early stages that ends with the death of the animal, are the most characteristic epidemiological data (Juste and Perez 2011).

Fig. 15.1 Severe emaciation (body condition score = 1) in an adult Serrana goat with advanced clinical paratuberculosis (provided by the authors)

15.3 *Postmortem* Diagnosis

15.3.1 *Macroscopic Features of Caprine Tuberculosis*

Postmortem examination of tuberculosis compatible lesions usually allows a presumptive diagnosis of the disease. However, small lesions may be undetected, which compromise the diagnosis of the disease (Garcia and Gutiérrez 1996a, b; Sánchez et al. 2008; Buendía et al. 2013). The evolution of caprine tuberculosis evolution is summarized in Table 15.1.

Animals infected with *M. bovis* and *M. caprae* frequently show, in lungs and mediastinal lymph nodes, or in the intestine (Fig. 15.2a) and mesenteric lymph nodes (Fig. 15.2b), caseous or caseocalcareous lesions, often encapsulated, circumscribed, whitish or pale yellow. Pulmonary lesions caused by *M. tuberculosis* are less severe. However, besides etiological agents, features of tuberculosis lesions in goats also depend on the animal health status and if it is primo-infection or reinfection (Crawshaw et al. 2008; Sharpe et al. 2010; Pesciaroli et al. 2014; Bezos et al. 2015).

Primary tuberculosis occurs after the first contact with the etiological agent. It is characterized by proliferative lesions and is more frequent in herds with a low incidence of the disease. Postprimary tuberculosis is characterized by exudative lesions and is more frequent in flocks with high incidence of disease (Bernabé et al. 1996).

Airborne transmission is the most common route of transmission. So, the primary complex is found in lungs and mediastinal lymph node (Ghon complex), although, in a high percentage of cases, the primary complexes are incomplete. During early generalization phase, lymphohematogenous spread leads to new lesions in lungs and other organs as intestine, mesenteric lymph nodes, liver (Fig. 15.2c, d), and spleen (Fig. 15.2e, f). In this phase, lesions in mesenteric lymph nodes and intestine should be distinguished from digestive primary complex (Bernabé et al. 1996; Sánchez et al. 2011).

Table 15.1 Lesional features of caprine tuberculosis

<table>
<tr><td colspan="9">Tuberculosis</td></tr>
<tr><td colspan="6">Primary</td><td colspan="3">Postprimary</td></tr>
<tr><td colspan="2">Complex</td><td colspan="4">Early generalization</td><td colspan="2">Organic—chronic</td><td>Late generalization</td></tr>
<tr><td>Complete</td><td>Incomplete</td><td>Miliary</td><td>Slow-Early</td><td>Large nodule</td><td>Serosas</td><td>Acinous—nodular</td><td>Cavernae</td><td>Caseous lobular pneumonia</td></tr>
<tr><td colspan="6">Proliferative lesions</td><td colspan="2">Proliferative—exsudative</td><td>Exsudative lesions</td></tr>
<tr><td colspan="4">Predominant cellular immune response</td><td colspan="5">Predominant type IV hypersensitivity reactions (delayed hypersensitivity)</td></tr>
</table>

Adapted from Bernabé et al. (1991b, c, 1996)

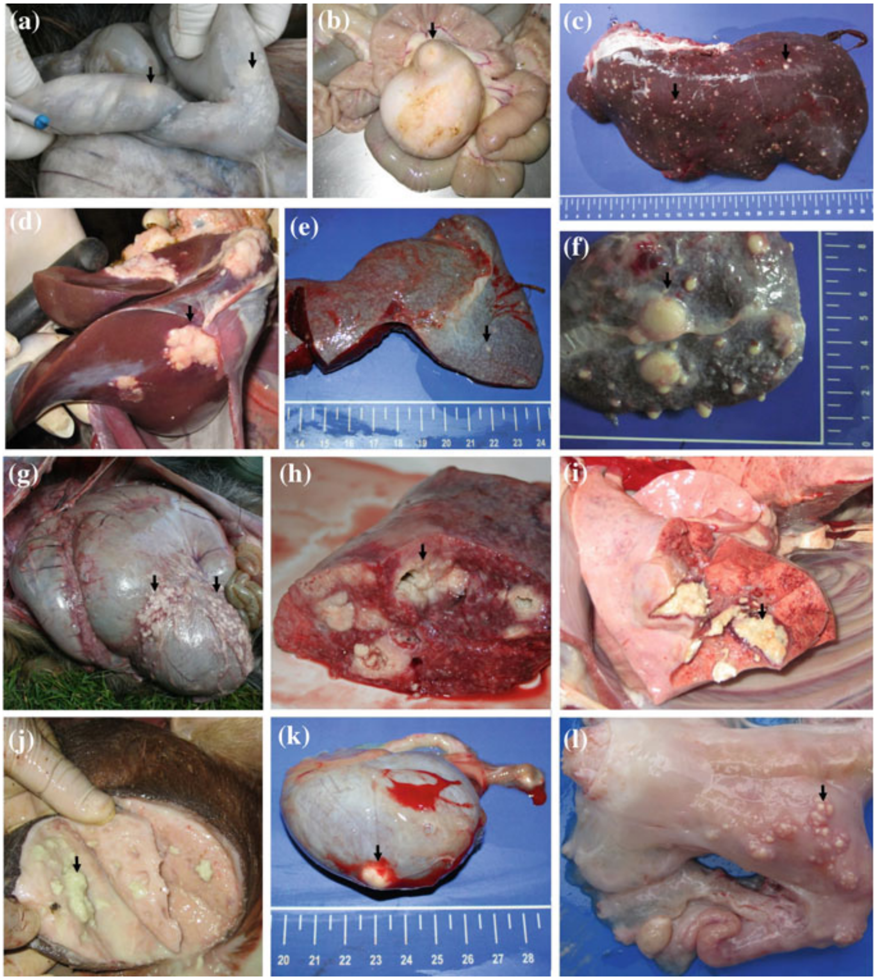

Fig. 15.2 Intestinal (**a**) and lymph node (**b**) primary complex macroscopic (caseocalcareus) lesions. Miliary (**c**) and large nodules (**d**) liver tuberculosis. Miliary (**e**) and large nodules (**f**) spleen tuberculosis. Serosal perlaceous tuberculosis (**g**) Lesional features of pulmonary tuberculosis (**h**, **i**) Mammary tuberculosis (**j**) Tuberculosis lesions in late generalization phase: kidney (**k**) and uterus (**l**) (provided by the authors)

The arrival at the same time of a large number of bacilli to organs is the base for miliary tuberculosis lesions, the most frequent picture of early generalization. However, the arrival of the agent at different times leads to early slow tuberculosis and, with the retrograde delivery of the bacilli, serosal perlaceous tuberculosis lesions (Fig. 15.2g) can arise (Bernabé et al. 1996).

When reactivation or reinfection occur due to decreased immunity or increased virulence of the agent, postprimary tuberculosis lesions occur. Chronic organic tuberculosis is characterized by the presence of extensive necrosis centers and more intense caseification necrosis. Acinous-nodular tuberculosis is the most frequent lesion in this phase due to the dissemination of the bacilli via intracanalicular and contiguity between the alveoli. However, due to liquefaction of these foci of necrosis by enzymatic action, destruction of the bronchial walls can occur, forming cavities and ulcers in bronchial wall and trachea (Bernabé et al. 1996). Figure 15.2h, i show some lesional features of pulmonary tuberculosis.

In late generalization phase, lesions of caseous lobular pneumonia can be found and, due to lymphohematogenous dissemination, lesions in mammary gland (Fig. 15.2j), kidney (Fig. 15.2k), and uterus (Fig. 15.2l) can also appear (Bernabé et al. 1991b, 1996).

Different types of lesions are commonly found in the same animal. However, it is important to note that sometimes there are very small lesions that may go undetected, which may compromise the diagnosis of the disease (Bernabé et al. 1991c; Sánchez et al. 2008). Thus, it is extremely important to perform a rigorous inspection of lungs and intestines and, above all, of lymph nodes associated with respiratory and digestive systems, by cross sectioning them (Bernabé et al. 1996). Differential diagnosis with other diseases such as caseous lymphadenitis, parasitic pneumonia, and abscess should be considered at all times (Sánchez et al. 2008).

15.3.2 Microscopic Features of Caprine Tuberculosis

Macroscopic diagnosis should be confirmed with histopathological analysis of samples and demonstration of alcohol acid bacilli with Ziehl-Neelsen staining. An alternative to this method is the immunocytochemistry, namely by avidin-biotin-peroxidase method. This technique allows the detection of mycobacteria with changes in the cell wall and free mycobacteria (Garcia and Gutiérrez 1996b; Ulrichs et al. 2005; Sánchez et al. 2008, 2011).

In caprine tuberculosis, three types of microscopic lesions are described: proliferative (i.e., tuberculoid granuloma), proliferative-exudative, and exudative (cavitary tuberculosis) lesions (Table 15.1).

Proliferative lesions are characterized by small granulomas with few central necrosis. Central calcification is surrounded by epithelioid cells and some Langhans-type giant cells, lymphocytes and a fibrous capsule. Only a few bacilli are observed, mostly with intracellular location (giant cells and epithelioid cells) (Bernabé et al. 1991a; Garcia and Gutiérrez 1996a, b; Sánchez et al. 2011).

Proliferative-exudative lesions present extensive caseification necrosis and occasional calcification. Small peripheral granulomas are noted, constituted by a diffuse infiltrate of epithelioid cells, Langhans-type giant cells, and lymphocytes, surrounded by a proteinaceous substance (Bernabé et al. 1991a; Garcia and Gutiérrez 1996a, b; Sánchez et al. 2011).

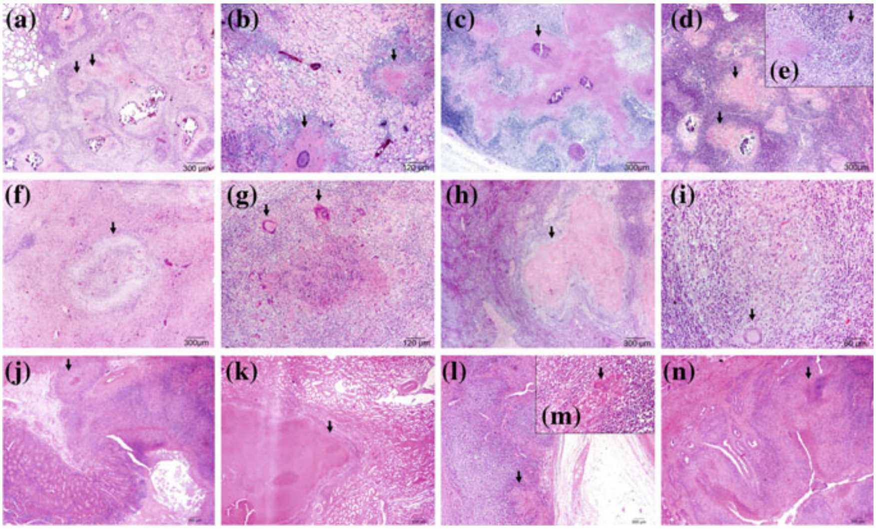

Fig. 15.3 Pulmonary tuberculosis lesions (**a**) lesions with exudative secretions (**b**). Tuberculosis microscopic lesions in mediastinal (**c**), and mesenteric lymph nodes (**d** and **e**). Liver tuberculosis microscopic lesions (**f** and **g**). Splenic tuberculosis (**h** and **i**) with the presence of Langhans-type giant cells. Tuberculosis lesions in intestine (**j**), kidney (**k**), trachea (**l** and **m**), and uterus (**n**) (hematoxylin and eosin stain) (provided by the authors)

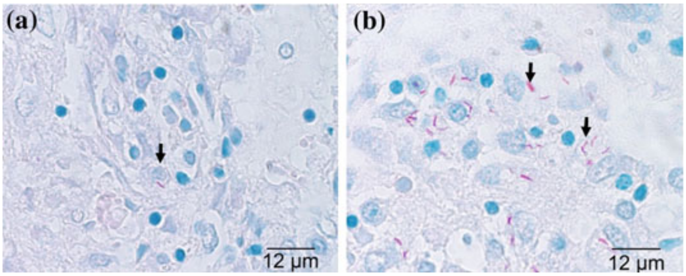

Fig. 15.4 Acid fast bacilli (**a** and **b**; Ziehl-Neelsen stain) (provided by the authors)

Exudative lesions are characterized by large areas of primary caseification necrosis, without calcification, surrounded by a specific or nonspecific cellular infiltrate and large areas of coagulated plasma. Pattern of fibrinous pneumonia and a large amount of bacilli intra- and extracellular are present (Bernabé et al. 1991a; Garcia and Gutiérrez 1996a, b; Sánchez et al. 2011).

Microscopic lesions can be found in several organs as lungs (Fig. 15.3a, b), lymph nodes (Fig. 15.3c, d, e), liver (Fig. 15.3f, g), spleen (Fig. 15.3h, i), intestine (Fig. 15.3j), kidney (Fig. 15.3k), trachea (Fig. 15.3l, m), uterus (Fig. 15.3n), among others. Figure 15.4 (a and b) show the presence of alcohol acid bacilli with Ziehl-Neelsen stain.

15.3.3 Macroscopic Features of Caprine Paratuberculosis

Macroscopic lesions of paratuberculosis in goats are variable. Laboratory confirmation is essential for definitive diagnosis of this disease (Navarre et al. 2002; Smith and Sherman 2009).

Emaciation, anemia, and hypoproteinemia (with intermandibular edema) are frequent. However, unlike cattle, the disease rarely occurs with chronic diarrhea and feces are often pelleted. However, feces may be soft and intermittent episodes of diarrhea may occur in terminal stages of disease. The exception is pygmy goats that developed severe diarrhea with sudden death (Morin 1982; Navarre et al. 2002; Smith and Sherman 2009; Uzal et al. 2016).

In sheep and goats, enteric gross lesions are subtler than that occurred in cattle. The accordion-type corrugated thickening resembling cerebral convolutions, which is typical of paratuberculosis in cattle, is not frequent in goats. When intestinal lesions are evident, a focal, nodular, or diffuse thickening or a rugose mucosa (Fig. 15.5a), often with ulceration foci in ileum, cecum, or spiral colon are observed. Lesions could be predominant at sites with gut-associated lymphoid tissue. Ileocecal junction is generally affected. Mesenteric adhesions could also be found (Siguräardóttir et al. 1999; Munjal et al. 2005; Krüger et al. 2015; Uzal et al. 2016).

Mesenterical lymph nodes are often enlarged and edematous. Whitish nodule with 1–4 mm in diameter could be found due to caseation areas with focal

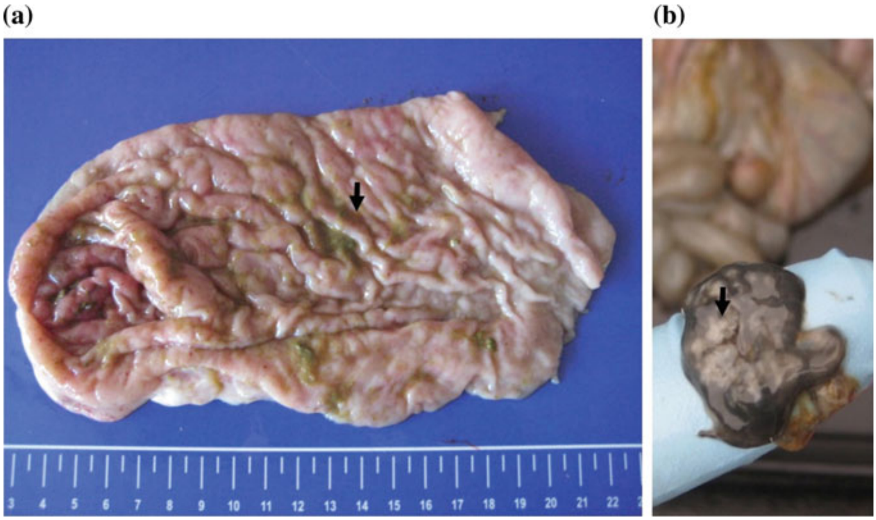

Fig. 15.5 Caprine paratuberculosis. gross lesions at necropsy: **a** diffuse thickening or edema of the cecum; and prominent, accordion-like, corrugated thickening of the intestinal wall **b** mesenteric lymph nodes enlarged and edematous, caseation of nodes with focal calcification (provided by the authors)

calcification (Fig. 15.5b). These granulomas could appear in other lymph nodes elsewhere, liver, lung, spleen, and other organs. Calcification of aorta could be present in goats with prolonged disease (Smith and Sherman 2009; Gelberg 2016).

For histopathological examination, a section of ileocecal junction, ileocecal lymph node, ileum, spiral colon, and other mesenteric lymph nodes should be collected (Navarre et al. 2002; Gelberg 2016).

15.3.4 Microscopic Features of Caprine Paratuberculosis

Microscopic lesions are of granulomatous type located at intestine (more severe in distal jejunum and/or ileocecal valve; Fig. 15.6a), lymphatics vessels, lymph nodes (Fig. 15.6b), and possibly in liver (Smith and Sherman 2009; Gelberg 2016; Uzal et al. 2016).

Lamina propria, especially in ileum, is distended with granulomatous inflammatory cells which compress the crypts. The inflammatory infiltrate could be focal, diffuse macrophagic, diffuse lymphocytic, or diffuse mixed (macrophagic and lymphocytic). Focal or multifocal epithelioid cells and lymphocytes predominate in paucibacillary form, with few bacillus. Multibacillary forms are characterized by a dense transmural intestinal inflammatory infiltrate with abundant organisms (Corpa et al. 2000; Uzal et al. 2016).

Unlike cattle, goat granulomas could have tubercle-like caseous necrosis, often mineralized, surrounded by epithelial macrophages and Langhan-type giant cells and fibrosis. In this kind of mature granulomas, acid-fast mycobacteria are less abundant (Navarre et al. 2002; Gelberg 2016; Uzal et al. 2016).

Mycobcterium containing macrophages could be revealed with Ziehl-Neelsen stain (Smith and Sherman 2009; Gelberg 2016) as we can see in Fig. 15.7a, b.

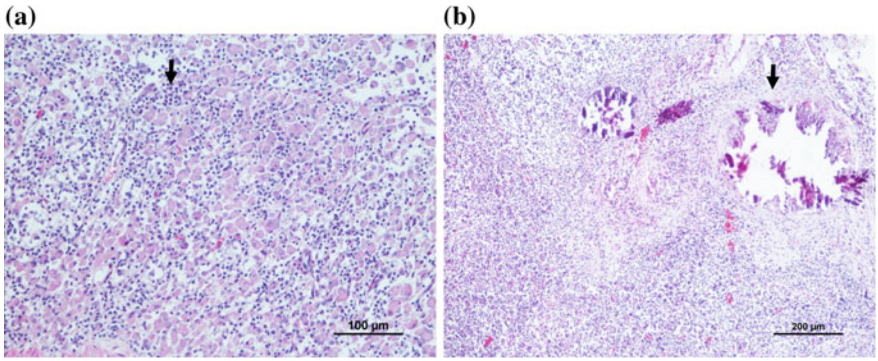

Fig. 15.6 Microscopical features of a paratuberculosis: (**a**) granulomatous enteritis and (**b**) mesenteric lymph node with tubercle-like caseous necrosis, with mineralization (hematoxylin and eosin stain). (provided by the authors)

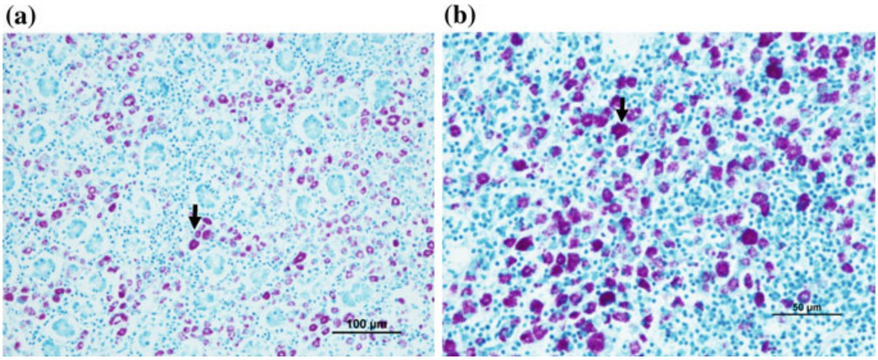

Fig. 15.7 *Mycobacterium* containing macrophages in intestinal (**a**) and mesenteric lymph node (**b**) lesions (Ziehl-Neelsen stain) (provided by the authors)

15.4 Direct Microscopy

Direct microscopy is the fastest, simplest, and cheapest way for the detection of acid-fast bacteria (Gormley et al. 2014). Diagnosis of *Mycobacterium* spp. infection with this technique is poor due to low numbers of mycobacteria, these can only be visualized if, at least, 5×10^4 mycobacteria/mL of material are present and sample contamination with other acid-fast bacteria (Markey et al. 2013).

MAP visualization on Ziehl-Neelsen-stained smears from feces, intestinal mucosa, or lymph node samples is considered a good technique for rapid diagnosis (OIE 2009). In the more advanced cases of the disease, the diagnosis offers no doubt since the bacilli are very abundant and adopt a characteristic arrangement in lumps, due to the maintenance of the structure that they have inside the macrophages. The test has low sensitivity in the early stages of the disease, but when the animal shows clinical stage, it reaches virtually 100% sensitivity (Coelho et al. 2010). In caprine tuberculosis, an alternative to Ziehl-Neelsen is the immunocytochemistry techniques, as the avidin-biotin-peroxidase (Garcia and Gutiérrez 1996b).

15.5 Bacteriological Diagnosis

The gold standard test for *Mycobacterium* spp. diagnosis is the microbiological culture. The isolation of *Mycobacterium* spp. in selective culture media is the most conclusive method of identification. The combination of bacteria that grow very slowly, acid-fast resistance, colony morphology, and uniform cell, offers little opportunity for error to the microbiologist responsible for identification.

The critical aspects of mycobacterial culture are the procedures used for processing and decontaminating samples, the culture media employed and the methods used for identifying mycobacteria (de Lisle et al. 2002). Decontamination involves the use of toxic chemicals to which mycobacteria are generally more refractory than the contaminating microorganisms. Non-sterile specimens need to be processed with detergent alkali or acid to eliminate rapidly growing microorganisms before culture decontamination in order to remove faster growing microbial species. Incubation with various decontamination agents such as 0.6–0.75% hexadecylpyridinium chloride (HPC) or NaOH for 3 h to overnight has been used. It is important that decontamination does not remove too many viable *Mycobacterium* cells (Ambrosio et al. 2008; Reddacliff et al. 2010).

The use of both an agar-based medium (e.g., 7H11) and an egg-based medium supplemented with sodium pyruvate (e.g., Löwenstein–Jensen) is recommended for the isolation of *M. bovis*. Growth of *M. bovis* generally occurs within 3–6 weeks of incubation depending on the media used. *M. bovis* will grow on Löwenstein–Jensen medium without pyruvate, but will grow less well when glycerol is added. Cultures are incubated for a minimum of 8 weeks (preferably for 10–12 weeks) at 37 °C with or without CO_2 (OIE 2009). In caprine tuberculosis there are several culture media that can be used for the isolation of *M. bovis* and *M. caprae*: liquid media and solid media as Löwestein-Jensen with or without TCH (thiophene-2-carboxylic acid hydrazide), Löwestein-Jensen with pyruvate, Stonebrink, Tharsis-modified B82, Middlebrook and Coletsos (Garcia and Gutiérrez 1996b; Duarte et al. 2008). Shorter incubation times can be achieved using automated broth-based systems, such as liquid culture. Examples of liquid culture systems are the BACTEC 460® System (Becton Dickinson Inc.), the MB/Bact® (Organon Teknika, Boxtel, Netherlands), and the BACTEC MGIT 960® (Becton Dickinson, Inc.) (Timms et al. 2011). These systems have been reported to be highly sensitive to culture (Katoch 2004).

Once the *Mycobacterium* is isolated, it is subjected to a complex and slow microbiological study based on the 22 microbiological and biochemical characteristics selected by Wayne and Kubica in the Bergey's Manual of Systematic Bacteriology (1986) to identify the species (Martín and León 1998).

In paratuberculosis the difficulties of culture are essentially due to their low growth rate; on the one hand, because any other normal growing bacterial species may deplete the culture medium before MAP growth begins and, on the other hand, because of the long incubation periods. Incubation should be carried out under such conditions as to provide the necessary nutrients and growth factors (mycobactin J), and without degrading them for periods of more than 6 weeks (up to 6–12 months) at 37 °C.

Traditionally, there are two basic methods for MAP culture. One is the method using oxalic acid and NaOH for decontamination and Löwenstein-Jenssen® and the second using hexadecylpyridinium chloride (HCP) for decontamination in combination with Herrold's Egg Yolk Medium (HEYM) for growth (OIE 2010). In goats, the culture has low sensitivity and may require more than 12 months of incubation, which makes it an impractical diagnostic method. The liquid culture system

BACTEC with variations in its composition, such as the addition of mycobactin J, egg yolk, and antibiotics can also be used for MAP detection in goats (Bauman et al. 2016b). The main advantage is its greater sensitivity to traditional cultures, showing high sensitivity, especially when double-incubation/centrifugation steps are included in the preparation of the sample (OIE 2010).

15.6 Immunological Methods

15.6.1 Intradermal Reaction (IDR)

The tests intradermal comparative tuberculin and single intradermal test can be used to detect infection (Bezos et al. 2012; Chartier et al. 2012). The intradermal tuberculin test involves the intradermal injection of bovine tuberculin purified protein derivative (PPD) and the subsequent detection of swelling (delayed hypersensitivity) at the site of injection 72 h later. This may be performed using bovine tuberculin alone or as a comparative test using avian and bovine tuberculins.

The test must be carried out on the side of the neck, with hair clipping at the site of testing, accurate intradermal injection, and careful pre- and postinoculation skin thickness measurement using calipers to obtain results that are valid. This test should also be performed to check for signs of inflammation (OIE 2009). In single intradermal reaction (IDR), a single injection of 0.1 mL of mammalian tuberculin is inoculated in the cervical area, the anal or caudal fold (OIE 2004). It is possible to perform an additional inoculation at the mucocutaneous junction of the vulvar lips. It is considered that the cervical test has greater sensitivity and that of the caudal fold greater specificity (Nuñez-Garcia et al. 2017).

Compared IDR can be used in goats with simultaneous injection of a mammalian tuberculin (prepared from *M. bovis* strain AN5) and an injection of avian tuberculin (prepared with *M. avium* strain D4ER) on different sides of the neck (Garcia and Gutiérrez 1996b; OIE 2004). They can also be inoculated on the same side in the area of the shoulder since separated by 10 cm (Garcia and Gutiérrez 1996b).

There are several limitations in terms of sensitivity and specificity of IDR and difficulties in adapting the technique to goats, particularly in the younger ones with thin skin (Shanahan et al. 2011). Animals with a chronic disease may experience anergy due to immune exhaustion and lead to the occurrence of false negatives to IDR. There are several causes of false positive in goats to IDR as nonspecific reactions of skin hypersensitivity; animals with mixed tuberculosis/paratuberculosis infections, animals vaccinated to paratuberculosis; infection with *M. avium* subspecies *avium*; ingestion of a pathogenic environmental mycobacteria or bacteria of the genus *Nocardia* or *Corynebacterium*; inoculations with fraudulent substances (e.g., turpentine essence); intervals of inoculations less than 60 days; and bacillus in latency phase (de la Rua-Domenech et al. 2006).

15.6.2 Interferon-Gamma (IFN-γ) Assay

Probes like the gamma-interferon (IFN-γ) assay and the lymphocyte proliferation assay which measure cellular immunity, and the enzyme-linked immunosorbent assay (ELISA) which measures humoral immunity, could be an alternative in goats (Fernández et al. 2009). Advantages of IFN-γ, lymphocyte proliferation, and ELISA assays are that they employ blood and serum and they enable testing without handling the animals twice and allow repeated testing (Palmer et al. 2004). IFN-γ is a cytokine released primarily by T lymphocytes in response to exposure to a given antigen and constitutes the major activating factor of macrophages in tuberculosis (Sánchez et al. 2008).

The IFN-γ test is based on the quantification of the release of this cytokine by T lymphocytes previously sensitized with tuberculin (mammalian protein purified derivative–PPD) or an *M. bovis*-like antigen. In this test heparinized blood is put in contact with mammal and avian PPD. If an animal has been infected by *M. avium* or other environmental mycobacteria, IFN-γ production will be increased when incubated with avian PPD. On the other hand, an animal is considered positive for tuberculosis when IFN-γ production is higher in samples incubated with mammalian PPD than in those incubated with avian PPD or negative control (Sánchez et al. 2008).

15.7 Serological Tests

Diagnosis of tuberculosis with ELISA can use different antigens, such as the mammalian PPD (bovine) (Garcia and Gutiérrez 1996b), and the protein antigens ESAT-6, CPF-10, MPT63, MTB70, MPB83, TB 10.4, PE 5, PE 13, which were recognized as triggers of a specific humoral response (Lyashchenko et al. 1998; Lightbody et al. 2000; Waters et al. 2006). Among these antigens, the MPB70, a secretory protein of some strains of *M. bovis*, is one of the components of PPD in the goat species (Marassi et al. 2009).

The use of ELISA with only one antigen demonstrated that the activity of antibodies to different antigens is developed at different stages during the course of infection (Kwok et al. 2010). The sensitivity of ELISA is dependent on the stage of the disease with a higher sensitivity of the test in case of a higher bacterial load. The test can detect the most severe infections in multibacillar lesions but show lower sensitivity in animals with paucibacillar lesions (Lyashchenko et al. 1998; Timms et al. 2011). An ELISA was developed for the detection of *M. bovis* infection, and adapted to goats, obtaining high sensitivities and specificities. However, the need for additional studies in this species to validate the test is recognized (Shuralev et al. 2012).

There are currently three techniques capable of determining the presence of MAP antibodies in the serum of infected animals. These are complement fixation

(FC), agar gel immunodiffusion (AGID), and ELISA. As a strong humoral response to the final stages of the disease does not occur, the sensitivity of these tests is higher in animals with multibacillary (lepromatous) lesions. AGID is a fast and inexpensive technique. Its main advantage is to provide specificity values that are around 100%. Regarding their sensitivity, several studies provided different values depending on the clinical status of the animals included in each study. AGID seems to provide a satisfying specificity that makes it very convenient for the rapid confirmation of suspected cases. The sensitivity and specificity of the ELISA to paratuberculosis diagnosis test are variable according to the individual modification of the test, as well as with the clinical stage of the animal or the nature of the sample (milk or serum) (Manning et al. 2003).

15.8 Molecular Techniques

During the past several years, many molecular methods have been developed for direct detection, species identification, and drug susceptibility testing of mycobacteria. These methods can potentially reduce the diagnostic time from weeks to days with a higher sensitivity. The use of molecular methods in goats is carried out at three levels: pathogen detection in host tissues or secretions (Garcia and Gutiérrez 1996b), strain typing, and quantification of the immune response (Sánchez et al. 2008). Molecular biology methods offer new opportunities to differentiate, identify, and type bacterial species and strains. These methods use the variability of nucleic sequences of genes such as 16S ribosomal DNA (rDNA), beta subunits of the RNA polymerase (rpoB) and DNA gyrase (gyrB), rDNA internal transcribed spacer among other genes. Some of the methods available to differentiate and identify species of mycobacteria at the DNA sequence level are PCR, PCR restriction endonuclease analysis (REA), sequencing analysis, spoligotyping, and DNA fingerprinting. These methods have been applied to both the "universal" part of the genome and to specific mycobacterial genes (OIE 2009, 2010).

In paratuberculosis, research on strain differentiation has focused on molecular techniques such as RFLPs, restriction endonucleases, pulsed field gel electrophoresis, which allows discriminating MAP from other species of *M. avium.* The PCR technique allows the rapid and specific detection of MAP in clinical samples, since the results may be available in three days, compared to the 16 weeks of culture. The main problem limiting the yield of the method is the presence of inhibitors in fecal samples. Several inhibitors are present in different sample types, for example, large amounts of irrelevant DNA, polysaccharides, bile salts among others (Coelho et al. 2010).

A great advantage of PCR-based methods is that they can be run directly from the clinical samples. An example is the 16S rRNA PCR, which is presented as a sensitive technique for the rapid and direct detection of MAP in clinical samples. When the PCR technique is applied to tissue samples, the sensitivity is higher, since, in addition to a lower dilution effect of the bacilli detached from infected tissues. Multiplex PCR has a sensitivity of 10^3 colony-forming unit (CFU) for each of the strains of bacteria in a single reaction tube (Chaubey et al. 2016).

The publications of the complete genome sequences of *M.* tuberculosis H37Rv, *M. bovis* AF2122/97, and *M. bovis* Bacillus Calmette-Guérin (BCG) were breakthroughs in molecular tuberculosis research. Since then, whole genome sequencing has become more available and has revolutionized genotyping by providing the highest level of discrimination (Gormley et al. 2014).

PCR-based diagnostic procedures are the most used, since their first applications in the detection of *M. bovis* DNA in animal tissue samples (Liébana et al. 1996). In RFLP the most used sequences are IS1081, DR (direct repeat), PGRS (polymorphic GCrich sequence), VNTR (variable number tandem repeat), but mainly the sequence IS6110, because it presents a variable number of copies between the different species of the complex *M. tuberculosis*. Spoligotyping allows obtaining a characteristic pattern for each *M. tuberculosis* complex. It can thus be used in the typing and identification of these microorganisms (Duarte et al. 2008).

15.9 Concluding Remarks

Mycobacterium spp. can cause serious infections in goats with an economic and public health concern. The diagnostic techniques used to detect the disease in goats were influenced by their evolution and the flock prevalence.

Diagnostic techniques range from clinical examination and immunological assays to histopathology, culture, immunological tests, and molecular biology. None of the methods available are sufficient to establish the diagnosis alone and only a combination of different tests can increase sensitivity and specificity of the diagnosis. Due to the economic value of the goat, in the future, it will be necessary to develop faster and low-cost diagnostic techniques.

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Chapter 16
Facing Anthelmintic Resistance in Goats

Carine Paraud and Christophe Chartier

Abstract Goats raised in pasture are inevitably infected by gastrointestinal nematodes, whatever the place and the climatic conditions. This parasitism results in production losses (growth or milk) and in some cases, in high mortality rates (with high parasite burden or in kids). For many years, these infections were controlled by conventional anthelmintics. Due to unsuitable usages (for example, high number of treatments or under-dosage), anthelmintic resistance has developed and is now very prevalent in goats as demonstrated by the numerous cases of simple or multiple anthelminthic resistance which have been reported throughout the world. Reports include resistance to the most recent anthelmintics, macrocyclic lactones and monepantel. Consequently, the way of managing gastrointestinal parasitism of goats has to move from anthelmintics alone to a more integrated management, including better use of anthelmintics, natural dewormers (nutraceuticals), enhancement of the immunity of the goats via alimentation or vaccination, selection of resistant goats or breeds and grazing management. The present chapter will give an overview of the situation regarding anthelmintic resistance in goats and integrated parasitism management.

16.1 Introduction

Goat population is expanding worldwide with more than 90% of the animals being found in Asia and Africa providing meat and/or milk in small farming systems (Hoste et al. 2010). Helminth infection is considered as a major threat for outdoor breeding of goats affecting health and production. The main helminth species found in goats are grossly similar to those of sheep and include numerous species belonging to trematodes (e.g. flukes), cestodes (e.g. tapeworms) and

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nematodes (e.g. gastrointestinal nematodes like *Haemonchus*, *Teladorsagia* and *Trichostrongylus*), for which the occurrence and frequency strongly depend on altitude, climate (tropics vs. temperate) and more generally on breeding location and management. Among these parasites, gastrointestinal (GI) nematodes are of particular concern because of their economic importance (loss of production and mortality of kids) and because of the escalating issue of anthelmintic resistance over the past 25 years (Hoste et al. 2010; Kaplan and Vidyashankar 2012). This problem can no longer be ignored in ruminants and especially in goats considering the high frequency, the nature (multi-resistance) and the widespread distribution of anthelmintic resistance deeply impacting the parasite control programs and calling for a shift to a less reliance on anthelmintics and a development of novel non-chemical approaches (Kaplan and Vidyashankar 2012).

The present chapter addresses anthelmintic resistance in goats and provides a holistic approach for parasitism management.

16.2 Anthelmintics

There are three main broad spectrum anthelmintic families against GI nematodes affecting goats: benzimidazoles (BZD) and probenzimidazoles, imidothiazoles (levamisole), and macrocyclic lactones (ML) (avermectins and milbemycins). Alongside these broad spectrum products, there are two narrow spectrum anthelmintics against haematophagous nematodes, mainly *Haemonchus*, namely salicylanilides (closantel) and nitrophenols (nitroxinil). The 'anthelmintic resources' may be considered to be limited or even stagnating: nearly 30 years passed between the release of MLs (ivermectin in 1981) and the launch of monepantel (firstly marketed for sheep in 1999 in New Zealand) which is a member of the Amino Acetonitril Derivatives (AAD) class and has a unique mode of action. Another anthelmintic with a unique mode of action, derquantel, is a member of the Spiroindol class and was registered for sheep in 2012 in Great Britain in the form of a combination with abamectin (Epe and Kaminsky 2013). Monepantel and derquantel are unavailable for goats.

Goats have specific pharmacological parameters regarding anthelmintics (Lespine et al. 2012). They generally have higher metabolisation capacities compared to sheep or cattle; this leads to higher elimination and consequently to lower exposure of the parasites to the anthelmintics.

Anthelmintics play a central and at times exclusive role in controlling goat nematodes. This has resulted in an overuse which may have had consequences in terms of anthelmintic resistance.

16.3 Anthelmintic Resistance

16.3.1 What Is Anthelmintic Resistance?

For a given population, resistance is the existence of a larger proportion of parasites able to survive a given exposure to an anthelmintic compared to a normal reference population. This characteristic is heritable. For an anthelmintic, one conventionally speaks of resistance when the reduction related to a treatment (faecal egg count or necropsy exam) is under 95% (Coles et al. 1992).

Within a parasite population that has not been previously selected by an anthelmintic, a tiny but not nil proportion of worms has the genetic ability to resist this anthelmintic (preadaptive phenomenon). The genetic diversity of nematode populations explains this pre-existence of resistant populations with a likely very low allele frequency. Resistance develops within a parasite population when the allele frequency of one or several resistance genes increases and leads to a reduced efficacy of the treatment compared to what is normally observed. Genotypic resistance (increase in the resistance allele frequency) evolves slowly and silently until, after reaching a certain allele frequency threshold, phenotypic resistance (reduced efficacy of the anthelmintic) brutally manifests itself (Kaplan and Vidyashankar 2012).

Anthelmintic resistance must be distinguished from the situation where worms naturally tolerate a given anthelmintic (for example, the ineffectiveness of levamisole against whipworms). It must also be distinguished from the general meaning of 'inefficacy'. Four causes of inefficacy have to be considered: (i) misdiagnosis; (ii) poor compliance of drug use, especially under-dosing; (iii) poor drug quality; and (iv) modified pharmacology of anthelmintic due to the way of administration, to the diet, to the level of parasitism and to body condition (Paraud and Chartier 2015).

Several mechanisms involved in resistance have been described. Some of them are specific (involving the target of the molecule), other ones are non-specific (detoxification) (Wolstenholme et al. 2004). Current scientific evidence about these phenomena is not consolidated in particular for the MLs where they are constantly evolving, which is notably the reason for the deficit of routine molecular diagnostic tools.

16.3.2 Factors Influencing Selection Pressure for Resistance

Several risk factors were identified in sheep and goats by Silvestre et al. (2002) and confirmed by Falzon et al. (2014a) by a meta-analysis:

- Indiscriminate and/or excessive use of anthelmintics;
- Under-dosing: this was experimentally demonstrated as a factor of selection of resistant populations of *Teladorsagia circumcincta* to BZD in sheep by Silvestre et al. (2001);
- Variability in pharmacokinetics and efficacy of ML: studies on ivermectin, eprinomectin and moxidectin formulations (oral, subcutaneous and pour on) have shown variability in bioavailability and efficacy in connection with variability in absorption (Lespine et al. 2012). This variability in parasite exposure to the drug, particularly when underexposed, could occur notably with pour on formulation and could result in an increased resistance selection process;
- Lack of nematode populations *in refugia* at the time of treatment. The population *in refugia* is defined as the parasite population (worms or infective larvae) unexposed to the anthelmintic and thus unselected during treatment; they thereby contribute to maintaining susceptibility alleles in the population. The use of *refugia* is a key component of sustainable treatment programs by limiting the selection pressure and thus slowing down the emergence of resistant populations (van Wyk 2001). There are three sources of refuge: infective larvae on pastures, worms in untreated animals, or inhibited stages (for the anthelmintics which do not affect these stages). With regard to infective larvae, refuge will be weak in all situations where pasture infectivity is low (e.g. end of winter, drought, resting plots, new pastures in temperate areas, etc.);
- Lack of effective quarantine anthelmintic treatments: as quarantine procedures and associated anthelmintic treatments are poorly practiced, the probability of buying animals carrying resistant worms is high. An example is given by Schnyder et al. (2005) in Switzerland with the importation of Boer goats from South Africa and the concurrent introduction of resistant strongyles.

In addition to the previous risk factors, the development of resistant populations depends on numerous factors associated with the parasite's biology (Churcher et al. 2010): biology (fecundity) and epidemiology of the nematode species, natural frequency of resistance genes in an unselected population, resistance genetics (mono, multigenic; recessive or dominant character, etc.). The issue of the fitness (biotic potential) of resistant versus susceptible worms is still open to debate although the hypothesis of a decreased fitness of resistant worms is not supported by evidence (Elard et al. 1998). In the absence of the anthelmintic, a resistant parasite population does not seem to return to susceptibility, although one case of reversion was recently described in sheep (Leathwick et al. 2015).

16.3.3 Detection of Anthelmintic Resistance

The methods to detect anthelmintic resistance were the subject of a reference publication in 1992 (Coles et al. 1992) and were amended in 2006 (Coles et al. 2006).

The main detection technique remains today the post-treatment Faecal Egg Count Reduction Test (FECRT); it can be used with all anthelmintics and is based on counting nematode eggs in faeces (eggs per gram of faeces) before and after treatment, with interval following treatment varying depending on the anthelmintic (e.g. 7–10 days for levamisole, 14 days for benzimidazoles and 16–17 days for ML). Several criteria need to be considered to obtain a reliable estimation of resistance with this test and are level of egg excretion, number of animals per group, sensitivity of the coproscopical method, among others (Levecke et al. 2012). Several calculation methods have been proposed, which can lead to different conclusions regarding resistance (Falzon et al. 2014b).

The necropsy examination test following an experimental infection and anthelmintic treatment could be considered as the reference method to use in confirmation and research studies but is quite expensive and incompatible with field surveys.

In vitro tests have also been described, including the egg hatch test, indicated only for benzimidazoles (ovicidal activity), and larval tests (larval development or motility) for the two other anthelmintic families (Demeler et al. 2012).

Lastly, PCR techniques have been published for benzimidazoles but molecular techniques remain in the domain of research and cannot be used for the routine diagnosis of resistance (Kaplan and Vidyashankar 2012).

16.3.4 Cost of Anthelmintic Resistance

Anthelmintic resistance is nearly undetectable by owners without doing faecal egg counts, unless the percentage of resistant adults in the parasitic population reaches very high levels. But even invisible, anthelmintic resistance has economic consequences. This was demonstrated in sheep by Sutherland et al. (2010). These authors compared weight gains of lambs treated with an anthelmintic fully efficient and weight gains of lambs treated with an anthelminthic showing efficacy from 40 to 50% and reported significant weight losses due to anthelmintic resistance. No similar experiment has been conducted in goats.

16.3.5 Epidemiology of Anthelmintic Resistance

Anthelmintic resistance in gastrointestinal strongyles in goats was first described in Australia and in France in the 1980s (Barton et al. 1985; Kerbœuf and Hubert 1985). These authors described strains of *Teladorsagia* and *Trichostrongylus* resistant to benzimidazoles in goat farms. Since then, resistance descriptions have been reported from all over the world, wherever there are goats raised on pasture, whatever the environmental conditions (humid, arid or semi-arid, highland or lowland) (Tables 16.1, 16.2, 16.3 and 16.4). Resistance has been reported in meat, fiber and dairy goats. The mainly involved genuses are *Haemonchus* in tropical and

Table 16.1 Anthelmintic resistance cases described in goats in Asia and Oceania (SCOPUS® search 'Goat' AND 'Anthelmintic resistance', 31/07/2017)

Country	Main anthelmintics	Main genus	References
India	BZD > LEV > AVM	Haem > Tricho	Ghalsasi et al. (2012) Singh et al. (2013) Jaiswal et al. (2013) Rialch et al. (2013) Arunachalam et al. (2015) Chandra et al. (2015) Kumar and Kumar (2015) Manikkavasagan et al. (2015) Rialch et al. (2015) Gelot et al. (2016) Singh et al. (2017)
Malaysia	Cases of multi-resistance BZD-LEV-ML	Haem > Tricho	Rahman (1994) Chandrawathani et al. (1999), (2004) and (2013) Abubakar et al. (2015)
Pakistan	BZD > LEV	Haem—Tricho	Saeed et al. (2007) and (2010) Jabbar et al. (2008) Muhammad et al. (2015)
Philippines	BZD	Haem	Venturina et al. (2003) Ancheta et al. (2004)
Australia	BZD, LEV	Tela, Tricho, Haem	Barton et al. (1985)
New Zealand	ML—monepantel	Tela/Tricho	Leathwick (1995) Scott et al. (2013)

BZD benzimidazoles; *LEV* levamisole; *AVM* avermectins; *ML* macrocyclic lactones
Haem Haemonchus contortus; *Tricho Trichostrongylus* spp.; *Tela Teladorsagia* spp.

subtropical countries and *Teladorsagia* and *Trichostrongylus* in temperate regions. All anthelmintic families are concerned even the last launched, monepantel (Scott et al. 2013). Moreover, multi-resistance (involving two or more anthelmintic families) is regularly described.

When evolution along time is considered, the situation regarding resistance becomes usually worst with years. Mahieu et al. (2014) reported that in Guadeloupe (French West Indies) goat farms, resistance progressed from a single benzimidazoles resistance to a double benzimidazoles plus MLs resistance in 15 years.

Table 16.2 Anthelmintic resistance cases described in goats in South and North America (SCOPUS® search 'Goat' AND 'Anthelmintic resistance', 31/07/2017)

Country	Main anthelmintics	Main genus	References
Brazil	Cases of multi-resistance BZD-LEV-ML-closantel	Haem > Tricho, Oeso	Vieira and Cavalcante (1999) Lima et al. (2010) Nunes et al. (2013) Bichuette et al. (2015) Borges et al. (2015)
Guadeloupe (French West Indies)	BZD (1997), BZD-AVM-LEV (2014)	Haem > Tricho	Barré et al. (1997) Mahieu et al. (2014)
Mexico	BZD	Haem	Torres-Acosta et al. (2005)
United States of America	Cases of multi-resistance BZD-LEV-ML since the 90s	Haem > Tricho	Craig and Miller (1990) Miller and Craig (1996) Zajac and Gipson (2000) Terrill et al. (2001) Mortensen et al. (2003) Kaplan et al. (2007) Howell et al. (2008) Crook et al. (2016) Goolsby et al. (2017)

BZD benzimidazoles; *LEV* levamisole; *AVM* avermectins; *ML* macrocyclic lactones
Haem Haemonchus contortus; *Tricho Trichostrongylus* spp.; *Tela Teladorsagia* spp.; *Oeso Oesophagostomum* spp.

16.4 How to Delay the Development of Resistance in Goat Farming?

Several methods have been proposed to prevent the development and spreading of anthelmintic resistance (Hoste and Torres-Acosta 2011; Kearney et al. 2016). They are based on three principles: (i) combining better use of anthelmintics and use of

Table 16.3 Anthelmintic resistance cases described in goats in Africa (SCOPUS® search 'Goat' AND 'Anthelmintic resistance', 31/07/2017)

Country	Main anthelmintics	Main genus	References
Ethiopia	Multi-resistance (2006 et 2009) Tetramisole (2010)	Haem	Sissay et al. (2006) Kumsa and Abebe (2009) Kumsa et al. (2010)
Kenya	LEV	Haem	Wanyangu et al. (1996) Waruiru et al. (2003) Mungube et al. (2015)
Nigeria	Suspicion with ML and LEV	Haem, Tricho, Oeso	Adediran and Uwalaka (2015)
South Africa	BZD, closantel, ML, LEV	Haem > Tricho	Bakunzi (2003) Tsotetsi et al. (2013) Bakunzi et al. (2013)
Uganda	ML, LEV, BZD	Haem	Byaruhanga and Okwee-Acai (2013) Nabukenya et al. (2014)

BZD benzimidazoles; *LEV* levamisole; *AVM* avermectins; *ML* macrocyclic lactones
Haem Haemonchus contortus; Tricho Trichostrongylus spp.; *Tela Teladorsagia* spp.; *Oeso Oesophagostomum* spp.

natural dewormers to reduce the worm population's burden; (ii) to reinforce immunity of the host; and (iii) to avoid contact between the third stage larvae and their hosts. These strategies have to be combined in an integrated management system.

16.4.1 Better Use of Anthelmintics

First, better use of anthelmintic means to avoid all the factors of anthelmintic resistance selection previously described: avoid under-dosing, reduce the number of annual treatments, prevent introduction of resistant strongyles and preserve *refugia* when treating.

One way of preserving *refugia* to delay the apparition of resistance is to use selective anthelmintic treatment. This strategy is based on the fact that strongyle infection is overdispersed in a flock, with most animals being slightly infected and few animals being heavily infected (Hoste et al. 2002b), the latter being the only ones needing treatment. The *refugia* will be determined by the untreated goats. Mathematical models have shown that a low to very low percentage of untreated animals (sometimes less than 5%) may be enough to significantly reduce selection pressure (Leathwick and Besier 2014). However, other results indicated a much higher percentage of untreated animals (70–80%) necessary to act as effective *refugia* (Gaba et al. 2010). Interestingly, according to the models of Leathwick et al. (2008), the size of successful refugia is linked to the proportion of resistant worm in

Table 16.4 Anthelmintic resistance cases described in goats in Europe (SCOPUS® search 'Goat' AND 'Anthelmintic resistance", 31/07/2017)

Country	Main anthelmintics	Main genus	References
Denmark	BZD, LEV, ML	Haem, Tricho	Maingi et al. (1996) Holm et al. (2014) Peña-Espinoza et al. (2014)
France	BZD > LEV	Tela/Tricho > Haem	Kerbœuf and Hubert (1985) Kerbœuf et al. (1988) Hubert et al. (1991) Beugnet (1992) Chartier and Pors (1994) Cabaret et al. (1995) Chartier et al. (1998) and (2001) Paraud et al. (2009)
Germany	BZD	Haem, Tela/Tricho	Bauer (2001)
Greece	BZD	Tela	Papadopoulos et al. (2001)
Italy	BZD, ML	Tricho, Tela	Cringoli et al. (2007) Zanzani et al. (2014)
Netherlands	BZD, ML	Haem, Tricho, Tela, *Cooperia* spp.	Borgsteede et al. (1996) Eysker et al. (2006)
Norway	BZD	Tela/Tricho, Haem	Domke et al. (2012)
Switzerland	ML, BZD	Haem, Tela/Tricho	Schnyder et al. (2005) Artho et al. (2007) Scheuerle et al. (2009) Murri et al. (2014)
Slovakia	BZD		Čorba et al. (2002)
Spain	BZD	Tela, Haem	Calvete et al. (2014) Requejo-Fernández et al. (1997)
United Kingdom	BZD, LEV	Haem, Tela/Tricho	Hong et al. (1996)

BZD benzimidazoles; *LEV* levamisole; *ML* macrocyclic lactones
Haem Haemonchus contortus; *Tricho Trichostrongylus* spp.; *Tela Teladorsagia* spp.; *Oeso Oesophagostomum* spp.

the population: when the resistance allele frequency is low, the percentage of animals to be left untreated can be reduced. For example, when allele frequency is 0.1%, keeping 1% of animals untreated could be enough whereas for allele frequency of 5%, the proportion of untreated animals should increase to 34%.

Several methods have been tested in goats to identify animals needing anthelmintic treatment in a flock: egg excretion counting, age (primiparous vs. multiparous), individual milk production, consistency of faeces, body condition scoring (BCS) (Fig. 16.1) and FAMACHA® method (Fig. 16.2).

Fig. 16.1 Body condition scoring (provided by the authors)

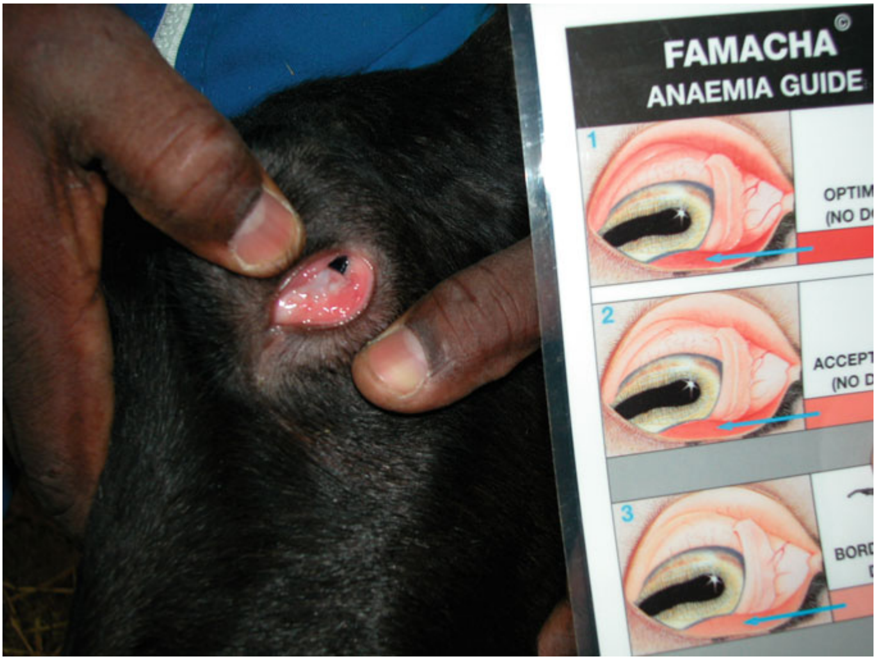

Fig. 16.2 FAMACHA® scoring (provided by the authors)

Individual egg excretion counting might be quickly excluded as it needs individual faecal sampling and individual laboratory analysis, which is not suitable for farmers (Gallidis et al. 2009).

Hoste et al. (2002a) compared the egg excretion, the milk production and the mean number of annual anthelmintic treatments between systematic (whole) treatment strategy and targeted selective treatment based on high-producing goats and primiparous goats. No difference was seen between the two strategies regarding mean egg excretion and mean milk production. The reduction of the number of treatments due to selective treatment was about 40%.

Gallidis et al. (2009) scored the body condition of adult dairy goats each 4 months for 1 year, treated only the goats presenting a bad condition score and evaluated the percentage of reduction of the number of treatments compared to the usual treatment scheme (all goats twice a year). This reduction of the number of treatments ranged from 37 to 83% according to the farm.

FAMACHA® method is a clinical indicator based on the evaluation of anaemia due to *Haemonchus contortus* (Fig. 16.3). It was initially developed for sheep in South Africa (Malan et al. 2001). Anaemia is measured at the lower eyelid and scored from 1 to 5 according to a chart (Fig. 16.2). Only animals that scored 3, 4 or 5 need to be treated. This method was tested and validated in goats in regions where *H. contortus* is the main strongyle species: Peru (Rendón et al. 2017), Brazil (Sotomaior et al. 2012; Vilela et al. 2012b), United States (Kaplan et al. 2004; Burke et al. 2007a), Nigeria (Idika et al. 2013), South Africa (Vatta et al. 2001; Sri Jeyakumar 2007), Uganda (Nabukenya et al. 2014) and Kenya (Ejlertsen et al. 2006). These last authors reported percentages of untreated goats higher than 77% after using the FAMACHA® chart in farm conditions. On the contrary, in temperate places where *H. contortus* is not dominant, the results of assays are less conclusive (Koopmann et al. 2006; Paraud et al. 2007b).

Combination of two nematocides is practiced on sheep in New Zealand and Australia and appears, through simulation models, to be more effective in slowing the development of resistance than alternating between two families (Leathwick

Fig. 16.3 *Haemonchus contortus* adults in abomasum (provided by the authors)

2012). This strategy is developed notably with the new molecules available for sheep. This approach remains nonetheless very theoretical and runs up against many practical difficulties.

16.4.2 Copper Oxide Wire Particles (COWP)

Administration of copper oxide wire particles (COWP) was evaluated as an alternative treatment to conventional anthelmintics. Chartier et al. (2000) reported that the curative or preventive administration of copper oxide needles to goats in both experimental and natural conditions reduced significantly the worm burden and the egg output of *H. contortus*. No significant effect was observed on intestinal species. These results were confirmed later by Burke et al. (2007b, 2010) and Vatta et al. (2009).

16.4.3 Natural Dewormers

Among natural dewormers, tannin-containing legumes have received a lot of attention. Three potential impacts of these tannin-containing legumes on the strongyle life cycle have been identified (Hoste et al. 2015): decrease of the establishment of infective larvae in the host; reduction of the female fertility and/or of the worm population, leading to a decrease of egg output; lower development of eggs into infective larvae. Two hypotheses exist regarding the mode of action: a direct action based on pharmacological-type of interactions between tannins and the parasitic stages or an indirect action by a possible improvement of host resistance via the nutritional effect of tannin-containing legumes (Hoste et al. 2015).

These legumes are qualified as nutraceuticals as they are considered as food while improving health. The healthy effect is obtained only after several days of distribution (Hoste et al. 2012).

Cultivated legumes can be distributed via direct grazing (Fig. 16.4), as hay or silage or as dehydrated pellets, so they need to be sufficiently palatable to be consumed by the goats. Tannin-containing legumes can also be part of native vegetation used to feed the animals (Brunet et al. 2008).

Several plants have shown anthelmintic properties in in vivo studies in small ruminants (Hoste et al. 2012): sulla (*Hedysarum coronarium*), big trefoil (*Lotus pedunculatus*), birdsfoot trefoil (*Lotus corniculatus*), sericea lespedeza (*Lespedeza cuneata*), sainfoin (*Onobrychris viciifolia*) and the tropical legume tree *Lysiloma latisiliquum*.

Sources of variability of the tannin content of the legumes and consequently of their anti-parasitic effect have been identified in small ruminants: type of legume, environmental conditions in which the legume is grown, technological processes

Fig. 16.4 Alpine goats at pasture (provided by the authors)

(fresh vs. hay, silage and pellet samples), parasitic species or stages, hosts (Hoste et al. 2012, 2015).

16.4.4 Action on the Host Immunity

The expression of immune response in goats and thus the ability to control challenge infections seem to be much lower compared to sheep, although this limitation does not always result in heavy infection, particularly when goats are raised on rangelands and are able to fulfil their browsing behavior (Hoste et al. 2010).

Immunity of the host can be enhanced in two ways, improvement of alimentation or vaccination.

The relationship between immunity towards gastrointestinal nematodes and alimentation was first explored in sheep and led to a theory of protein partitioning between maintenance/gain of body protein, acquisition/expression of immunity and production efforts (pregnancy or lactation) (Coop and Kyriazakis 1999). This framework was confirmed in goats in pens and in field studies reviewed by Hoste et al. (2008) and Torres-Acosta et al. (2012).

In French dairy goats, Etter et al. (1999) eliminated the periparturient rise of egg excretion by increasing the protein supply to 128 or 144% coverage of requirements. This was later confirmed under tropical conditions (Faye et al. 2003; Nnadi et al. 2009). These last authors showed that feeding high protein to West African Dwarf goats experimentally infected by *H. contortus*, from the day of mating to 6 weeks post-partum, significantly improved the BCS of the does and the birth weights of their kids.

In growing kids, positive effects of dietary supplementation were also demonstrated. In browsing Criollo kids, supplementation significantly improved packed cell volume, significantly reduced the length of *Trichostrongylus colubriformis* females and the number of eggs in utero of both *T. colubriformis* and *H. contortus* females compared to non-supplemented kids (Martínez Ortiz de Montellano et al. 2007). Bambou et al. (2011) reported a significant reduction of faecal egg count excretion and an improvement of packed cell volume in experimentally infected and supplemented Creole kids (whatever the level of supplementation) compared to infected non-supplemented kids.

As mentioned before, distribution of tannin-containing legumes may also improve immunity due to an improvement of the protein supply.

Attempts of vaccination in goats were mainly directed against *H. contortus*, with several proteins (Ruiz et al. 2004; Yanming et al. 2007; Sun et al. 2011; Han et al. 2012; Zhao et al. 2012; Yan et al. 2013; Meier et al. 2016) and generally concluded to a partial induced protection. A commercial vaccine against *H. contortus* was launched in 2014 in Australia for sheep, Barbervax®. This vaccine was tested in Anglo-Nubian and Saanen goats in Brazil by Matos et al. (2017). These authors reported a significant reduction of faecal egg outputs in the two breeds and a significant improvement of the packed cell volume (PCV) and of the total plasma proteins for Anglo-Nubian goats only.

16.4.5 Breeding for Resistance

Host resistance limits larvae installation and/or reproduction of the strongyles, which leads to a reduction of the contamination for the rest of the flock.

Several goat breeds, usually originating from tropical places, show natural resistance traits against gastrointestinal parasites, as reviewed by Zvinorova et al. (2016): Small East African goats, Jamunapari goats, Creole goats and West African Dwarf goats. However, little work has been done to take advantage of these genetic traits in breeding schemes.

On the contrary, breeding for resistance to strongyles in selected breeds has been extensively studied in sheep and is now integrated in selection schemes in Australia and New Zealand (Woolaston and Baker 1996) for a long time and, more recently, in France (Jacquiet et al. 2015). The selection of the most resistant animals is possible due to the genetic diversity among a flock. Selection is mostly based on phenotypic markers, like faecal egg counts. Genetic markers of resistance in goats are under research. For example, about ten quantitative trait loci (QTL) related to resistance, resilience and humoral response towards *H. contortus* infection have been identified in Creole goats (de la Chevrotière et al. 2012).

16.4.6 Grazing Management

Practising grazing management requires knowing numerous epidemiological data (Barger 2001), in particular survival rate of infective larvae and climatic requirements for egg hatching and larval development.

The strategies of grazing management can be classified as preventive strategies, i.e. putting worm-free animals on clean pastures, evasive strategies as removing animals before the pasture contamination becomes too high (rotational grazing) and diluting strategies, e.g. reducing the pasture contamination by grazing animals of different susceptibility together or alternatively (different ages or species) (Barger 1997).

These methods were rarely evaluated in experimental or natural conditions, whatever the ruminant species considered. Evasive strategies were evaluated in cattle by Eysker et al. (1998) and Larsson et al. (2007) and by Eysker et al. (2005) in sheep. In goats, Silva et al. (2011) compared the strongyle infections among goats raised under rotational grazing and feed supplementation and goats using a permanent pasture and regularly dewormed. They demonstrated that strongyle infections can be well controlled by the system of rotational grazing. In the tropics, as the survival of infective larvae on pasture is limited to 6–7 weeks (Aumont et al. 1996), this can be exploited through very effective pasture rotation strategies as demonstrated by Barger et al. (1994). Mathematical models were developed to predict the risk of larval contamination so that owners know when they have to move their animals to another pasture. These models take into account meteorological data, grazing management practices and anthelmintic treatment (Chauvin et al. 2015). These models were developed in cattle and need to be validated in goats.

A few studies demonstrated the benefits of mixed grazing between sheep and cattle (Mahieu 1997; Mahieu and Aumont 2009). In French goats, Doumenc et al. (2004) evaluated the effects of different levels of mixed grazing with cattle on the intensity and diversity of goat parasitism (no mixed grazing, occasional alternate grazing, or continuous mixed grazing). These authors reported that when the highest level of mixed grazing was used, the lowest *Teladorsagia* and *Trichostrongylus* burden were obtained. Marshall et al. (2012) confirmed these results with *H. contortus* in the south-eastern region of the United States.

In Guadeloupe (French West Indies), a combination of alternate grazing between goat and cattle and pasture rotation allowed a very effective control of GI nematodes infection in goats (Mahieu 2013).

16.4.7 Nematophagous Fungi

Nematophagous fungi have the capacity to trap and destroy infective larvae before they leave the faeces and can be used as a mean for biological control of gastrointestinal nematodes. One species has received a lot of attention, *Duddingtonia flagrans*. This net-trapping fungus produces thick wall chlamydospores and is able to survive passage through the gastrointestinal tract of ruminants (Larsen 2000).

D. flagrans, administered as spores to goats by oral route for several days, has demonstrated its ability to reduce the number of gastrointestinal nematode larvae of the main nematode species in goat faeces in laboratory or plot studies (Chartier and Pors 2003; Paraud and Chartier 2003; Waghorn et al. 2003; Terrill et al. 2004; Ojeda-Robertos et al. 2005; Paraud et al. 2005).

Efficacy of administration of *D. flagrans* to goats was also tested in field conditions. In most studies, *D. flagrans* was administered as spores, in the daily feeding of the kids or does. One study used a pellet formulation in a sodium alginate matrix (Vilela et al. 2012a). Some authors reported positive effects of the distribution of the spores (Wright et al. 2003; Gómez-Rincón et al. 2007; Sanyal et al. 2008; Vilela et al. 2012a), while other studies showed inconstant or inconclusive results (Maingi et al. 2006; Paraud et al. 2007a; Epe et al. 2009).

D. flagrans spores are commercialised as a feed additive in Australia (BioWorma®, International Animal Health Products PTY LTD).

16.4.8 Integrated Parasitism Management

None of the methods previously described is sufficient on their own to control the gastrointestinal parasitism. Integrated approaches, based on a combination of different methods, targeting different parasite stages, with different ways of action, are needed (Hoste and Torres-Acosta 2011). Different combinations have already been tested in goats: supplementary feeding and COWP (Martínez Ortiz de Montellano et al. 2007), resistant host and supplementary feeding (Bambou et al. 2011), targeted selective treatment using FAMACHA® method and COWP (Spickett et al. 2012).

Goat owners will have to move from a simple option (anthelmintic treatment) to a wider range of options. These options should be practical, affordable, available and appropriate to be adopted by the farmers (Krecek and Waller 2006). Uptake of alternative methods can be difficult as underlined by Besier and Love (2012). This point has been considered by several authors. In the United States, Terrill et al. (2012) reported that FAMACHA® method was the most easily adopted by sheep and goat farmers; in a smaller proportion, farmers also used grazing management and genetic selection. In the same way, Walker et al. (2015) tested uptake of targeted selective treatment based on several criteria in resource-poor goat farms sharing communal pastures in Botswana. They demonstrated that engaged and formed farmers can use targeted selective treatment and save anthelmintic treatment while improving the health of their goats.

16.5 Conclusions

For the past 30 years, anthelmintics have represented an increasingly powerful therapeutic arsenal which has become more and more adapted to the requirements of veterinarians and farmers. We have now reached a point where this system must be rethought in terms of a dual objective, a quest for production performance but, at the same time, a reduced selection pressure and less development of resistant parasites. The adoption of integrated approaches including a rationalised use of anthelmintics by targeting animals which need to be treated and the use of the alternative methods to chemical products is required.

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Chapter 17
Haemoparasitism of Goats and Sheep

Snorre Stuen

Abstract Haemoparasites of goats and sheep occur worldwide and are transmitted by vectors, especially ticks and tsetse flies. Several of these parasites have a significant impact on the development of the small ruminant industry. However, only scattered information is available on haemoparasitism of small ruminants. In addition, climate change and transport of vectors/pathogens between geographical areas will have an impact on the distribution. Active surveillance is necessary to obtain reliable maps concerning establishment of both vectors and pathogens. Moreover, new pathogens in small ruminants will be revealed in the future and perhaps become more abundant. Management of these infections should include integrated control strategies, such as host and breed resistance to the vectors and their pathogens, vector control and the use of available vaccines against vectors and vector-borne infections. The present chapter focus on the following haemoparasites: *Anaplasma ovis*, *A. phagocytophilum*, *Babesia ovis/motasi, Ehrlichia ruminantium, Theileria* spp. and *Trypanosoma* spp.

17.1 Introduction

In recent years, a series of vector-borne diseases have emerged and spread across the world. Several of these diseases are caused by haemoparasites, transported mainly by ticks and biting flies. Climate change will affect the distribution of vector and pathogen populations (Shope 1991; Geiger et al. 2015), and for instance, several tick species may establish more northern populations according to climate-warming models (Gray et al. 2009). In addition, migrating birds may each year transport millions of ticks to new geographical areas (Jaensson et al. 2012).

Ticks in the genera *Amblyomma*, *Haemaphysalis, Hyalomma* and *Rhipicephalus* are frequently associated with small ruminants, but also ticks in the genera

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Dermacentor and *Ixodes* are important vectors (Liebisch 1997). On small ruminants in Europe, more than 12 species have been observed, whereas the main species are *Dermacentor marginatus* ('the ornate sheep tick'), *Haemaphysalis punctata* ('the red sheep tick'), *Ixodes ricinus* ('the sheep tick') and *Rhipicephalus bursa* (Estrada-Peña et al. 2004; Stuen 2016). Several ticks may infest small ruminants on other continents; however, only scattered information on their distribution is available.

Important vectors of haemoparasites are also tsetse flies, *Glossina* spp., in sub-Saharan Africa transporting parasites in the genus *Trypanosoma*. More than 31 species or subspecies of tsetse flies have been identified, whereas 8–10 species are considered of economic importance (Vreysen et al. 2013). Transmission of trypanosomes may however also involve other biting flies, especially outside Africa (Smith and Sherman 2009).

New technologies have identified variants/strains of already well-known microbes, which challenge earlier identification and characterization. In addition, 'new pathogens' have recent years been detected in small ruminants (Loftis et al. 2006; Zobba et al. 2014; Li et al. 2015). The epidemiological consequences of these findings are unknown. The present chapter will focus on the following haemoparasites: *Anaplasma ovis*, *A. phagocytophilum*, *Babesia ovis/motasi, Ehrlichia ruminantium*, *Theileria* spp. and *Trypanosoma* spp.

17.2 Anaplasmosis

17.2.1 Pathogen

Anaplasmosis in small ruminants is due to the rickettsia *A. ovis*. *A. mesaeterum*, a similar organism, may also be involved. These bacteria are obligate microbes of erythrocytes (Uilenberg et al. 1979; Dumler et al. 2001).

17.2.2 Distribution

Anaplasmosis is a widespread tick-borne disease in small ruminants in Southern and Central Europe, but is also endemic in tropical and subtropical Africa, Asia and in the western US (Friedhoff 1997; Woldehiwet 2007). *A. mesaeterum* has so far only been reported in the Netherlands. Several tick species are involved particularly in the genera *Rhipicephalus* and *Dermacentor*, in Europe and in the US mainly by *R. bursa* and *D. andersoni,* respectively (Friedhoff 1997; Renneker et al. 2013) (Table 17.1). Since subclinical infection with *A. ovis* is common, only an active surveillance will reveal the distribution (Renneker et al. 2013).

Table 17.1 Haemoparasites detected in small ruminants, possible vectors and continent of appearance

Genus	Species	Vector	Continent
Anaplasma	'*A. capra*'	*Ha. longicornis*; *I. persulcatus*	As
	A. bovis	*Amblyomma* spp.; *Hyalomma* sp.; *Rhipicephalus* sp.	Af, As
	A. ovis	*Rhipicephalus* spp.; *R. bursa; Dermacentor* spp.; *Haemaphysalis* spp.	Af, As, Eu, NA
	A. phagocytophilum	*Ixodes* spp.; *I. persulcatus*; *I. ricinus*; *I. scapularis*; *Dermacentor* spp.; *Haemaphysalis* spp.; *Rhipicephalus* spp.	Af, As, Eu, NA
	A. platys	*Rhipicephalus* spp.; *R. sanguineus*	Af, As, Eu
Babesia	*B. crassa*	*Hyalomma* sp.; *Rhipicephalus* spp.	As
	B. motasi	*Haemaphysalis* spp.; *Ha. punctata*; *I. persulcatus*; *D. silvarum*; *Rhipicephalus* spp.	Af, As, Eu
	B. ovis	*R. bursa*; *R. sanguineus*; *R. turanicus*; *I. ricinus*; *I. persulcatus*; *D. reticulatus*; *Hyalomma* spp.	Af, As, Eu
	B. sp. Xinjiang	*Hy anatolicum*; *Ha. longicornis*; *Ha qinghaiensis*	As
Ehrlichia	*E. chaffeensis*	*Am. americanum*	NA
	E. ewingii	*Am. americanum*; *D. variabilis*; *R. sanguineus*	NA
	E. ruminantium	*Amblyomma* spp.; *Am. variegatum*; *Am. hebraeum*	Af, CA
	Panola Mountain Ehrlichia	*Am. americanum*; *Am. maculatum*; *Am. variegatum*	NA
Mycoplasma	*M. ovis*	Biting insects; *Stomoxys calcitrans*; *Melophagus ovinus*	Worldwide
Rickettsia	*R. conorii*	*R. sanguineus*	Eu, Af, As
Theileria	*T. annulata*	*Hyalomma* spp.	Eu, Af, As
	T. lestoquardi (hirci)	*Hy. anatolicum*; *Ha. qinghaiensis*; *R. bursa*	Eu, Af, As
	T. luwenshuni	*Haemaphysalis* spp.	As, Eu
	T. ovis	*Rhipicephalus* spp.; *Rh. bursa*; *Rh. evertsi*; *Hy. anatolicum*	Af, As, Eu
	T. OT1	*Ha. punctata*; *I. ricinus*; *D. reticulatus*	As, Eu
	T. OT3	*Ha. punctata*	As, Eu
	T. recondita	*Ha. punctata*	Eu
	T. separata	*Rh. evertsi*	As
	T. uilenbergi	*Haemaphysalis* spp.	As
	Theileria sp. MK	Unknown	As

(continued)

Table 17.1 (continued)

Genus	Species	Vector	Continent
Trypanosoma	*T. brucei brucei*	*Glossina* spp.	Af
	T. equiperdum	Venereal	Af, As, CA, Eu, SA
	T. evansi	Biting flies	Af, As, SA
	T. cruzi	Blood sucking bugs	Af, As, CA, SA
	T. congolense	*Glossina* spp.	Af
	T. gambiense	*Glossina* spp.; other flies	Af
	T. melophagium	*Glossina* spp.	Af, As, NA, Eu SA
	T. rhodesiense	*Glossina* spp.; other flies	Af
	T. simiae	*Glossina* spp.; *Stomoxys* spp.; *Tabanus* spp.	Af
	T. theodori	*Lipoptena caprina*	Israel
	T. uniforme	*Glossina* spp.	Af
	T. vivax	*Glossina* spp.; biting flies	Af, SA

Af Africa; *As* Asia; *Eu* Europe; *CA* Central America; *NA* North America; *SA* South America
I Ixodes; *R* Rhipicephalus; *D* Dermacentor; *Ha* Haemaphysalis; *Hy* Hyalomma; *Am* Amblyomma
Mainly based on Preston (2001), Gutierrez et al. (2006), Smith and Sherman (2009), Taylor et al. (2016)

17.2.3 Clinics

A. ovis may cause haemolytic anaemia in small ruminants. However, anaplasmosis in sheep and goats is normally subclinical. Outbreaks of severe illness in sheep are rare and occur mainly under extreme conditions (Friedhoff 1997). Clinical cases in goats have been observed during nutritional stress (Ilemobade 1982). Goats seem to be more affected than sheep; however, this may be due to strains/variants of *A. ovis* involved or different breed susceptibility (de la Fuente et al. 2007; Smith and Sherman 2009). Abortion outbreaks in Boer goats have been recorded (Barry and Van-Niekerk 1990). Other clinical signs are fever, anorexia, depression, weakness and dyspnea. Icterus may be present in severe cases, but haemoglobinuria is uncommon (Smith and Sherman 2009). Clinical signs may depend on several factors involving weather, body condition, tick infestations and co-infections (Torina et al. 2010; Renneker et al. 2013). Infection with *A. ovis* may predispose animals to other infections and parasite infestation resulting in clinical disease or even death and may have an impact on health, milk and meat production (Ndungu et al. 1995). Anaplasmosis in small ruminants should therefore not be neglected (Kocan et al. 2004; Renneker et al. 2013).

In utero transmission of *A. ovis* has been observed with anaemia and death of the foetus (Barry and Van-Niekerk 1990). In addition, the pathogen has been detected from milk of both species; however, the importance of this transmission pathway has to be further elucidated (Zhang et al. 2016a). Besides ticks, *A. ovis* may also be transmitted by other vectors including *Melophagus ovinus* (Hornok et al. 2011; Renneker et al. 2013). Human infection has recently been reported (Chochlakis et al. 2010).

17.2.4 Diagnosis

In early infection, light microscopy of stained blood smears can detect the organisms on erythrocytes (Dumler et al. 2001). However due to low bacteraemia, PCR and gene sequencing should be performed in order to verify an *A. ovis* infection (Palmer et al. 1998). Several serological tests are available, involving ELISA and the capillary tube agglutination (Mallick et al. 1979; Ndungu et al. 1995). At post-mortem, icteric tissues, enlarged liver and increasing amount of body cavity fluid have been reported (Smith and Sherman 2009).

17.2.5 Treatment and Control

Treatment should be applied during bacteraemia in order to reduce the degree of infection (Smith and Sherman 2009). Oxytetracycline or tetracycline hydrochloride has successfully been applied to treat diseased goats. However, 5 day treatment was not enough to clear the organisms from the peripheral blood (Smith and Sherman 2009).

Prophylactic tick control should involve dipping, spraying or pour-on treatment. A vaccine against *A. ovis* is not available. In order to prevent disease outbreak, the use of prophylactic antibiotics has been suggested. However, consequences for antibiotic/pesticide resistance and human/animal health make these treatments questionable (Smith and Sherman 2009; Stuen 2016).

17.3 Tick-Borne Fever

17.3.1 Pathogen

Tick-borne fever (TBF) is caused by the rickettsia *A. phagocytophilum* (formerly *Ehrlichia phagocytophila*) (Dumler et al. 2001). Several strain/variants of *A. phagocytophilum* have been reported, also within the same flock (Ladbury et al. 2008).

17.3.2 Distribution

The infection has earlier been associated with *Ixodes* spp. ticks, but has been detected in other tick species, such as *D. marginatus*, *H. punctata, Hyalomma marginatum, R. bursa* and *R. sanguineus. A. phagocytophilum* infection in *I. ricinus* ticks is widespread in Europe, while only scattered information is available from other continents, such as Northern Africa, Asia and the US (Table 17.1). Only few cases of *A. phagocytophilum* infection in goats have been reported.

17.3.3 Clinics

TBF may cause severe economic and welfare challenges in the sheep industry in Europe. The most characteristic symptoms of the disease in domestic ruminants are high fever (up to 42 °C or more), inclusions in neutrophils and severe neutropenia, although clinical signs may vary according to the age of the animals, breed, variant of *A. phagocytophilum* involved, host species and immunological status of the host (Stuen and Longbottom 2010). Other clinical signs are often absent or mild; a few days of coughing, reduced appetite and dullness may occur. However, high mortality, especially in pregnant ewes, has been observed (Stuen 2003). Only scattered information exists about infected goats (van Miert et al. 1984; Smith and Sherman 2009). Although an experimental trial indicates a difference in clinical response between goat and sheep to an *A. phagocytophilum* infection (Gokce and Woldehiwet 1999), more studies are needed to verify this observation.

TBF causes immunosuppression in sheep. Infected animals may, therefore, be vulnerable to secondary infections, for example, tick pyaemia (caused by *Staphylococcus* spp.) or *Bibersteinia*/*Mannheimia* septicaemia (Foggie 1951; Stuen and Longbottom 2010). In contrast, secondary bacterial infections are not a significant part in the reported outbreaks of caprine TBF (Smith and Sherman 2009).

TBF may also cause abortion, reduced milk yield, impaired spermatogenesis and reduced weight gain. As already mentioned, genetic variants of *A. phagocytophilum* exist with different clinical manifestation and a variable degree of cross-protective immunity (Ladbury et al. 2008; Silaghi et al. 2011; Stuen et al. 2013b; Yang et al. 2016).

The pathogen has recently been detected from milk of infected goats (Zhang et al. 2016a). In addition, intrauterine transmission in sheep may occur during the acute and persistent phase of the infection (Reppert et al. 2013; Stuen unpublished results); however, the importance of these transmission pathways has to be further elucidated. In addition, strains/variants of *A. phagocytophilum* may cause severe human disease called human granulocytic anaplasmosis (Bakken and Dumler 2015).

17.3.4 Diagnosis

Microscopy of blood smears taken during the fever period is normally sufficient to confirm the diagnosis. Stained with May-Grünwald Giemsa, the organisms appear as light-blue inclusions (Figs. 17.1 and 17.2). PCR is also commonly used to identify the organism in blood or tissue samples, both in the acute and persistent phase of the infection. Serology, such as an indirect immunofluorescent antibody (IFA) test is also available. At *post-mortem*, an enlarged spleen, up to four to five times the normal size, is an indication of an acute *A. phagocytophilum* infection (Stuen 2003).

17.3.5 Treatment and Control

Control strategies involve reduction of tick infestation on pasture. This is normally based on acaricide treatment by dipping or pour-on applications of pyrethroids (Woldehiwet and Scott 1993; Stuen 2003). Acute infection could be treated with oxytetracycline, for instance, in goat with 10 mg/kg intravenous treatment (Anika et al. 1986). However, a 5-day oxytetracycline treatment in lambs did not clear the organism from the peripheral blood (Stuen 2003). Long-acting tetracycline may be used prophylactically before animals are moved to tick areas (Brodie et al. 1988;

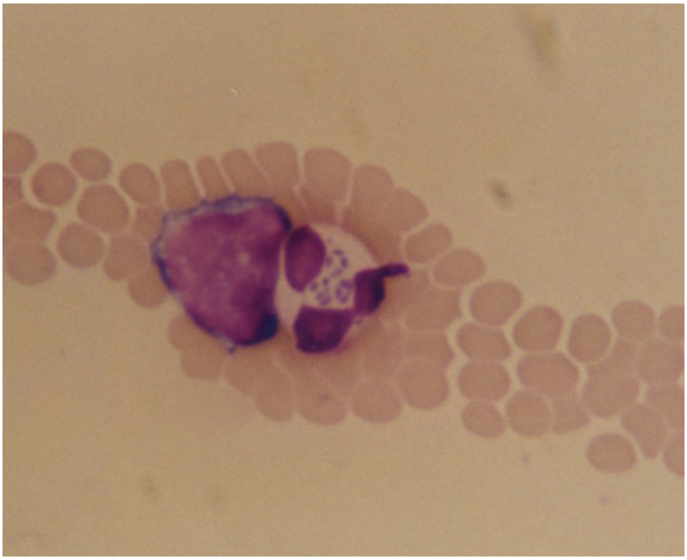

Fig. 17.1 Light microscopy of a May-Grünwald Giemsa-stained blood smear (sheep) including cytoplasmatic *Anaplasma phagocytophilum* inclusions (morulae) with basophilic appearance in a neutrophil granulocyte (×1000). Similar observation can be made in goats (provided by S. Stuen)

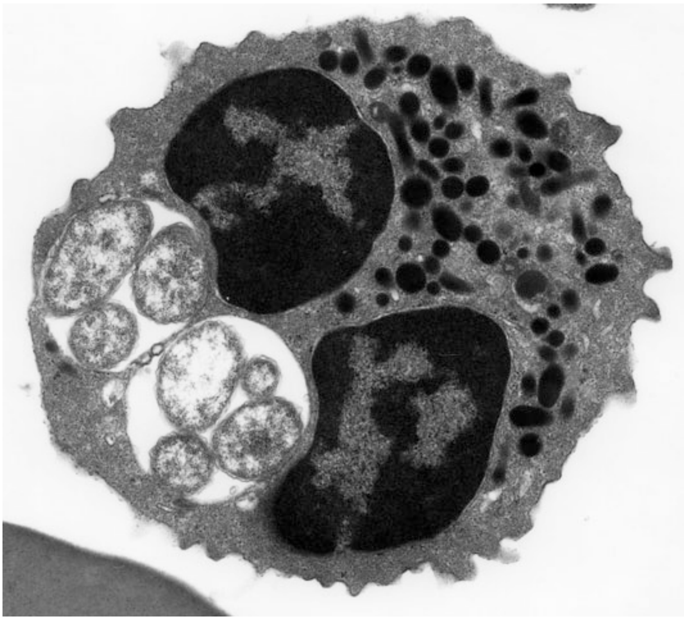

Fig. 17.2 Electron microscopy of an *Anaplasma phagocytophilum* infected neutrophil granulocyte (sheep). Two vacuoles (phagolysosomes) with bacteria are clearly visible in the cytoplasm (×31,500). Similar observation can be made in goats (provided courtesy of V. Popov)

Woldehiwet 2007). However, there is a growing concern about antimicrobial/acaricide resistance and animal/human health when applying these procedures (Samish et al. 2004).

Another strategy to reduce losses is to infect lambs as early as possible, since lambs younger than 2 weeks of age seems to be more protected than older lambs. If possible, newborn lambs should be infected, especially since 3- to 6-week old lambs are very vulnerable to *A. phagocytophilum* (Stuen 2003). No information concerning age-related resistance has been obtained from goats.

A vaccine against *A. phagocytophilum* is not yet available. In order to develop a vaccine, the challenge is to choose the right antigens that are conserved among all variants, especially since the antigenic variation of the bacterial surface proteins occurs during the infection period (Stuen et al. 2013b).

Strains/variants of *A. phagocytophilum* may cause different natural enzootic cycles (Bown et al. 2009; Scharf et al. 2011; Jahfari et al. 2014). The epidemiology of variants isolated from small ruminants is unknown. According to earlier studies, red deer (*Cervus elaphus*) may act as host for variants of *A. phagocytophilum* known to cause TBF in sheep (Stuen et al. 2013a).

Since the bacteria may cause persistent infections in sheep for a long period, *A. phagocytophilum* can be carried to new areas by purchasing animals (Foggie 1951; Stuen 2003; Stuen et al. 2013b).

17.4 Babesiosis

17.4.1 Pathogen

Babesiosis is caused by protozoa in the genus *Babesia*. The main species involved are *B. ovis*, *B. motasi* and *B. crassa,* whereas *B. motasi* is the dominant species in goats (Smith and Sherman 2009). Other *Babesia* spp. involving other hosts have occasionally been detected in small ruminants (Schnittger et al. 2012). However, the situation regarding several *Babesia* spp. isolates is confusing and includes unclassified subspecies/species, such as, for instance, *Babesia* sp. Xinjiang (Niu et al. 2016; Schreeg et al. 2016; Ozubek and Aktas 2017).

17.4.2 Distribution

The most pathogenic species is *B. ovis* (small species), with a worldwide distribution (Friedhoff 1997) (Table 17.1). *Rhipicephalus* ticks, such as *R. bursa*, *R. sanguineus* and *R. turanicus*, have been implemented in the transmission of *B. ovis*, whereas *R. bursa* may transmit *B. ovis* transovarially (Esmaeilnejad et al. 2014). Other tick species such as *I. ricinus*, *I. persulcatus, Hyalomma marginatum, H. parva* and *Dermacentor reticulatus* may occasionally be involved in the transmission cycle (Aydin et al. 2015; Taylor et al. 2016; Stuen 2016).

In contrast to *B. ovis*, *B. motasi* (large species) is normally less pathogenic. This species is associated with the tick *H. punctata*, although other ticks in the genus *Haemaphysalis* may be involved (Smith and Sherman 2009). Several phylogenetic groups occur within this species which needs further characterization (Niu et al. 2016). *B. motasi*- and *B. motasi*-like parasites have been detected in several countries in Europe, Central and Northern Africa, Asia and Central America (Friedhoff 1997; Woldehiwet 2007; Ros-Garcia et al. 2013; Ozubek and Aktas 2017) (Table 17.1). *B. crassa* has only been detected in few countries including Iran and Turkey, and is known only in areas where *Hyalomma* spp. and *Rhipicephalus* spp. are common (Smith and Sherman 2009). In addition, *Babesia* sp. Xinjiang has so far only been detected in China especially involving *Hyalomma anatolicum* (Guan et al. 2009). Recently, a new *Babesia* sp. has been detected in goats in Turkey, which may use *R. bursa* and *R. turanicus* as vectors (Ozubek and Aktas 2017).

17.4.3 Clinics

Acute *B. ovis* infection can cause fever, anaemia, jaundice and haemoglobinuria, and mortality may occur. Severity is associated with age, immunity and general health condition. Indigenous sheep normally show mild symptoms, in contrast to animals brought in from non-endemic areas. In goats, natural infection with *B. ovis* has only been reported in a few countries and only as a subclinical infection (Smith and Sherman 2009; Esmaeilnejad et al. 2014).

Surviving animals may become carriers for years without apparent illness (Uilenberg 2006). However, stress factors such as poor nutrition or other infections may cause remission of *B. ovis* in the peripheral blood (Yeruham et al. 1998). In addition, carrier animals may spread the infection via blood sucking ticks (Habela et al. 1990).

B. motasi causes moderate fever, haemoglobinuria and anaemia, and is seldom responsible for fatal infections (Taylor et al. 2016). However, more severe symptoms have been recorded in goats with high morbidity and mortality. Death may occur 48 h after onset of clinical symptoms. Chronic infections may occur with anaemia and ill thrift (Smith and Sherman 2009). At least two species of *B. motasi* are reported which may differ in severity (Friedhoff 1997; Niu et al. 2016). In contrast, *B. crassa* and *Babesia* sp. Xinjiang infection in small ruminants seems to be non-pathogenic (Guan et al. 2009; Smith and Sherman 2009). At the moment, little information is available concerning the clinical importance of other *Babesia* species/subspecies (Niu et al. 2017).

17.4.4 Diagnosis

High fever, anaemia, jaundice, haemoglobinuria and the presence of protozoa in the erythrocytes on Giemsa-stained blood smears are the basis for the diagnosis. However, parasitaemia seldom exceed a few percentages during the infection (Yeruham et al. 1998; Taylor et al. 2016). PCR and serological tests should therefore be applied, especially to identify a subclinical *B. ovis* infection (Ros-Garcia et al. 2013; Esmaeilnejad et al. 2014).

17.4.5 Treatment and Control

Imidocarb dipropionate may be used to treat *B. ovis* infected sheep (McHardy et al. 1986). In goats, diminazene as an intramuscular dose up to 12 mg/kg has been tried without adverse effect (Smith and Sherman 2009). However, diminazene aceturate is now withdrawn from Europe. New drugs will hopefully be available in the future (Mosqueda et al. 2012).

17.5 Heartwater

17.5.1 Pathogen

Heartwater (also see Chap. 20 of volume 1) is caused by the rickettsia *Ehrlichia ruminantium* (formerly *Cowdria ruminantium*) in the genus *Ehrlichia*, which is transmitted by ticks in the genus *Amblyomma* (Dumler et al. 2001). Various strains of *E. ruminantium* exist with a variable degree of cross-protective immunity (Uilenberg 1983; Jongejan et al. 1988; Allsopp et al. 2007).

17.5.2 Distribution

Heartwater is an endemic disease in domestic and some wild ruminants throughout sub-Saharan Africa, including islands near Eastern Africa, but occurs also in the Caribbean after the introduction of infected *Amblyomma variegatum* ticks probably in the eighteenth century (Maillard and Maillard 1998) (Table 17.1).

17.5.3 Clinics

There are four clinical forms of heartwater: peracute, acute, subacute and subclinical, whereas the acute form is most common (Smith and Sherman 2009). The clinical symptoms depend on host susceptibility, virulence of the infective strains and previous exposure. The disease is characterized by sudden onset of high fever (up to 42 °C), nervous signs, rapid and abdominal breathing. Auscultation may indicate pulmonary oedema and hydropericardium. Recumbency, convulsions and death may follow within 24 h. *E. ruminantium* may cause high mortalities in sheep and goats, largely influenced by breed, age, animal species and bacterial strains (Mahan 2006). More than 90 and 50% mortality has been observed in non-indigenous goat and sheep breeds, respectively (Uilenberg and Camus 1993). Subclinical and mild cases are common in young animals and in local indigenous breeds.

An age-related resistance occurs in young domestic ruminants, independent of maternally transferred immunity. The period of resistance in lambs gradually wanes after approximately the first 3 weeks of life, while the protective period in kids may even be shorter (Smith and Sherman 2009).

17.5.4 Diagnosis

Presumptive diagnosis is based on clinical history and the presence of *Amblyomma* ticks in the region. At post-mortem, massive transudates into the body cavities, especially hydropericardium, hydrothorax and oedema of the lungs and brain, are recorded. In addition, splenomegaly and enlargement of the lymph nodes are seen. Clusters of the organisms may occur in the vascular endothelium of virtually all tissues examined by histology, especially in the brain cortex. For rapid field diagnosis, *E. ruminantium* can be detected by squash preparations of the cerebrum (Smith and Sherman 2009). Confirmation of diagnosis was previously made by the intravenous inoculation of infected blood into susceptible goats or sheep, but now molecular methods such as PCR are used (Martinez et al. 1994).

Several serological tests are available for detecting antibodies against *E. ruminantium.* However, since a large proportion of infected animals die following a primary infection, antibody detection is not often an option. Serological methods that have high sensitivity and specificity to diagnose heartwater during early infection or after recovery are still lacking (Mahan 2006).

17.5.5 Treatment and Control

Successful therapy depends on early antibiotic treatment. Animals treated during the acute febrile stage respond favourably to tetracycline, 5–10 mg/kg intravenously or intramuscularly administrated at the first sign of fever and repeated one additional time either 1 or 2 days later. The use of long-acting tetracycline at a dose of 20 mg/kg is also effective. Therapy initiated after the onset of neurological signs is almost always inefficient (Prozesky and Du Plessis 1985). Treatment should therefore not be delayed until laboratory confirmation is established. Recovered animals can be carriers of the infection (Uilenberg and Camus 1993).

Although heartwater has been known for more than a century, it is still considered as a major obstacle against expansion and development of the livestock industry in Southern Africa (Provost and Bezuidenhout 1987). Imported breeds, in particular, are very susceptible, and severe infection with high mortality rates may occur (Uilenberg and Camus 1993). There is a considerable concern about the possible spread of heartwater to tropical and subtropical regions of North, South and Central America (Smith and Sherman 2009). *E. ruminantium* can be transmitted by at least 13 species of *Amblyomma* ticks, whereas *A. variegatum* and *A. hebraeum* are the two major vectors in Africa (Walker and Olwage 1987).

The current methods for heartwater control include the use of acaricides to control the tick vector, antibiotic prophylaxis, immunization by infection and treatment, farming with animal breeds resistant to the disease and establishment of endemic stability (van der Merwe 1987; Peregrine 1994; Camus et al. 1996). All of these methods have serious drawbacks, for instance, acaricides are expensive, environmentally unfriendly and may induce resistance to ticks. In addition, treatment has to be repeated several times during the tick season. Another drawback of using acaricides is also that it hinders the creation of endemic stability as treated animals remain fully susceptible to infection (Mahan 2006). Attempts to control heartwater by controlling tick infestation have only partly been successful. Eradication of the disease by vector control seems therefore unlikely (Allsopp 2009).

Currently, there is no safe, user-friendly and reliable vaccine commercially available. At the moment, the only commercially available immunization method is the 'infection and treatment method' by using an attenuated strain of *E. ruminantium*. Successful vaccination depends on the proper timing of the treatment. The disadvantages of such a procedure include the possible use of chemotherapeutics after immunization and distribution of a deep-frozen vaccine, since the vaccine rapidly loses its infectivity and immunogenicity when thawed. In addition, the procedure needs intravenous injection of the vaccine dose. Control of heartwater through discovery and development of improved vaccines is the target for future research (Allsopp 2009).

17.6 Theileriosis

17.6.1 Pathogen

Theileriosis is caused by parasitic protozoan that belongs to the genus *Theileria*. In small ruminants, genus *Theileria* involve several species including *T. lestoquardi* (formerly *T. hirci*), *T. ovis*, *T. recondita*, *T. annulata*, *T. uilenbergi*, *T. separata*, *T. luwenshuni*/sp. OT1, *Theileria* sp. OT3 and *Theileria* sp. MK (Nagore et al. 2004; Altay et al. 2012; Taylor et al. 2016). In addition, *Theileria* species of small ruminants include several uncharacterized isolates (Yin et al. 2007).

17.6.2 Distribution

The distribution of *Theileria* species in small ruminants is widespread, but only scattered information is available. Transmission is caused by several tick species in the genera *Haemaphysalis*, *Hyalomma* and *Rhipicephalus* (Mans et al. 2015) (Table 17.1). For instance, *T. lestoquardi* is mainly transmitted by *Hyalomma anatolicum* and *H. qinghaiensis* and *T. ovis* by *R. bursa* and *H. punctata. Theileria* sp. OT1 has been associated with *I. ricinus*, *H. punctata* and *D. reticulatus*, while *H. punctata* is suspected as a vector of *Theileria* sp. OT3 (Ros-Garcia et al. 2013).

The pathogenic species *T. luwenshuni* and *T. uilenbergi* seem to involve the tick species *H. qinghaiensis* and *H. longicornis* (Yin et al. 2007).

17.6.3 Clinics

Only *T. lestoquardi*, *T. luwenshuni* and *T. uilenbergi* are considered highly pathogenic in small ruminants; however, a variation in their pathogenicity has been observed (Yin et al. 2007; Ge et al. 2012). *T. lestoquardi* causing malignant theileriosis may introduce severe infection in sheep (46–100% mortality) (Woldehiwet 2007; Taylor et al. 2016). In malign theileriosis, an acute form is common, but subacute and chronic forms have been observed. Clinical signs in the acute form are fever, diarrhoea, jaundice, swelling of lymph nodes and submucosal/subcutaneous bleedings. Intermittent fever, emaciation, anaemia and jaundice may be present in chronic cases. In general, *Theileria* spp. seems to cause much fewer symptoms in goats than in sheep (Smith and Sherman 2009; Stuen 2016).

Other *Theileria* species may cause mild or even inappreciable clinical symptoms, such as *T. ovis* causing benign theileriosis, *Theileria* sp. OT1, *Theileria* sp. OT3, *T. recondita*, and *T. separata* (Friedhoff 1997; Preston 2001; Duh et al. 2008). No information is available about the pathogenicity of *Theileria* sp. MK (Altay et al. 2012).

17.6.4 Diagnosis

In live animals, detection of piroplasms in blood smear or lymph node biopsies should be applied. At *post-mortem*, organisms can be found in lymph nodes or spleen smears (Taylor et al. 2016). In addition, PCR may be used for *Theileria* detection (Sparagano et al. 2006; Duh et al. 2008). Serology, including IFA and ELISA, tests are useful for identifying infected and carrier animals (Preston 2001).

17.6.5 Treatment and Control

Specific treatment of caprine theileriosis is lacking. For *T. lestoquardi*, injection of parvaquone/buparvaquone may be effective. In addition, one dose of halofuginone could also be useful (Smith and Sherman 2009; Taylor et al. 2016). Treatment of *T. ovis* is usually not required. A vaccine is not available. Tick control should be applied in order to control the disease and dissemination of pathogen species (Stuen 2016).

17.7 Trypanosomosis

17.7.1 Pathogen

Trypanosomosis (also see Chap. 20 of volume 1) is caused by haemoflagellates in the genus *Trypanosoma*. Several species are involved although not all of them seem to be pathogenic for small ruminants (Table 17.1). Natural infections with *Trypanosoma congolense, T. vivax, T. brucei*, and *T. evansi* have been described in goats (Gutierrez et al. 2006). However, recent molecular methods indicate that *T. evansi* may be a subspecies or strain of *T. brucei* (Wen et al. 2016).

17.7.2 Distribution

The most important species for small ruminants are *T. congolense*, *T. vivax* and *T. brucei* (Gutierrez et al. 2006). However, their real distribution is unknown. Trypanosomes are widespread in tropical and subtropical areas, especially in Africa, but some *Trypanosoma* species have also been detected in Europe, West Indies, Central and South America and Asia (Smith and Sherman 2009; Taylor et al. 2016). In Africa, all species seem to be transmitted by tsetse flies (*Glossina* spp.) except for *T. evansi*, whereas mechanical transmission by other biting flies may occur elsewhere (Taylor et al. 2016). In addition, the distribution and prevalence vary between goats and sheep, *T. melophagium* has for instance only been detected in sheep. Trypanosomosis is a major concern in small ruminant livestock production in sub-Saharan Africa (Smith and Sherman 2009).

17.7.3 Clinics

Several strains with variable virulence occur within each species of trypanosomes (Smith and Sherman 2009). The main clinical symptom is anaemia. Clinical signs depend on the species of *Trypanosoma* involved. *T. vivax* and *T. congolense* cause acute, subacute and chronic disease, whereas the acute form may cause death or recovery within four to six weeks. Clinical signs may involve depression, anorexia, rumen atony, enlarged lymph nodes and weight loss. Jaundice and haemoglobinuria are, however, uncommon findings. In chronic cases, severe emaciation may occur. *T. congolense* infection often results in cyclic fever and parasitemia, and the mortality rate is high if the infection has last for more than 12 weeks.

In *T. brucei* cases, central nervous system symptoms such as head pressing, circling and opisthotonus may occur. In addition, lymphadenopathy is common, but anaemia is less pronounced compared to *T. vivax* and *T. congolense* infections.

T. brucei infection may last 2–5 months, often with a fatal outcome (Smith and Sherman 2009).

Goats with chronic infection may be more susceptible to helminthiasis and carry heavier helminth burden probably as a result of immunosuppression. Reduction in milk quality and production have been observed in *T. vivax* infected goats (Lopes et al. 2016). In addition, trypanosome infection in goats may be associated with ovarian dysfunction, irregular estrus cycles and testicular atrophy (Smith and Sherman 2009).

Several species have been detected in goats which normally cause non-pathogenic or subclinical symptoms, such as *T. cruzi, T. evansi*, *T. equiperdum*, *T. gambiense*, *T. rhodesiense*, *T. simiae*, *T. theodori* and *T. uniforme* (Smith and Sherman 2009; Taylor et al. 2016). However, as already mentioned *T. evansi* and even *T. equiperdum* may be subspecies/strains of *T. brucei* (Wen et al. 2016).

17.7.4 Diagnosis

Anaemia and emaciation in animals from areas with tsetse flies indicate the diagnosis of trypanosomosis. Diagnosis is based on organisms found in Romanowsky-stained blood smears or tissues. However, trypanosomes may be difficult to identify in chronic infections due to low parasitemia. To confirm *T. brucei* infection, examination of smears of lymph node aspirate or mouse inoculation are the preferred methods. Several serological tests for antibody detection is available. In addition, PCR methods are developed, but demand well-equipped labs and do not replace the classical field methods (Smith and Sherman 2009).

17.7.5 Treatment and Control

Curative and prophylactic use of trypanocidal drugs generally administrated by the farmers is the most important method of controlling animal trypanosomosis (Vreysen et al. 2013). A variety of trypanocidal compounds are available, such as diminazene aceturate (intramuscular 3.5 mg/kg) and homidium chloride (intramuscular 1 mg/kg). However, there are numerous constraints on control, such as reservoirs of infection in wild animal populations, the ability of trypanosomes to continuously alter their antigenic surface, resistance to trypanocidal drugs, lack of vector control and lack of economic resources (Smith and Sherman 2009).

Breed differences have been observed in goats related to resistance against trypanosomes, with indigenous breeds performing better than imported breeds or cross-breeds. Preliminary field studies indicate that some goat breeds, such as Dwarf West African goat may inherent trypanotolerance. However, more studies are needed to obtain conclusive results (Gutierrez et al. 2006; Smith and Sherman

2009). Goat may also serve as reservoir for trypanosome species affected other mammalian species including human (Smith and Sherman 2009; Ruiz et al. 2015).

In sub-Saharan Africa, the major front in trypanosomosis control is reduction or elimination of the tsetse flies (Smith and Sherman 2009). No effective vaccine is yet available.

17.8 Other Haemoparasites

Mycoplasma ovis (formerly *Eperythrozoon ovis*) infection seems to be widespread in small ruminants (Neimark et al. 2004) (Table 17.1). The infection in sheep is characterized by moderate anaemia and reduced weight gain, although severe anaemia and even death is reported (Hornok et al. 2009). In goats, however, clinical disease is uncommon (Smith and Sherman 2009).

Haemoparasites involving other hosts have occasionally been detected in goats and sheep, such as *Anaplasma marginale*, *A. centrale*, *A. bovis*, *Ehrlichia canis*, *E. chaffeensis* and *Rickettsia conorii*, but the importance of these parasites in small ruminant health management and production seems to be limited (Smith and Sherman 2009; Ben Said et al. 2015b; Zhang et al. 2015; Qiu et al. 2016; Taylor et al. 2016). In addition, *A. platys* (or a similar organism) normally related to dogs has been reported in small ruminants in South Europe and North Africa (Zobba et al. 2014; Ben Said et al. 2017).

'New' pathogen, such as Panola Mountain *Ehrlichia* (PME), has been detected in goats in the US (Loftis et al. 2006). Molecular analysis revealed this *Ehrlichia* sp. to be closely related to *E. ruminantium*. Goats experimentally infected with PME developed fever and serous nasal discharge. The pathogen is transmitted by the several *Amblyomma* species, and preliminary studies indicate that PME is spread in the US and Africa (Loftis et al. 2016). Goats could serve as a reservoir host of the infection (Loftis et al. 2006; Goddard and Varela-Stokes 2009).

Ehrlichia ewingii has also recently been isolated from goats in the US, with similar unspecific symptoms as mentioned for PME. The distribution of this pathogen in goats is however unknown. Both *Ehrlichia* species have a zoonotic potential, and goats seem to be persistently infected (Loftis et al. 2008).

An *Anaplasma* species with the proposed name '*Anaplasma capra*' has been detected in goats in China and Korea (Li et al. 2015; Seong et al. 2015). The pathogen is closely related to erythrocytic anaplasmas such as *A. marginale*. Preliminary studies indicate that goats may be a reservoir host, since *A. capra* infection is widespread in the studied areas. However, nothing is known about the pathogenicity in goats, but the bacteria has a zoonotic potential (Li et al. 2015). Ticks such as *I. persulcatus* and *H. longicornis* may transmit the pathogen (Li et al. 2015; Sun et al. 2015). In addition, molecular survey of *Anaplasma* species among small ruminants in Northern Africa detects novel *Anaplasma* strains closely related to *A. phagocytophilum* (Djiba et al. 2013; Ben Said et al. 2015a). In conclusion, the epidemiological consequences and clinical/economical relevance of these 'new' infections in the goat and sheep industry are at the moment unknown.

17.9 Concluding Remarks

Vector-borne haemoparasites are widely distributed, but only scattered information is available on their occurrence. An active surveillance is necessary to map the real distribution. Variable clinical manifestation occurs within strains/variants. New pathogens will be detected in the future and perhaps be abundant. At the moment, *Anaplasma ovis*, *A. phagocytophilum*, *Ehrlichia ruminantium*, *Babesia ovis/motasi, Theileria* spp. and *Trypanosoma* spp. infection are the most important haemoparasites in goats and sheep.

Vector-borne diseases may spread across the world to new geographical areas. These changes could have a profound impact on infection ecology and disease management. In addition, the amount of co-infections of different haemoparasites both in vectors and hosts are unknown and should be revealed (Hornok et al. 2009; Liu et al. 2012; Ros-Garcia et al. 2013; Zhang et al. 2016b). Studies are therefore needed to determine the effect of multiple vector-borne infections on the clinical outcome, epidemiology and flock health of small ruminants. In addition, breed resistance may exist, which also has to be further elucidated.

In summary, the prevalence of vector-borne diseases is affected by a number of factors such as age, breed, management and vector-borne populations. Integrated control strategies should therefore be implemented, including natural resistance to vectors and pathogens, vector control and the use of available vaccines (Jongejan and Uilenberg 2004; Pieragostini et al. 2011; Stuen 2016). The main challenges are, however, the variability of potential pathogens, such as seasonal, annual and geographical variation, host–pathogen interaction and adaptation, co-infections, natural reservoirs and, in general, the dynamic nature of all vector-borne infections.

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Chapter 18
Understanding Mastitis in Goats (I): Etiopathophysiological Particularities

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Abstract Mastitis represents one major constraint in dairy goat farms implicating adverse effects on milk yield and composition and, in some cases, public health constraints. Intramammary infection, the principal cause of mastitis, can reach high prevalence in dairy goat herds, commonly more than 30%. Coagulase-negative staphylococci and coagulase-positive staphylococci, with emphasis for *Staphylococcus aureus*, are the major bacterial species related with in intramammary infection. Milk pathogens overtake anatomical, physiological, and immunological local defenses of the mammary glands. However, some enzootic systemic disease, such as contagious agalaxia, among others, with systemic tropism for the mammary gland, can have a significant impact on the milk production and quality. At immune level, neutrophils play a major role in the healthy and infected mammary gland representing 45–75% of total leucocyte counts in milk. Apparently, the threshold for significant neutrophils increase is 700,000 cells/ml. Moreover, the continuous renewal of epithelial cells from apocrine glands, which have phagocytosis cytokine production properties, improves significantly the somatic cells in milk. All these topics are discussed in the present chapter providing key points to improve the udder health status in goats.

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18.1 Introduction

Mastitis is the inflammation of the mammary gland, a multifactorial disease characterized by physiological, chemical, and bacteriological changes in milk, along with pathological modifications in the glandular tissue (Contreras et al. 1997a; Matthews 2009). Normally, it is the response to an infection and aims to eliminate the pathogen involved, restoring the integrity of affected tissue, and functionality of the mammary gland (Contreras et al. 1997b).

To understand the significance of mastitis, the first concept that is important to interiorize is that the milk secretion, since correctly collected, should be sterile (Poutrel 1983; Leitner et al. 2012), even milk microbiota concept has recently been also reported in goats (McInnis et al. 2015; Li et al. 2017). Therefore, the milk flora that has so much interest in the cheese industry is formed by environmental agents, including commensal bacteria from skin teats (Tormo et al. 2007), which are incorporated into milk after leaving the udder (Contreras et al. 1997b). This flora is usually conveyed by the teats and air at the time of milking, or through the milking machine itself (Tormo et al. 2006), such as the total mesophilic aerobic flora (Muehlherr et al. 2003), or even psychrotrophic bacteria, apparently associated with problems in milk cooling or long periods of storage (Contreras et al. 1997a, 2003), among others microorganisms, including milk pathogens.

With the presence of a pathogen, usually bacterial, an intramammary infection (IMI) take place into the mammary gland with associated inflammatory processes which negatively modify the milk yield and composition (Merin et al. 2004; Leitner et al. 2007; Le Maréchal et al. 2011; Gelasakis et al. 2016). Each pathogen induces a specific modification in milk during mastitis (Le Maréchal et al. 2011). The milk from clinical mastitis (IMI with milk and udder macroscopic changes) is immediately rejected for human and animal consummation. Inversely, untreated goats presenting subclinical mastitis also contribute with their milk for the bulk milk tank or direct consummation. However, several aspects must be taken into account with emphasis for IMI diagnosis, mastitis control and prevention management, total bacterial count in milk, milk pasteurization, and cheese ripening, among others.

The milk of subclinical mastitis is pasteurized, which kills bacteria, and manufactured or directly used for raw milk cheese (with more than 60 days of ripening). However, the high prevalence of infected goats can pose some constraints promoting, production and manufacture losses. For example, *Staphylococcus aureus*, one of the most prevalent milk pathogen, can be present in a significant proportion of bulk tanks milk, such as the recently reported by Cortimiglia et al. (2015) in Italy (43.1%) and by Merz et al. (2016) in Switzerland (46%). On the other hand, milk raw and unpasteurized dairy products contaminated by *S. aureus* can cause food poisoning (Oliver et al. 2009) in human and animals due to several (exo) enterotoxins (Dinges et al. 2000; Le Loir et al. 2003; Johler et al. 2015; Jans et al. 2017). Enteropathogenic and Shiga toxin-producing *Escherichia coli* are other significant endotoxins related with dairy products and potential adverse impact on public health (Álvarez-Suárez et al. 2015). Besides, subclinical mastitis is difficult to detect, is of long duration and usually precedes the clinical form. This chapter aims to describe the particularities of mastitis in goats regarding their etiophysiopathology, and consequently a better understanding of the health concepts for a more profit milk production.

18.2 Clinical and Subclinical Mastitis Occurrence

Clinical mastitis causes visible variable changes, ranging from a small change in the macroscopic characteristics of milk secretion, with or without local inflammatory changes, to manifestations of systemic disease (e.g., gangrenous mastitis) (Contreras et al. 1997b). In addition to the decrease in milk production, often the first sign detected, is the appearance of hungry kids or the increased mortality rate of suckling kids (Smith and Sherman 2009). Due to its faster evolution and the more intense severity of clinical symptoms, different categories have been proposed to classify clinical mastitis: hyperacute, acute, subacute, and chronic (Figs. 18.1 and 18.2).

In subclinical mastitis, which causes the greatest impact on dairy farms; the subsequent inflammation is not visible but changes in milk quality as well as, a decrease in production occur. In addition to these poorly perceptible but constant losses, the infected animals contaminate the milking teats and/or the milker hands,

Fig. 18.1 Chronic mastitis in a primiparous goat with atrophy of the left mammary gland (provided courtesy of C. Gutiérrez)

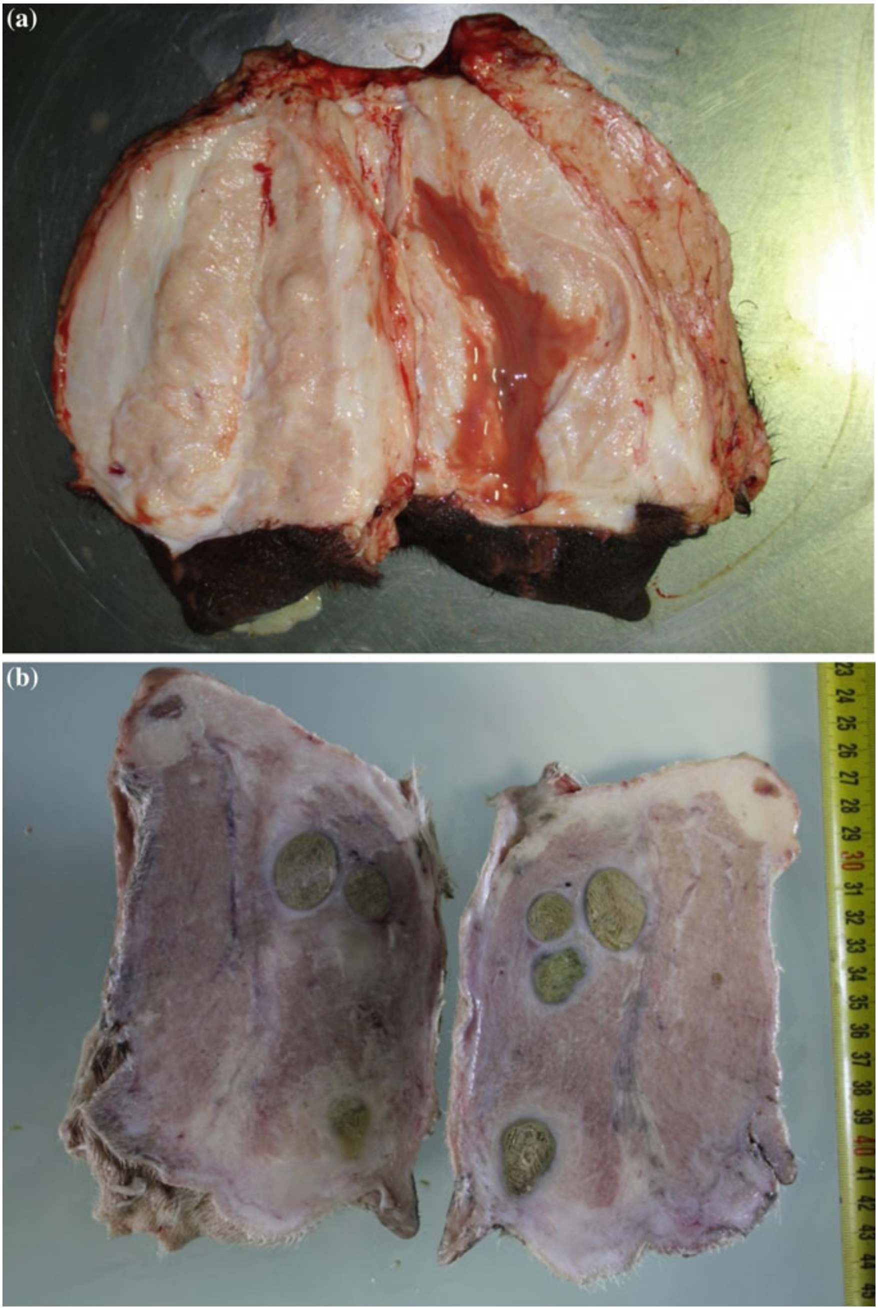

Fig. 18.2 Sagittal cut of unilateral udders with serosanguinous exudate (**a**) and purulent abscesses (**b**) in unilateral udder with mastitis (provided courtesy of R. Jiménez-Granado and A. Méndez, respectively)

spreading the infection. Many of the agents involved in IMI, such as coagulase-negative Staphylococci (CNS), are able to persist in the mammary gland throughout lactation and even during the drying period. Thus, kidding goats with IMI will present subclinical mastitis during the new lactation period (Poutrel 1984; Contreras et al. 1997a; Bergonier et al. 2003). Although persistent, this subclinical mastitis does not alter the macroscopic appearance of the milk but can be detected through bacteriological isolation or associated cell recruitment, (i.e., somatic cells count (SCC) at the laboratory or Californian mastitis test at the farm) (Plummer and Plummer 2012).

In an appropriate sanitary context, the prevalence of clinical mastitis should not exceed 5% of the flock (Bergonier et al. 1997; Contreras et al. 2007) but this incidence can become greater sporadically. The presence of mycoplasmas in the herds may alter the relative proportions of the other bacteriological agents causing clinical mastitis. In endemic areas for contagious agalactia, the prevalence of clinical cases is generally low, but may increase drastically, especially in newly infected herds (Bergonier and Berthelot 2008). In Spain, the analysis of 820 milk samples from clinical mastitis allowed to identify 78.6% of IMI caused by (other) bacterial agents, 16.5% by mycoplasmas, and 4.9% caused simultaneously by mycoplasmas and other bacteria (Amores et al. 2012a, b). In these studies, staphylococci were the most prevalent bacteria (75.5%, of which 19% were *Staphylococcus aureus*) followed by Gram-negative bacilli (11.7%), streptococci (7.7%) and other bacteria (5.1%). The most frequently identified mycoplasmas were *Mycoplasma agalactiae* (91.4%), *M. mycoides* subsp. c*apri* (5.7%) and *M. putrefaciens* (3%).

The prevalence of subclinical mastitis varies on average from 5 to 30% (Contreras et al. 2007), although some herds present higher values (Contreras et al. 1999; Rovai et al. 2014), reaching up to 70% in certain herds (Vega et al. 2004; Bazan et al. 2009). In this sense, according to Andrews et al. (1983). Kalogridou-Vassiliadou (1991) considers an animal as infected by a pathogen when the same microorganism is isolated in two of three consecutive examinations, and he found 65% of goats infected with pathogenic microorganisms with no clinical signs of mastitis in Greece. CNS are the main agents isolated from goats milk with subclinical mastitis, with a total average between 25 and 95% of isolates, followed by *S. aureus* (5–35%), streptococci (5–15%) and Enterobacteriaceae (2–12%) (Contreras et al. 2007). Nineteen staphylococcal species have been identified from subclinical intramammary infections in goats (Contreras et al. 2007). In Greece, even in low-input dairy goat farms, CNS reached 50.2% of isolates followed by coagulase-positive Staphylococci (e.g., *S. aureus* and *S. intermedius*) with 34.5% (Gelasakis et al. 2016). Similar high values (59.5%) of SCN prevalence were reported in China in dairy goats (Zhao et al. 2015).

18.3 Etiology

Caprine mastitis may be due to mechanical, traumatic (e.g., footprints, wounds, blows, etc.) or caused by bacterial toxins (Stehling et al. 1986), but in the overwhelming majority are due to bacterial infections, without excluding lentiviruses and fungi (Bergonier et al. 1997, 2003). Vega et al. (2004) isolated 86 different microorganisms in 166 goats from 16 goat herds. Most of these pathogens are reported in Table 18.1, according to each biological group. In most of the milk samples, only one of the microorganisms is isolated, but some samples contained two or more kinds of microorganisms.

The pathogens responsible for caprine mastitis can also be divided into two groups according to their virulence: major pathogens and minor pathogens (White et al. 2001; Bagnicka et al. 2011). Major pathogens induce more intense immune responses and consequently result in higher SCC and are often associated with clinical mastitis. As an example, IMI caused by *S. aureus* show higher SCC than those caused by CNS or other bacteria (Persson et al. 2015). In this, major pathogens class are included bacteria, such as *S. aureus, M. agalactiae, M. mycoides* subsp. *capri, M. capricolum* subsp. *capricolum, M. putrefaciens, Corynebacterium pseudotuberculosis, Trueperella pyogenes, Streptococcus* spp. (*Strep. agalactiae, Strep. dysgalactiae*, *Strep. uberis,* and *Strep. bovis*), *Brucella* spp., *Pasteurella* spp./*Mannheimia* spp.*, Aspergillus fumigatus, Nocardia asteroides, E. coli, Klebsiella* spp.*, Pseudomonas aeruginosa, Enterococcus faecium*, *Enterococcus faecalis and* CNS novobiocin-sensitive.

Minor pathogens would cause subclinical mastitis with low SCC. The inclusion of CNS as a minor pathogen is not consensual. Classically, due to their classification in cattle, they were considered as "minor" agents, but their importance in caprine mastitis led some authors to consider this as a non-proper classification (Maisi and Riipinen 1991; Contreras et al. 1995, 2003; Bergonier et al. 1997, 2003). In other words, subclinical mastitis caused by some CNS can cause, in goats, high SCC, considerable lesions in the mammary tissue, and significant economic losses due to production decrease and altered milk quality (Bergonier et al. 2003; Contreras et al. 2007; Le Maréchal et al. 2011). Thus, it is thought that the individual classification of the different CNS species (Sánchez et al. 1998; Bergonier et al. 2003), as proposed in sheep, consider the in vitro susceptibility to novobiocin as classification criterion in goats, since it seems to be associated with the virulence of CNS in this species (Sánchez et al. 1998).

The CNS resistant to novobiocin, i.e., *S. xylosus, S. saprophyticus, S. lentus, S. sciuri* and *S. arlettae*, behave as minor pathogens inducing small changes in SCC and a slightly reduction in milk production. Nevertheless, the novobiocin-susceptible CNS, i.e., *S. epidermidis, S. simulans, S. chromogenes, S. warneri,* and *S. lugdunensis*, are considered major pathogens inducing important changes in SCC and considerable breaks in milk production (Gonzalo et al. 1998; Sánchez et al. 1998). *S. epidermidis* and *S. simulans* would be the responsible for

Table 18.1 Milk pathogens in goats

Group	Genus	Species
Gram-positive bacteria	*Staphylococus* spp.	*Staphylococus* coagulase-positive (*S. aureus*, *S. intermedius*) *Staphylococus* coagulase negative (*S. capitis, S. haemolyticus, S. xylosis, S. simulans, S. caprae, S. epidermidis, S. warneii, S. sciuri, S. hominis, S. auricularis*)
	Micrococcus spp.	
	Streptococcus spp.	*St. agalactia; St. uberis; St. dysgalactia*
	Corynebacterium spp.	*C. bovis; C. pseudotuberculosis*
	Trueperella spp.	*T. pyogenes*
	Bacillus spp.	*B. cereus*
	Clostridium spp.	*C. perfringens*
	Nocardia spp.	*N. asteroides; N. farcinica; N.brasiliensis; N. brevicatena; N.transvalensis*
Gram-negative bacteria	*Escherichia* spp.	*E. coli*
Enterobacteriaceae	*Klebsiella* spp.	*K. pneumoniae; K. oxytoca*
	Enterobacter spp.	
	Proteus spp.	
	Serratia spp. *Citrobacter* spp. *Pantoea* spp.	*S. marcescens;* Outras serratias *Citrobacter koseri*
Non-enterobacteriaceae	*Pseudomonas* spp.	*P. fluorescens*; *P. aeruginosa*
	Mannheimia spp.	*M. haemolytica*
	Pasteurella spp.	*P. multocida*
Micoplasma	*Mycoplasma* spp.	*M. agalactiae; M. mycoides subsp. Capri; M. capricolum subsp. Capricolum; M. putrefaciens*
Fungi	*Acholeplasmas* spp.	*A. laidlawwii; A. modicum*
	Candida spp.	*C. albicans*; *C. lusitaniae; C. parapsilosis; C. glabrata,*
	Cryptococcus spp.	*C. neoformans*
	Aspergillus spp.	*A. fumigatus*
Virus	Caprine arthritis encephalitis virus	

Source Corrales et al. (1997), Wahba et al. (2011), Persson et al. (2015), Scaccabarozzi et al. (2015), Doğruer et al. (2016), Dore et al. (2016), Gelasakis et al. (2016), Göçmen et al. (2016), İlhan et al. (2016), Koltas and Ilhan (2016), Tariba et al. (2017)

the higher SCC. However, these considerations should always be carefully analyzed due to the variations among isolation frequencies in different herds and from different studies, as well as the variations in the invasiveness and virulence of the numerous bacterial strains (Sánchez et al. 1998).

These pathogenic microorganisms can still be divided into (1) Contagious (Gelasakis et al. 2016): their main habitat is the mammary gland in such a way that infection occurs normally during milking operations. This group includes *Strep. agalactiae* and *Mycoplasma* spp., although its main habitat is not the internal udder, but the internal and external teat epithelium. This group also includes *S. aureus*, a major pathogens. Merz et al. (2016), which studied the *S. aureus*-specific staphylococcal protein A and clonal complexes, suggested that *S. aureus* isolated from milk samples of goats and ewes in Swiss farms are sufficiently genetically close to form distinct population from dairy cattle; (2) Environmental (Gelasakis et al. 2016): infections do not occur during milking but rather with the contact of animals with contaminated materials (e.g., soil, bed, water, manure, food, among others). In this group *Streptococcus* spp., excluding *Strep. agalactiae,* are included, and some bacillus species and Gram-negative bacteria in general; and, (3) Opportunists: their natural habitat is the animal and human skin, mainly the *Staphylococcus* genus, and they compose the principal cause of subclinical mastitis in caprine herds: CNS (Corrales et al. 1997; Chu et al. 2012).

18.4 Pathogeny

Pathogens enter into the mammary gland through teats canal or by hematogenous dissemination, being the first the main route of entry to the main milk pathogens reported above. Other biological agents such as those belonging to the complex *Mycobacterium tuberculosis, Brucella melitensis, Listeria monocytogenes*, mycoplasmas, and lentivirus cause systemic infection and have tropism for the mammary gland (Contreras et al. 1995, 1997b). Therefore, IMI occurs when a pathogen can overcome anatomical defenses, multiply in the gland cistern and reach the alveoli. The inflammatory phenomena (i.e., mastitis) accompanying the infection may be visible or not (Radostits et al. 2007).

Mammary gland protection involves the innate and adaptive immune response (Leitner et al. 2000), which work together. The innate immune response consists of passive defense mechanisms, such as the physical barriers of the teat canal, and active, formed by the resident cells in the mammary gland (i.e., cellular component) and some factors soluble (i.e., humorous component) (Sordillo and Streicher 2002; Rainard and Riollet 2006; Sladek and Rysanek 2010).

The teat canal is the main barrier against bacterial infections (Zecconi et al. 2000; Sudhan and Sharma 2010; Ezzat Alnakip et al. 2014). The teat sphincter, consisting of smooth and elastic muscle cells, ensures the closure of the teat canal among milking, constituting an anatomical barrier to the entry of pathogens. Similarly, in the proximal part of the teat canal (Fasulkov et al. 2014; Vesterinen et al. 2015), the folds in the mucosa of the Fürstenberg rosette also play the same protective role similar to the reported in cows (Hibbitt et al. 1996; Ezzat Alnakip et al. 2014). The elimination of foreign agents is further favored by the downward flow of milk during milking and by the shedding of keratinized epithelial cells from the canal.

Keratin has the ability to bind to bacteria and is composed of substances with bacteriostatic properties that prevent bacterial multiplication (Capuco et al. 1992; Paape and Capuco 1997). Its constant renewal at each milking allows the elimination of the bacteria that keratin agglutinates. Similarly, continuous renewal of epithelial cells may also play an important role in defense against invading agents (Leitner et al. 2012).

Cellular defense is ensured by leukocytes, which vary according to the SCC apparently with the threshold at 700,000 cells/ml (Albenzio et al. 2015), and epithelial cells of the mammary gland (Table 18.2). Leukocytes include not only polymorphonuclear leukocytes (mainly neutrophils in goat milk, but also some eosinophils and basophils), monocytes/macrophages, natural killer (NK) cells, and dendritic cells (Paape and Capuco 1997; Oviedo-Boyso et al. 2006; Sladek and Rysanek 2010). In the mammary gland, recognition of foreign agents is performed by resident macrophages and epithelial cells, due to the presence of lipopolysaccharides, peptidoglycans, or lipoteichoic acid in the bacterial cell wall, for which these cells have receptors (Oviedo-Boyso et al. 2006).

The epithelial cells of the mammary gland have the ability to phagocyte and produce cytokines, behaving like macrophages (Monks et al. 2002; Atabai et al. 2007; Monks and Henson 2009) playing a central role in the proinflammatory

Table 18.2 Milk somatic cell count and cell type distribution in different animal species, in the absence of intramammary infection

Species	Cells type					
	SCC (10^6 cells/ml)	Cytoplasmic particles (10^3/ml)	Epithelial cells[a] (%)	PMNL (%)	Lymphocytes (%)	Macrophages (%)
Human	0.009	90	50–90	6	5–9	8
Cattle	0.075	Not observed	Very low*	5–20	20–30	61
Sheep	0.11	15	Very low*	22	10–25	70
Goats	1.1	128	10–20	45–75	3–10	10–35
Swine	1	—	60–90	5–10	15–25	5–10

Source Paape et al. (2000), Boutinaud and Jammes (2002)

SCC Somatic cells count; *PMNL* Polymorphonuclear leucocytes (neutrofils, eosinofils, and basofils)

*Currently, with the use of monoclonal antibodies, the % obtained today is significantly different (Leitner et al. 2012): Cattle and goats ~50% and Sheep ~80%

[a]Percentage of total cells

response by secreting chemotactic factors (e.g., IL-8) and several acute phase proteins, such as serum amyloid A3 (SAA3), pentraxin 3 (PTX3), and antiproteinase alpha-1 (SERPINA1) (Brenaut et al. 2014). Thus, after coming into contact with the pathogens, epithelial cells, and macrophages produce proinflammatory cytokines (i.e., IL-8 signaling pathway) that promote the mobilization of neutrophils from the bloodstream to the mammary gland (Leitner et al. 2000; Sladek and Rysanek 2010; Brenaut et al. 2014) through the activation of intercellular and vascular adhesion molecules of the endothelial cells. These adhesion molecules promote neutrophil extravasation and migration (i.e., diapedesis) through the vascular endothelium to the mammary gland (Paape et al. 2002; Oviedo-Boyso et al. 2006). After that, the receptors present on neutrophils recognize the molecular pattern associated with the pathogen and begin the process of phagocytosis (Blagitz et al. 2011). Neutrophils (Fig. 18.3) contribute to contain bacterial invasion by phagocytizing the pathogens and by releasing compounds with high oxidative capacity (e.g., reactive oxygen species: ROS) (Paape et al. 2003; Rinaldi et al. 2007). The phagocytic and bactericidal properties of neutrophils are the main infection control element in the mammary gland (Fetherson et al. 2001).

In addition, due to several inflammatory mediators (Le Maréchal et al. 2011), the intervention of T and B lymphocytes and macrophages occurs, but neutrophils are always maintained as the most representative cell line. Macrophages, in addition to their phagocytic capacity, play a key role in IMI, through the secretion of a wide range of cytokines, such as interleukins (IL) 1β, IL-6, IL-8, tumor necrosis factor α (TNFα), and interferon γ (IFNγ), which induce the acute phase response and will

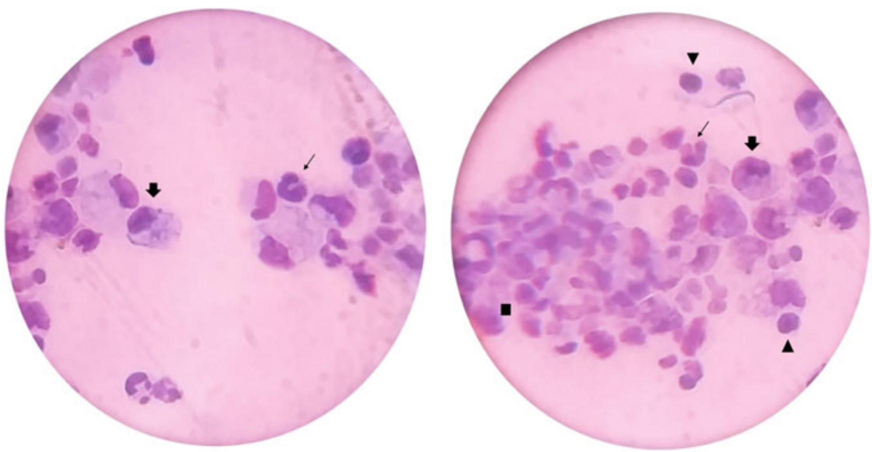

Fig. 18.3 Neutrophils (polymorphonuclear) content in goat milk into two plates (×1000). Milk sample (1.5×10^6 cell/ml) centrifuged at ×1000 rpm for 5 min. The somatic cell counts includes macrophages, neutrophils, lymphocytes and epithelial cells. Quick diff staining (provided by G. Margatho)

successively attract more neutrophils into the mammary gland until resolution of the infection (Oviedo-Boyso et al. 2006; Rainard and Riollet 2006).

Neutrophils become 50–70% of the SCC in normal goat milk, in contrast to only 5–20% of the SCC in normal cow milk (Dulin et al. 1983; Poutrel and Lerondelle 1983). However, the number of neutrophils migrating to the healthy mammary glands is small compared to those that migrate in the case of an IMI (Paape et al. 2002, 2003). The massive recruitment of neutrophils in the udder leads to a marked increase in somatic cells in milk (Kehrli and Shuster 1994; Table 18.3) which support the use of this method for the diagnosis of subclinical mastitis in ruminants (Kehrli and Shuster 1994; Bergonier et al. 2003).

Therefore, IMI changes the number of leukocytes in milk. However, the response is not uniform: the bacterial species involved and the duration of infection play an important role in defining the percentage in which leukocytes are present in milk during mastitis (Leitner et al. 2012). The localization of the leukocyte populations is variable; the neutrophils are in a greater quantity in the milk, and the lymphocytes and macrophages in the tissues (Leitner et al. 2003). The vascular changes seen in this process are responsible for the cardinal signs of inflammation: increased vascular permeability, vasodilatation, and increased vascular flow (i.e., pain, heat, redness, and edema) and decreased milk synthesis capacity of the mammary gland (i.e., loss of function); this latter due to the combined action of bacterial toxins and inflammatory mediators that damage milk-producing acini cells (Oviedo-Boyso et al. 2006).

An effective innate immune response can quickly eliminate invading pathogens without major quantitative and qualitative changes in milk (Sordillo and Streicher 2002; Baumert et al. 2009). After removing pathogens, neutrophils undergo apoptosis and are phagocytized by macrophages, leading to resolution of the inflammatory process (Baumert et al. 2009; Sladek and Rysanek 2010). However, the significant increase of neutrophils in the mammary gland due to the infection can result in a large amount of neutrophils in apoptosis and exceed the phagocytic capacity of macrophages, leading to increased lysis, and necrosis of resident

Table 18.3 Inflammatory cell populations from milk samples with different levels of somatic cells count (SCC) in goats (adapted from Albenzio et al. 2015)

Inflammatory cells	L-SCC (n = 525)	M-SCC (n = 560)	H-SCC (n = 515)	±S.E.M.
Lymphocytes (%)	51.0[a]	37.1[b]	33.1[b]	2.4
Macrophages (%)	4.7[a]	5.7[b]	7.3[b]	0.5
PMNL (%)	42.0[a]	58.1[ab]	60.3[b]	2.4
Nonviable PMNL (%)	18.7[a]	9.2[b]	5.6[c]	1.4

L-SCC Low SCC (<0.7 × 10^6 cells/ml); *M-SCC* medium SCC (from 0.7 × 10^6 to 1.5 × 10^6 cells/ml); *H-SCC* high SCC (>1.5 × 10^6 cells/ml)
PMNL Polymorphonuclear leucocytes (neutrofils, eosinofils, and basofils)
[a–c]Means within a row with different superscripts differ ($P < 0.05$)

neutrophils (Paape and Capuco 1997; Kobayashi et al. 2003; Albenzio and Caroprese 2011). This may lead to the release of cytotoxic granules and oxygen free radicals that will damage the surrounding tissue and convert the matrix proteins into chemotactic factors that amplify the inflammatory process, attracting more cells (Paape and Capuco 1997; Paape et al. 2002; Kobayashi et al. 2003; Sladek and Rysanek 2006). The importance of this phenomenon is based on several factors: (a) the type of apocrine secretion, and the physiologically high SCC; (b) the fact that neutrophils are the most common cell population in goats' milk (Paape and Capuco 1997; Paape et al. 2001; Bergonier et al. 2003; Tian et al. 2005; Gomes et al. 2006; Madureira and Gomes 2010); and, (c) the 30% of milk neutrophils that undergo apoptosis or necrosis in milk with low SCC ($<300 \times 10^3$ cells/ml) (Tian et al. 2005).

Nevertheless, the ejection of milk during milking contributes to a constant supply of neutrophils to the gland and allows the removal of dead neutrophils, avoiding the release of toxic substances in the mammary parenchyma. In addition, frequent milking during clinical mastitis seems to favor the proper functioning of the immune system (Paape and Capuco 1997). The efficacy of neutrophils and macrophages in milk is decreased by ingestion of fat globules and casein particles (Paape and Wergin 1977; Cooray 1996; Amorena and Perez 1998; Tian et al. 2005). This fact, together with specific evasion mechanisms of some bacteria, can justify the persistence of some mastitis outbreaks.

Finally, the presence of caprine arthritis encephalitis virus in farms should be taken into account. According to Kaba et al. (2012), goats infected by this lentivirus only show a small decrease in total protein (0.05%), fat (0.15%), and lactose (0.05%), without significant yield milk variation. A decrease of 4.6 g per 1 kg milk from infected goats was observed after manufacturing fresh cheese (Nowicka et al. 2015) in accordance with the previous study.

There are some evidence that caprine arthritis encephalitis virus improves the SCC (Ryan et al. 1993; Nord and Adnøy 1997; Sánchez et al. 2001; Turin et al. 2005) but this response is not consensual (Leitner et al. 2010; Kaba et al. 2012) or can interact with other milk pathogens (Sánchez et al. 1998, 2001; Martínez 2000). The virus replication takes place in macrophages, at the low number in milk during the normal lactation, which increases in infected goats (Lerondelle et al. 1995). However, the SCC increase appears to be similar to an IMI caused by SCN (Ryan et al. 1993; Paape et al. 2007) and apparently nonadditive effects are observed (Sánchez et al. 1998, 2001).

18.5 Concluding Remarks

A "normal" milk flora mainly constituted by nonpathogenic environmental agents and commensal bacteria from the skin is essential for a goat udder health and for the cheese industry. For a correct cheese processing, the milk should be originated from goat farms with low IMI prevalence. Especial attention should be given to milk pathogens provoking a high inflammatory response as well as potential toxins production (e.g., *S. aureus* and *E. coli.*). Moreover, systemic pathogens with tropism for mammary gland, normally in endemic diseases, also can play a significant role.

Polymorphonuclear leukocytes (neutrophils) represents the major part of total leucocytes, even in noninfected mammary glands; and assume a great importance in cellular response to milk pathogens. However, little information about the key role of these cells in the caprine mastitis has been found. In consequence, further researches about leucocyte distribution and their relation with other inflammatory mediators are needed for a better understanding of the response to IMI in goats.

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Chapter 19
Understanding Mastitis in Goats (II): Microbiological Diagnosis and Somatic Cells Count

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Abstract Mastitis control plans include not only mastitis treatment but particularly intramammary infection diagnosis mainly caused by bacteria. Microbiological diagnosis and SCC should be used together, representing the best practice for a proper diagnosis, treatment, and prevention of mastitis. The detection and identification of bacteria are done by bacterial cultures and complemented by detection of specific bacterial DNA fragments using the more recent PCR techniques. Both methods show intrinsic advantages and limitations regarding the milk sample techniques and the bacterial species present in the mammary gland. So, SCC, as a tool of indirect mastitis detection measuring inflammation indicators, acquires a great importance. However, goats produce a more physiological number of somatic cells than other domestic ruminant species. Other than an inflammatory response to milk pathogens, SCC varies according to several noninflammatory intrinsic (e.g., lactation phase and parity of females) and extrinsic (e.g., milking procedures) factors. Consequently, a SCC threshold differentiating infected from noninfected goats should be taken into account and carefully used and interpreted for udder health management in farms. This chapter describes all these aspects and the laboratorial and field particularities that should be taken into consideration to diagnosis mastitis in goats properly.

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19.1 Introduction

Bacterial cultures and SCC are the choice tools to diagnose (sub)clinical mastitis and to implement mastitis control programs. The identification of milk pathogens is essential for the establishment of therapeutic plans and to define adequate prophylactic and handling strategies to control mastitis. Bacterial culture is the most appropriate diagnostic method to detect IMI in goats (Paterna et al. 2014) and is considered as the reference method by many authors (Contreras et al. 2007).

In addition to microbial culture, the identification of macroscopic changes in milk and signs of inflammation in the udder are essential for the diagnosis of clinical mastitis in goats (Smith and Sherman 2009). In the absence of these signs, indirect methods of diagnosis based on the measurement of inflammation indicators, with emphasis on SCC, are the main tools in the diagnosis of subclinical mastitis. However, SCC performance in goats should be assessed in depth with the same efficiency and objectivity in the overall management of the herd as in dairy cows (Burriel 2000). To obtain high-quality milk, it is very important to understand which are the infectious and noninfectious-related factors contributing to SCC variations. In fact, a considerable number of inflammatory and noninflammatory factors may influence milk SCC in goats (Jiménez-Granado et al. 2014). In the absence of mastitis, the SCC in goat milk can vary between 270,000 and 2,000,000 cells/mL (Paape et al. 2001). However, although physiological (or noninfectious) factors of variation of SCC are particularly numerous in goats, bacterial infections are the main cause of fluctuations in counts (de Crémoux et al. 1994; Raynal-Ljutovac et al. 2007; Leitner et al. 2012). Besides, sometimes, cutoff values for SCC show large differences because these depend on counting methods, which require further DNA techniques.

This chapter aims to discuss several specific aspects regarding milk pathogen detection and SCC at individual and farm levels as valuable tools for mastitis treatment and control in goats.

19.2 Microbiological Diagnosis

The classical diagnosis of clinical or subclinical mastitis using microbiological cultures is relatively easy and does not require complex laboratory procedures. Normally, aerobic blood agar, complying with the protocols of the US National Mastitis Council is used for the bacterial culture (Oliver et al. 2004; Paterna et al. 2014). For determination of total bacterial growth, plate count agar (PCA) is used according to ISO 4833: 2003 (Zweifel et al. 2005; Dik et al. 2009). These procedures require that the milk collection be done under aseptic conditions and after eliminating the first jets of milk. According to the methodology, the samples are cultured and incubated for 24–72 h, and the result is a count of observable colonies expressed in the colony-forming unit (CFU) per mL (Contreras et al. 2007).

With some exceptions (i.e., *Staphylococcus aureus* and *Mycoplasma* spp.), the infection threshold used in the diagnosis of subclinical IMI ranges from 250 to 500 CFU/mL (Contreras et al. 1997a; Paterna et al. 2014).

Although bacterial culture is used to validate other diagnostic tests, its limitations lead some authors to consider this method as a “pseudo” gold standard (Koop et al. 2012). Bacterial contamination of the sample can generate false negative results due to the inhibition of bacterial growth caused by pH reduction due to the fermentation of the contaminating flora, reducing the sensitivity of the test. It also presents limitations in the identification of mastitis caused by *S. aureus* (Koop et al. 2011, 2012). On the other hand, *Mycoplasma* spp. diagnosis in caprine mastitis requires the use of specific media enriched under special conditions of low oxygen and humidity (Razin and Freundt 1984). The methodology is technically more demanding, time-consuming (i.e., several days or weeks) and costly which makes its isolation difficult and leads to the fact that not all laboratories routinely search for mycoplasmas, being omitted in some studies and not considering *Mycoplasma* spp. in the etiology of goat IMI (Contreras et al. 2007).

For the diagnosis of subclinical mastitis, some authors have proposed that the isolation of the same pathogen should be done in, at least, two consecutive milk samples separated by at least 24 h (Sears and McCarthy 2003) or in 3 weekly samples (Dohoo et al. 2011). Koop et al. (2012) suggested that this last criterion is the best approach to the so-called gold standard. Due to the intermittent excretion of some infectious agents (i.e., *Mycoplasma* spp.) the culture, or PCR, of successive samples is necessary to correctly identify farms/herds affected by subclinical mastitis (Amores et al. 2012). However, due to practical reasons, only a single sample is taken, accepting the limitations of this practice (Contreras et al. 1997a; Paterna et al. 2014). Therefore, concomitant to isolation, inflammatory responses should be monitored, such as increased SCC, to identify true infections (Rovai et al. 2014).

Sánchez et al. (2004) recommended that, for microbiological analysis, the sample should be c-ollected after milking in order to minimize false positives. With this procedure, they were able to increase the sensitivity from 97.4% (samples taken before milking) to 99.4% (samples taken after milking). However, attention is drawn to the fact that milk harvested after milking is not valid because it overestimates SCC. Besides, the first squirts taken before the beginning of milking are normally the fraction used for bacteriological diagnosis and SCC (Jiménez-Granado et al. 2014). However, several studies have found that the first milk squirts have a similar SCC independently of the milk status (de Crémoux et al. 1996b).

After isolation and identification, the most prevalent microorganisms and those that cause the most severe forms of mastitis should be subjected to antibiogram in order to direct the treatment, avoiding the use of antibiotics that show *in vitro* resistance to these bacteria (Paterna et al. 2014).

Methods based on the detection of specific DNA fragments by PCR can be used in a complementary way to the bacterial culture (Paterna et al. 2014). The advantages that can be achieved with the use of PCR in relation to traditional methods include the reduction of false negatives (Schwaiger et al. 2012) due to the high specificity obtained, for the speed and ability to detect inactivated pathogens or altered ones by storage conditions (i.e., freezing) or by chemical preservatives (Amores et al. 2010, 2011; Rovai et al. 2014).

In clinical mastitis, the quickness of the results allows an early treatment and may reduce its total duration, improve therapeutic results, and decrease the unnecessary use of antibiotics (Pyörälä 2002; Barkema et al. 2006; van den Borne et al. 2010). In subclinical mastitis, where the duration of diagnosis is not crucial, the election of PCR or bacterial culture depends on the cost-benefit analysis associated with improved milk production and composition (Rovai et al. 2014). In the diagnosis of mycoplasmas, the PCR can even be used routinely given the complexity and cost of the culture and isolation (Tola et al. 1997; Lorusso et al. 2007; Oravcová et al. 2009; Amores et al. 2010, 2011).

The interpretation of PCR results should be careful because the sample may contain more than one bacterial species or give false-positive results in animals without inflammation (Koskinen et al. 2009). Contamination by extra-mammary bacteria may be the justification for these two misinterpretations (Taponen et al. 2009). This requires the application of rigorous aseptic procedures during collection and processing samples (Rovai et al. 2014). The isolation of several species can even be considered as “true positives”. The “false positives” to the PCR (i.e., considering the bacterial culture as the gold standard) may also be caused by low bacterial excretion or the medium used that does not allow the growth of the microorganisms present in the sample (Taponen et al. 2009). Rovai et al. (2014) found 98.9% agreement between PCR results and bacterial culture.

There are numerous protocols described for identification of agents responsible for IMI (Poulsen et al. 2003; Onni et al. 2010, 2011). The first step involves extracting the DNA from the sample according to the protocol of Tola et al. (1997). The identification and classification of coagulase-negative staphylococci in goats can be done by PCR-RFLP (Restriction fragment length polymorphism) based on the gap genes and 16 s after amplification and restriction of the groEL gene (Onni et al. 2010). The different restriction profiles with reference strains allowed the reclassification of some isolates previously identified by traditional biochemical techniques (Onni et al. 2010, 2011). Protocols for *S. aureus* allow to distinguish it from other coagulase-positive staphylococci but may also be useful for distinguishing resistant strains for some antibiotics. For example, amplification of the *S. aureus* specific nuc gene and mecA, which confers resistance to methicillin (Poulsen et al. 2003).

To detect *Mycoplasma agalactiae* it can be used, among many other protocols, the one suggested by Marenda et al. (2005), which focus on the poIC gene, capable of distinguishing *M. agalactiae* from different origins and phylogenetically close species, such as *M. bovis*. *M. capricolum* subsp. *capricolum*, *M. mycoides* subsp. *capri,* and *M. mycoides* subs. *mycoides* LC (Large colony; now considered subspecies of the previous one) belong to the so-called cluster Mycoides. The presence of mycoplasmas belonging to this group can be proven with the protocol developed by Woubit et al. (2007). The differentiation of the several mycoplasmas of this group can be conducted through the sequencing of the fusA gene

(Manso-Silván et al. 2009). To differentiate *M. putrefaciens*, Peyraud et al. (2003) described and validated a protocol centered on the ArcB gene.

Another option for the diagnosis of the four agents of contagious agalactia is the use of multiplex real-time PCR (MRT-PCR) based on the identification of poIC genes for *M. agalactiae* and fusA for the cluster Mycoides and *M. putrefaciens* (Becker et al. 2012). MRT-PCR allows a faster diagnosis of the disease with a single test, can quantify the DNA in the milk sample (Lorusso et al. 2007; Oravcová et al. 2009) and has a higher sensitivity (i.e., detection limit of 350 UFC/mL) (Becker et al. 2012). PCR—single-strand confirmation polimorphism (PCR-SSCP), a technique developed to identify all bacterial and bacterial communities with the help of universal primers (Com1 and Com2-Ph), already used in the diagnosis of mastitis in cattle (Schwaiger et al. 2012), can also be useful in the diagnosis of IMI in goats (Paterna et al. 2014).

Microbial culture is often time-consuming and fastidious or even PCR, more expensive, cannot be routinely used. In these situations, automatic counting systems of total bacteria can be used in milk samples. Nowadays, these are used by the industry in some regions of the world and the result determines, in part, the price of milk paid to the producer. Many of these methods use flow cytometry to count bacteria in raw milk, such as BactoScan FC® (Foss, Germany). The principle behind the cytometry is as follows: after milk homogenization, the suspension of bacteria present in the milk is stained and forced through a capillary tube, where the unit of measurement is subjected to a specific wavelength, and the light emitted recorded. Thus, each passing bacterium is recorded and the end result is the number of bacteria per unit volume, which is later converted to CFU/mL. This method offers good validity parameters. In the case of BactoScan FC®, the total bacterial counts (TBC) provided are highly correlated with the reference method (i.e., bacterial culture: coagulase-positive staphylococci); the repeatability and reproducibility are excellent (Tirard-Collet et al. 1991).

19.3 Somatic Cells Count: Methods and Techniques

Cells counting by direct microscopy is universally considered the SCC reference method (ISO/IDF 2008). However, methylene blue, indicated by the International Dairy Federation for cow's milk, should not be used in goat's milk, because it is not a specific DNA staining and thus does not distinguish between leukocytes and cytoplasmic particles, which translates into higher counts than the real ones (Raynal-Ljutovac et al. 2007). The reason is because goat milk secretion is apocrine and, besides the presence of somatic cells, there are also extracellular membranous material, nuclear debris, and cell fragments that correspond to large portions of cytoplasm originated from the distal alveolar mammary secretory cells (Gonzalo et al. 1998). In this sense, ISO 13366-1: 2008 recommends the methyl green pyronin as SCC staining in goat's milk. This technique is, however, time-consuming, tedious, and impractical as a routine examination. Its use is restricted to experimental studies with the calibration of automatic devices that differentiate different cell types (Guillout 2011).

California Mastitis Test Mastitis test is a semi-quantitative method to estimate the amount of DNA in milk and, indirectly, the amount of cells in milk. The interpretation of results is based on a rating scale ranging from 0 (negative) to 3+ (gel formation). This technique, which is widely used in cattle, has lower followers in goats, because of the greater physiological number of cells in this species. However, it is an easy and fast field test which can be used in real-time during milking procedures.

The fluoro-opto-electronic method (e.g., Fossomatic®, Foss, Denmark; Somacount®, Bentley, USA; and, Somascope®, Delta, USA) is a specific DNA method based on the counting nucleated elements after staining nuclear DNA with a fluorescent dye (i.e., ethidium bromide). Its use allows the automatic counting with results highly correlated with those obtained from counting in direct microscopy (Droke et al. 1993; Gonzalo et al. 2006). The use of this method with equipment that counts through flow cytometry has shown that differential counting is faster and more objective than direct microscopy examination (Boulaaba et al. 2011). This type of equipment has been used at laboratory level to carry out SCC of bulk tank milk, which serves as a parameter for establishing payment to milk producers in some regions. For example, in the Poitou Charentes region of France, it is used since 1994 (de Crémoux et al. 1997).

The physiological factors are always related to udder infection status, and their influence decreases during IMI (Luengo et al. 2004) or is even null in the case of infections by major pathogens (de Crémoux et al. 1994). It can be extrapolated that SCC normally results double in case of infection by minor pathogens and, at least quadrupled in case of infection by major pathogens. Mycoplasmas are not usually included in these studies, but in case of clinical mastitis, there is a very important increase in SCC similar to that of other major pathogens (Contreras et al. 2007; Paape et al. 2007; Raynal-Ljutovac et al. 2007; Paterna et al. 2014).

When there is unilateral mastitis, there is an increase of SCC in this affected mammary gland and in the another mammary gland too (Dulin et al. 1983; Droke et al. 1993; Aulrich and Barth 2008), at very similar levels, registering correlation coefficients of 0.9 between counts in the two mammary glands (Poutrel and Lerondelle 1983).

19.4 Factors Influencing Individual Somatic Cells Count in Goat's Milk

There are several inflammatory and noninflammatory factors (Table 19.1) that should be taken into consideration for a proper SCC interpretation in goats (Jiménez-Granado et al. 2014). Reviewing 12 references, Martínez (2000) found a range of SCC means from 272,000 to 2,000,000 somatic cells/mL from

Table 19.1 Main factors affecting somatic cell counts in goat milk

Inflammatory	Infectious etiology	– Bacteria – Caprine arthritis encephalitis virus – Mycoplasma
	Noninfectious etiology	– Physical agents – Chemical agents
Non inflammatory	Intrinsic	– Fraction of milking – Time between milking – Milking frequency – Daily variations – Stage of lactation – Number of lactation – Prolificacy – Breed – Production level – Heat – Parasitic infectations
	Extrinsic	– Type of milking – Feed – Stress – Seasonality – Farming system – Facilities – Mycotoxins – Vaccinations – Hormones for synchronization of estrus
Other factors	– Counting methods – Conservation and storage of samples	

Adapted from Jiménez-Granado et al. (2014)

pathogen-free udders; hence, it is key to consider all noninflammatory factors to understand SCC. However, a special attention to the milk samples' conservation and storage, from farm to laboratory, is crucial for a correct SCC procedure (Fig. 19.1).

19.4.1 Conservation and Storage of Milk Samples

At room temperature goat milk, as similar to cow (Kennedy et al. 1982) and sheep milk (Gonzalo et al. 2003), suffers a rapid deterioration of somatic cell integrity and counts tend to decrease over time (Jiménez-Granado et al. 2014). Although studies with sheep milk warn against this practice (Gonzalo et al. 1998), the cooling (4 °C) of the goat milk without any preservative for 10 days kept the counts relatively stable (Sánchez et al. 2005). In the analysis, at 60 and at 40 °C, of frozen goat milk samples no significant differences were found in the SCC between the temperatures used (Sierra et al. 2006), unlike what happens with sheep milk, where at 60 °C

Fig. 19.1 Rotary (carousel) radial milking machine with 32 places. At the end of milking, the teat cups detach automatically from teats preventing long milking duration and consequently potential udder damage (Besier et al. 2016) (provided by J. Simões)

there is a decrease of SCC (Martínez et al. 2003). However, Gonzalo et al. (2004) had already warned that the temperature in SCC in sheep milk did not affect the precision of the analysis, but its repeatability.

Regarding the preservative used in goat milk, bronopol compared to azidiol and a control group showed the best results by reducing SCC in less than 5% during the first 10 days of refrigeration (Elizondo et al. 2007). Bronopol also allowed a great stabilization of the somatic cells in frozen samples with a break of only 4–7% in the counts (Sánchez et al. 2005). It should be noted that bronopol is bactericidal and cannot be used for bacterial cultures. According to the available data for goat milk, the best results for accuracy and repeatability in SCC are obtained using bronopol as a preservative in samples refrigerated at 4 °C, which should be analyzed at 40 °C for the first 5 days after collection (Raynal-Ljutovac et al. 2007).

19.4.2 Inflammatory Factors from Infectious Origin

Such as indicated in the previous chapter, IMI always causes high SCC regardless of the responsible agent. This increase is more pronounced for major pathogens than for minor pathogens (Poutrel and Lerondelle 1983; Lerondelle and Poutrel 1984; Moroni et al. 2005a; Min et al. 2007; Bagnicka et al. 2011).

SCC from milk in bulk tank (SCCt) are only associated with the prevalence of IMI at the beginning of lactation (McDougall et al. 2014). From this point on, the SCCt can present important variations. There are a few studies that correlate total bacterial counts and SCCt (Park and Humphrey 1986; Tirard-Collet et al. 1991; Zeng and Escobar 1996; Raynal-Ljutovac et al. 2007), and correlation coefficients founded are low (0.4 on average). The variation of SCCt and total bacterial counts is explained in part by the IMI, but also by the dilution/concentration phenomenon, depending on the lactation phase (Koop et al. 2009). However, the total staphylococci rate (Staphylococci count) is correlated with the SCCt. So, an increase of one logarithmic unit (log10SCCt) corresponds to an increase of 100,000 cells/mL. Despite the high individual SCC during an IMI by *S. aureus*, no correlation was found between this bacterium counts and the SCCt, given its low prevalence in the IMI in some studies (Koop et al. 2010). Other major pathogens, such as streptococci and mycoplasmas, are also associated with significant increases in SCCt. There were no statistically significant differences in SCCt between farms chronically infected with *Mycoplasma* spp. (i.e., without clinical signs) and those where disease outbreaks occur (Corrales et al. 2004). The coliforms, however, are not correlated neither with standard plate count or total bacterial counts nor with SCCt, which can be explained by variations among farms and by their low percentage in total flora, about 1% (Koop et al. 2010).

Other than bacteria, caprine arthritis encephalitis virus (CAEV) plays a role in SCC. A positive association between seropositivity to the CAEV and the increase of the SCC was widely observed (Nord and Adnøy 1997; Turin et al. 2005; Lerondelle et al. 1992, 1995; Martínez 2000; Sánchez et al. 2001). However, some researchers (Luengo et al. 2004; Leitner et al. 2010) did not find significant differences between seropositive and seronegative goats in relation to milk production, the health status of the mammary gland, and SCC. In fact, macrophages, which are the cells where the virus replicates, suffer a great increase in milk from affected goats (Lerondelle et al. 1995); but there seems to be no additive effect on SCC due to the joint action of both processes: bacterial infection attracting neutrophils and CAEV infection attracting macrophages. This phenomenon is probably due to a decrease in macrophage functionality caused by CAEV infection, limiting the cellular response caused by IMI of bacterial origin (Sánchez et al. 1998, 2001).

Similar to cows, a correct dry-off therapy of goats with IMI can reduce the SCC in the next lactation (Baştan et al. 2015). In order to limit the use of antimicrobials, an approach to organic farms regarding low IMI prevalence and consequently an increase of microbiological quality of goat milk was done (Kyozaire et al. 2005; Malissiova et al. 2017). Vaccination against *Staphylococcus* spp. (Kautz et al. 2014), a major group of milk pathogens, is another approach to reduce IMI prevalence and consequently minimizing the antibiotic usage.

19.4.3 Inflammatory Factors from Noninfectious Origin

Physical factors, such as the trauma of various origins, occasional (i.e., during grazing or stabling) or repeated (i.e., during milking or nursing) can lead to increases in SCC in the absence of IMI (Perrin and Baudry 1993).

Chemical agents such as active principles and excipients of intramammary therapeutic specialties may elevate SCC (Long et al. 1984). Similarly, metabolites, such as urea, may have an irritating effect on the breast tissue (Issartial 1990).

19.4.4 Intrinsic Noninflammatory Factors

The lactation stage is the most important noninfectious source of SCC variation (Raynal-Ljutovac et al. 2007). The SCC decrease during the first days of lactation, and then increase gradually to drying period (Perrin and Baudry 1993; Wilson et al. 1995; Zeng and Escobar 1996; Haenlein 2002; McDougall et al. 2002; Karziz et al. 2007; Paape et al. 2007; McDougall et al. 2010; Madureira and Gomes 2010; Barrón-Bravo et al. 2013; Persson et al. 2014). Therefore, SCC is higher at the end of lactation (Baudry et al. 1993; Gomes et al. 2006) existing a negative correlation between SCC and milk yield (Rota et al. 1993; Zeng and Escobar 1995). At the end of lactation, the cell concentration is so high that it may become impossible to distinguish between infected and noninfected glands through SCC (Corrales et al. 1996). This trend is generally attributed to a dilution phenomenon: as lactation progresses and milk production is progressively lower the cellular elements of the milk are more concentrated (Wilson et al. 1995; Zeng et al. 1996).

A SCC daily variation also occurs. SCC are generally higher during afternoon milking than during morning milking. In addition, counts also tend to be increased from the beginning to the end of milking (Perrin and Baudry 1993; Zeng et al. 1997; Haenlein 2002; Persson et al. 2014). The fraction of the “clearing” at milking end has worse correlations with the total milk fraction of the gland, therefore, this fraction should not be used to determine the SCC (Contreras et al. 1998).

SCC also increase with the number of lactations. Most of the researchers (Dulin et al. 1983; Wilson et al. 1995; de Crémoux et al. 1994, 1996b; Boscos et al. 1996; Contreras et al. 1997b; McDougall et al. 2002; Bergonier et al. 2003; Luengo et al. 2004; Paape et al. 2007; Quintas 2015) observed a positive correlation between the number of lactations and SCC, although other studies do not support this evidence (Zeng and Escobar 1995; Leitner et al. 2004a). The influence of a number of lactations on SCC seems to depend on the health status of the udder and the agent involved in case of IMI.

During goats estrus there is an increase of SCC (Mehdid et al. 2013) and a decreased milk production (Bergonier et al. 2003). The effect of estrus on SCC is transient, lasting only a few days (Moroni et al. 2007; Christodoulopoulos et al. 2008) and occurs independently of the decrease in milk production (McDougall and Voermans 2002). So, milk samples taken from a bulk tank or individual goats should be avoided during estrus synchronization programs (Talafha et al. 2008).

Toggenburg and Alpina breeds are the ones that present the highest SCC means and the Oberhasli the smallest one (Paape et al. 2007; Barrón-Bravo et al. 2013). Moreover, a SCC reduction by genetic selection in goats has been suggested (Rupp et al. 2011; Bagnicka et al. 2016). However, the differences among breeds do not categorically confirm the genetic implication of this factor (Jiménez-Granado et al. 2014). The possible racial differences can be attributed to different health status, levels of production, and differences in management among farms of the studied breeds (Sánchez et al. 1998).

The number of born kids can influence SCC (Luengo et al. 2004; Jiménez-Granado et al. 2012a; Quintas 2015). Higher SCC may be the result of increased development of the mammary parenchyma in pregnant goats with multiple births (Luengo et al. 2004) or due to a poor udder health status in goats nursing more than one kid.

Finally, several authors have noted a significant variability in daily (Zeng et al. 1997), weekly (Pettersen 1981) as well as monthly SCC (Martínez 2000). Thus, in primiparous goats, the SCC can range from day to day values of less than 200.000 to 1,000,000 cells/mL (or even over 2,000,000 cells/mL) and the next day back again to the normal mean value (Zeng et al. 1997).

19.4.5 Extrinsic Noninflammatory Factors

The SCC of the goat milk obtained at the end-of-day milking is 17–78% higher than that obtained at the morning milking (Sinapis and Vlachos 1999; Cedden et al. 2008). This fact is due to: (a) the "dilution effect", since the milk yield obtained in the morning milking is 35–69% higher than at the end-of-day milking (Aleandri et al. 1996; Contreras et al. 1998); (b) the effect of intra-alveolar pressure variation on the leukocyte diapedesis into the *acini lumen*. At the morning milking, there is a greater amount of milk in the udder, and therefore, this intramammary pressure results in a smaller transfer of leukocytes from the blood into the milk (Bergonier et al. 1996); (c) the "pulling effect" of milking from morning to end-of-day. At the end of the morning milking, there remains in the udder some residual milk with high SCC. This milk, together with the fact that the milking interval is shorter with lower milk yield, contains higher somatic cell concentration at the time of end-of-day milking (Gonzalo et al. 1994); hence, the time between milking is considered as a SCC variation factor (Jimenez-Granado et al. 2014).

Milking frequency, twice a day (2x) or only once a day (1x), varies with the breed and production system considered (Capote et al. 2008; Castel et al. 2010). However, its effect on goat milk's SCC is controversial (Jimenez-Granado et al. 2014).

The influence of the type of milking in goats, manual or mechanical, on SCC has been studied by several researchers. The results observed are not coincident, probably due to the existence of differences in IMI prevalence, productive periods, age of goats, among other factors (Sánchez et al. 1998). Thus, Kosev et al. (1996) observed lower SCC in manually milked goats; Randy et al. (1991) obtained lower SCC in machine-milked animals; and Zeng et al. (1996) observed no significant differences between the two types of milking. On the other hand, mechanical milking has been associated with 1.3 times greater risk of general microbiological positivity, and 1.5 times greater risk of positivity for *Streptococcus uberis*. In turn, manual milking has been associated with a 3.4-fold higher risk of positivity for *Staphylococcus caprae* (Marogna et al. 2012).

In the analysis of parameters and mechanical milking conditions, no influence has been found on the SCC when comparing different combinations of parameters: vacuum level, frequency and pulse ratio of 40/90/60 versus 36/120/60, respectively, (Díaz et al. 2004). On the other hand, the SCC do not vary with the type of milk conduction in the milking line (i.e., medium line vs. low line) (Manzur 2007; Manzur et al. 2012). However, the use of teats with automatic valves, where the vacuum is not interrupted manually before separating teats, increases the risk of mastitis and the SCC at the beginning of lactation (Manzur 2007).

Sánchez-Rodríguez et al. (2005) observed significant differences in SCC and bacterial counts between the "most appropriate" and the other milking facilities (i.e., "good" vs. "regular"). Nevertheless, in that study, no significant differences were found between different milking facilities. These data reinforce the premise that the improvement of the hygienic-sanitary quality of milk should not only focus on the milking machine and routine, but also taken into account the central role that good facilities can play (Sánchez-Rodríguez et al. 2005; Jiménez-Granado et al. 2014).

The farm production system can influence the SCC. When comparing intensive and semi-intensive production systems, Sánchez-Rodríguez et al. (2005) found significant differences recording the lowest values in intensive farms. This may be due to the existence of better facilities and milking routines, as well as better hygienic practices in these farms (Jiménez-Granado et al. 2014); besides, some goats can suffer injuries while grazing and browsing.

In the absence of infection, the less productive goats have higher SCC (Wilson et al. 1995; Martínez 2000; Sánchez-Rodríguez et al. 2000; Jiménez-Granado et al. 2012b). Therefore, it is important to emphasize that milk production is lower in primiparous compared to multiparous goats; and that the highest yields are recorded in goats from the third and fourth kidding (Goetsch et al. 2011). Jiménez-Granado et al. (2012c) established the SCC threshold <1,300,000 cells/mL as a target to maintain bromatological quality (i.e., fat and protein contents) in Florida goat's milk.

A rise in SCC may be associated with dietary management disturbances, such as those causing acidosis, alkalosis, or other metabolic disorders (Lerondelle et al. 1992; Fedele et al. 1996). This increase may be caused, at least in part, by the decrease in milk production in animals with these disorders, which results in a higher concentration of somatic cells (Jiménez-Granado et al. 2014). Thus, an unbalanced ration in nitrogen, energy or minerals can cause a significant increase in the SCC at tank milk level (Sánchez et al. 2007). The provision of complete and balanced diets was shown to lead to significantly lower SCC than other diets (i.e., semi-completed, grain mix, or compound feed) (Sánchez-Rodríguez et al. 2005). When goat diets are based only on grazing, SCC values are slightly lower than when they are supplemented with a source of energy (i.e., barley-based concentrate). The highest counts are obtained when animals are supplemented with a protein concentrate (Fedele et al. 1996).

González López (2017) verified the effect of ingestion of moldy silages on goats, identifying mycotoxin T-2, associated to a reduction of milk yield (0.2–0.5 L of milk per day) and an irregular increase in SCC.

Feeding stress (i.e., sudden diet change) and collective treatments are associated with elevations in SCC (McDougall et al. 2001; Bergonier et al. 2003; Raynal-Ljutovac et al. 2007). SCC increasing are described after vaccination against enterotoxemia (Lerondelle et al. 1992) and in response to stress caused by parasitic infestations of scabies (Pérez-Baena et al. 2012); in the latter case associated with the decrease in milk production. Significant temporary increases in SCC of the tank milk were also observed after blood sampling, or tuberculin skin test (Corrales et al. 1997).

The transport of goats by truck for 45 min, however, did not affect SCC within 1 hr after transport (McDougall et al. 2002).

The effect of seasonality is expressed by the influence of the photoperiod-temperature binomial on milk production and, indirectly, on SCC (Peris et al. 2002a). The long days were associated with the percentage increase of the milk fat and the decrease of the SCC (García-Hernández et al. 2007; Barrón-Bravo et al. 2013). Thus, in spring with increasing photoperiod, mild temperature, and generally availability of better food, tends to increase production and, therefore, SCC decreases (Peris et al. 2002b). In the summer, SCC is expected to increase as high temperatures decrease milk production. In the autumn and winter months, the situation tends to be opposite to that found in spring (Delgado-Pertíñez et al. 2003).

The use of sponges with progestagens for synchronization of estrus causes a reduction of the SCC in the luteal phase and increase the counting during the estrus (Moroni et al. 2007). In addition, Jiménez et al. (2009) observed that the application of melatonin implants decrease SCC in goats.

Finally, significant temporary increases in SCC of the tank milk have been registered after the introduction of bucks on the farm in the reproductive season (Aleandri et al. 1996; Calderini et al. 1996; Borges-Pizarro et al. 2004). However, it is not entirely clear, whether in the latter case, the increase is due to stress by the presence of the males, the estrus or both causes simultaneously.

19.5 Interpreting the Somatic Cells Count

The definition of a threshold of positivity for individual SCC is controversial (Souza et al. 2012). For McDougall et al. (2001), when examining a particular animal, the influence of the various physiological factors, the lactation phase, and the number of lactations does not allow to know the predicted value of the result based on SCC, which, despite the limitations, consider to be a very useful tool.

Thus, other researchers suggest the interpretation of the SCC regarding the lactation phase, according to the regression curve of the estimated SCC in function of the lactation phase, even with a low regression coefficient (r^2=0.64) (Haenlein 2002). Min et al. (2007), although observed significant differences ($P < 0.01$) between the mean SCC of infected mammary glands (4,761,000 cells/mL) and that of the noninfected ones (2,259,000 cells/mL), they verified that there was not always a correlation between SCC and IMI. Therefore, they suggested that bacterial culture should always be included in the diagnosis of mastitis.

In Spain, the most consensual threshold for diagnosis of subclinical IMI in Murciano-Granadina goats is, considering the geometric mean of SCC monitored monthly for 7 months, 1,100,000 cells/mL (Sánchez et al. 1999; Paterna et al. 2014). This threshold correctly classifies 75% of mammary glands with a sensitivity of 57% and specificity of 75% (Sánchez et al. 1999). This threshold may be reduced to 500,000 cells/mL at the beginning of lactation in farms with optimal management conditions (Contreras et al. 1996).

de Crémoux et al. (1994) defined SCC thresholds that allow presuming the status of IMI, in order to obtain the most adequate parameters of sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) (Table 19.2). These researchers suggested that the best SCC thresholds to account into consideration between healthy goats and goats infected by CNS or between these latter and goats infected by major pathogens is 750,000 cells/mL and 1,750,000 cells/mL, respectively.

Taking into account variations during lactation, it is advisable to determine a threshold for the peak of lactation. Koop et al. (2011), using the Fossomatic® cell counter, proposed a SCC threshold of 1,500,000 cells/mL to detect mastitis by *S. aureus* in goats, for the compound of samples from the two mammary glands (composite milk) with a sensitivity value of 0.9 and 0.95 of specificity. This threshold may be raised to 2,000,000 cells/mL or more at the end of lactation, keeping the percentage of false positives at acceptable levels. To avoid the effect of decreased specificity of the test due to SCC variations during lactation, these researchers do not recommend its use at the end of lactation, although its

Table 19.2 Health status in relation to each possible SCC threshold value (annual geometric mean of 1060 goats)

	Threshold value ($\times 10^3$ cells/ml)									
	Healthy goats versus infected by CNS					Infected goats by CNS versus MP				
Threshold chosen	500	**750**	1000	1500	1750	500	750	1000	1500	**1750**
Sensitivity (%)	82.1	**66.5**	52.4	33.3	27.6	98.0	91.0	88.4	81.9	**70.9**
Specificity (%)	54.1	**65.8**	73.3	83.5	86.1	17.9	33.5	47.6	66.7	**72.4**
PPV (%)	74.5	**76.0**	76.3	76.7	76.5	7.3	8.2	9.9	13.9	**14.4**
VPN (%)	64.8	**54.5**	48.5	43.4	42.1	99.3	98.3	98.4	98.3	**97.4**
Efficiency (%)	71.5	**66.2**	60.3	52.4	49.8	22.9	37.0	50.1	67.6	**72.3**

bold indicates SCC thresholds defined by de Crémoux et al. (1994)
Adapted from de Crémoux et al. (1994)
CNS coagulase-negative staphylococci; *MP* Major pathogens; *PPV* Positive predictive value; *NPV* Negative predictive value

determination is necessary to calculate the SCC mean of lactation. In the case of IMI by major pathogens (i.e., *S. aureus*) the sensitivity and specificity of the threshold of 2,000,000 cells/mL are influenced not only by the lactation stage but also by the number of lactations and milk production (Koop et al. 2013).

On the other hand, Persson and Olofsson (2011) using the DeLaval® portable counting equipment observed SCC means of 711,000 cells/mL for the infected glands and 481,000 cells/ml for the noninfected ones, with sensitivity and specificity values of 0.67 and 0.63, respectively.

19.5.1 Somatic Cells Count and Milk Production and Quality

Goats with high SCC produce less milk liters (Wilson et al. 1995; Leitner et al. 2004b; Moroni et al. 2005a). A study carried out by Baudry et al. (1997) on thousands of goats, comparing batches of animals from the same farm, of the same breed and the same number of lactations, in order to determine the impact of these factors, showed an important loss of daily milk production when SCC are high. In this study, goats were categorized into three classes according to SCC (Table 19.3). The loss of milk production was approximately 7% (55 kg) for the SSC2 goat class and 17% (132 kg) for the SCC3 goat class (Baudry et al. 1997).

On the other hand, goat milk with high SCC have as much or more protein than milk with low SCC, that is, the casein content is similar or lower but has more soluble proteins because of the inflammation (Leitner et al. 2004a, 2007). At the same way, it contains less fat and lactose due to decreased udder secretion capacity (de Crémoux et al. 1996a; Baudry et al. 1997; Leitner et al. 2004a, b, 2011; Moroni et al. 2005b; Bernacka 2006; Raynal-Ljutovac et al. 2007) (Table 19.4). However, seeing the impact on milk production, the total protein amount is reduced by 25% and fat by 31%.

Table 19.3 Goat health status according to SCC in milk (Baudry et al. 1997)

Category	Criterion	Conclusion
SCC1	Animals with all counts <750,000 cells/ml, with one exception, at most	Presumably healthy goats
SCC2	Animals with at least 2 counts> 750,000 cells/ml; and, at most two counts >1,750,000 cells/ml	Goats presumably infected by minor pathogens
SCC3	At least three counts >1,750,000 cells/ml	Goats presumably infected by major pathogens

SCC Somatic cells count

Table 19.4 Effects of the degree of the mammary inflammation on milk yield and composition at 200-days of lactation

SCC (×1000/ml)	Goats (n)	Results for 200 days of lactation				
		Milk (kg)	Fatty matter (kg)	Protein matter (kg)	Fat (g/kg)	Protein (g/kg)
<200	235	790	25.5	22.1	32.3	28.1
200–400	2169	723 (−8%)	23.0 (−10%)	20.3 (−8%)	31.8	28.0
400–800	6070	700 (−11%)	21.8 (−15%)	19.6 (−11%)	31.2	27.9
800–1600	7841	660 (−16%)	20.5 (−20%)	18.6 (−16%)	31.1	28.2
1600–3200	4291	622 (−21%)	19.1 (−25%)	17.8 (−19%)	30.8	28.6
>3200	1054	571 (−28%)	17.5 (−31%)	16.6 (−25%)	30.6	29.1

Source de Crémoux et al. (1996a)
SCC Somatic cells count

Table 19.5 Distribution of milk goat quality categorized by SCC according to SCCt

SCCt (×1000/ml)	SCC1 (%)	SCC2 (%)	SCC3 (%)
<500	>72	6–11	2
1000–1250	52 ± 6.3	34.5 ± 6.6	8.1 ± 1.9
>2000	<50	>35	>15

Source de Crémoux (2003)
SCC Somatic cells count; *SCCt* Somatic cells count in bulk tank milk
SCC1, SCC2, and SCC3—SCC of goat classification according to the criteria proposed by Baudry et al. (1997) (see Table 19.2)

19.5.2 Somatic Cells Count and Intramammary Infection

de Crémoux (2003) proposed rules of interpretation of the annual geometric means of SCCt in order to estimate the prevalence of IMI, by measuring SCC. For this purpose, SCC and SCCt data from 226 farms were used (Table 19.5) and goats were categorized according to Baudry et al. (1997) criteria. For SCCt in orders of 1,000,000–1,250,000 cells/mL, about 42% (SCC2 + SCC3) of goats are infected, while for SCCt over 2,000,000 cells/mL the proportion of infected goats increases for more than a half (de Crémoux 2003). Bergonier et al. (2003), estimated the percentage of infected animals, without isolate the agents, of 30% (±12), 39% (±8), and 51% (±8) for annual geometric means of 750,000; 1,000,000, and 1,500,000 cells/mL, respectively.

19.6 Concluding Remarks

The diagnosis of IMI is crucial to treat mastitis and implant a control plan in dairy herds. Similar to dairy cows and ewes, microbiological, and SCC assessments are currently used for milking goats. However, several particularities of the goat species and its management should be taken into consideration.

Other than the frequent coagulase-positive and -negative staphylococci bacterium isolation, *Mycoplasma* spp., and CAEV can pose several constraints during diagnosis and results in interpretation in endemic farms or regions. Moreover, goats present a significant epithelial cells/cytoplasmic particles excreted from apocrine glands to milk as well as inflammatory cells which varies not only with IMI, but also with intrinsic and extrinsic noninflammatory factors. All these variables should be taken into account to determine an SCC threshold in individual goats and in bulk tank milk for mastitis assessment in farms.

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Chapter 20
Control Strategies to Face Major Tropical and Subtropical Diseases Affecting Goats

Carlos Gutiérrez and João Simões

Abstract Many tropical and subtropical animal diseases are currently threatening the survival of livestock and people living in those affected regions. Unfortunately, they have received little attention by researchers and pharmaceutical companies but examples like rinderpest, officially eradicated in 2011, suppose a hope that global efforts can gain the battle against devastating tropical animal diseases. A second example would be the foot-and-mouth disease, which was eradicated from Europe after continental efforts coordinated by a special commission, which was set up in 1954. Despite some outbreaks occurred in England (2001 and 2007) and Bulgaria (2011), the control measures laid down in Council Directive 2003/85/EC, were able to control and eventually eradicate the outbreaks. Diseases that affect goats such as Rift Valley fever, peste des petits ruminants, goat pox, contagious caprine pleuropneumonia, heartwater or trypanosomosis are highly relevant in Africa, Asia and Latin America to a lesser extent, and would be a real threat for farmers but also a challenge for scientists. In fact, the next challenge for the international animal health organizations seems to be the eradication of Pest des Petits Ruminants, which has been estimated to be in 2030. The present chapter supposes a state-of-the-art review of the major tropical and subtropical diseases affecting goats with particular emphasis to the control strategies in the fight against them.

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20.1 Introduction

Many tropical and subtropical animal diseases are currently considered as neglected given the little attention received by both pharmaceutical companies and researchers. The presence of these diseases in the poorest and marginalized areas of Africa, Asia and Latin America has a negative impact on animal production and, consequently, on the local economy. However, examples like rinderpest could be a hope that with coordinated efforts at worldwide scale can gain the fight against devastating tropical animal diseases. Known since eighteenth century, in 1994 the Food and Agriculture Organization (FAO) established the Global Rinderpest Eradication Programme, which coordinated multiple actions by several organizations that led to be rinderpest declared as officially eradicated by a FAO/OIE (World Organization for Animal Health) joint committee in 2011, 10 years after last outbreak occurred in Kenya (FAO/OIE 2011). A second interesting example would be the FMD in Europe, where a special FAO commission (EuFMD) was set up in 1954, when the disease was affecting severely the continent; thus, coordinated efforts have also made Europe an FMD-free territory (FAO/EuFMD 2017), with the exception of the epidemic outbreaks occurred in England in 2001, which were controlled by implementing urgent measures. Since then, other outbreaks have occurred in UK in 2007, or more recently in Bulgaria in 2011 (European Commission 2017). Thus, all control measures are laid down in Council Directive 2003/85/EC, which is of application to all member states. In Latin America PANAFTOSA (2017) and in Southeast Asia SEAFMD (2017), research centres were established in 1951 and in 1997, respectively, to control and eradicate FMD from their regions. Important advances have been made since they were inaugurated supposing also examples that global and regional collaborations are another essential key to achieve the diseases' control.

Many other tropical diseases, unfortunately, have not received the same attention and suppose nowadays a real threat for farmers, but also a challenge for scientists. At this concern, among the different tropical and subtropical diseases, there is no consensus on how many of them we can consider at the highest relevance, but probably those affecting seriously livestock in terms of virulence, contagiousness and mortality should be taken into consideration when control strategies are set up in an affected geographical region. Diseases affecting animal productions in terms of low milk, meat or other by-products' performances would make unsustainable the livestock and their associated economy and must also be taken into account. In the particular case of goats, diseases like RVF, PPR, goat pox, contagious caprine pleuropneumonia (CCPP), heartwater or trypanosomosis seem to be highly relevant particularly in Africa and Asia and also in Latin America to a lesser extent.

The present chapter supposes a state-of-the-art review of major tropical and subtropical diseases affecting goats with particular emphasis to the control strategies in the fight against them. Some important diseases, like FMD, will not be considered given the enormous available information that Organizations such as OIE, FAO and others offer at different ways and permanently updated.

20.2 Rift Valley Fever

20.2.1 Background

RFV (family *Bunyaviridae*, genus *Phlebovirus*,) is a mosquito-borne pathogen that affects humans and animals in Africa continent since 1931 (Hartman 2017), but also in Saudi Arabian and Yemen in the Arabian Peninsula (2000) and the island of Madagascar (2008) (WHO 2016). Domestic ruminants are particularly affected by RFV, goats included (OIE 2016), although others domestic species like camels or horses and wild animals like lions or elephants can also become infected (Hartman 2017). Rift Valley fever virus (RVFV) supposes a classic example of the multi-faceted intersection among human health, animal health and vector ecology representing the 'One-Health' aspects of most zoonotic arboviruses (Fig. 20.1) (Bird and McElroy 2016).

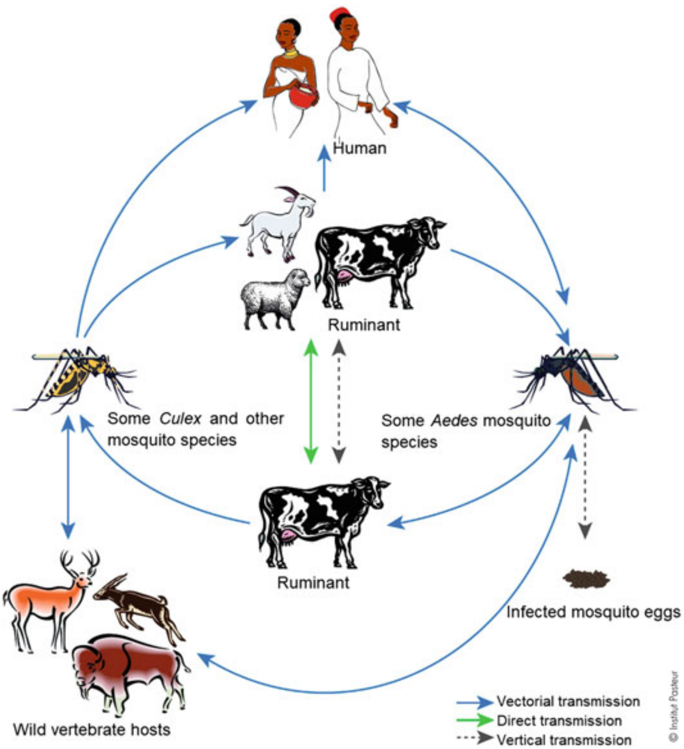

Fig. 20.1 Cycle of Rift Valley fever zoonosis. The enzootic form involves *Aedes* mosquitoes which also can transmit the virus to offspring (vertical transmission). The infection of hosts occurs by direct contact and/or vector (mosquito) transmission. Epizootic outbreaks surge by hatching of infected Aedes eggs, normally in unusual rains or warm seasons (adapted from Balenghien et al. 2013)

Clinical signs of the disease are usually nonspecific, making difficult to detect infected individuals during epidemics (Mansfield et al. 2015); however, signs will depend on the animal species and some animal conditions such as age and pregnancy. In general, RFV can be suspected in the presence of abortions, mortalities among young animals and together with disease in humans (OIE 2016). Human beings can become infected by mosquito bites or by contact with contaminated livestock tissues, fluids or aborted materials (Bird and McElroy 2016). In the particular case of goats, an experimental study has demonstrated an innate immune response to RVF based on the secretion of cytokines (IFN-γ, IL-12 and other proinflammatory cytokines but not IFN-α) that neutralized antibodies after viremia had been cleared (Nfon et al. 2012). The same study revealed that the course of infection with insect cell-derived RVFV (IN-RVFV) appeared to be different from mammalian cell-derived RVFV (MAM-RVFV), confirming that there were possible differences depending on whether infection occurred by mosquito bites or by contact with other infected materials, which should be taken into account when testing RVF vaccines at laboratory level.

Diagnostic methods for RVF virus include virus isolation in cell culture or in sucking mice, ELISA (antigen-detection enzyme-linked immunosorbent assay), PNRT (plaque reduction neutralization test), RT-PCR (reverse-transcription polymerase chain reaction) or immunopathology. RVFV can be isolated from blood, ideally preserved with anticoagulant, during the febrile phase of the disease, or from organ samples (liver, brain or spleen) of died animals or from the organs of aborted fetuses (OIE 2016).

20.2.2 Control Strategies in Livestock

Once an outbreak has been detected in a particular herd, several control measures must urgently be implemented for preventing spread of the disease by mosquito control, immobilization of the infected animals, ban on infected animal slaughtering, use of protective material for people handling animals, carcasses, aborted fetuses (gowns, gloves and masks) (Hartman 2017). Measures to protect people from an RVF outbreak in livestock are given by WHO (http://www.who.int/mediacentre/factsheets/fs207/en/).

To prevent RVF, nowadays there are available live attenuated and inactivated vaccines, but regional or national regulatory agencies can recommend the particular use/availability of some of them in a determined area (OIE 2016). In fact, vaccination of the animals is not only a tool for controlling epizootics but it also prevents the possibility of spread to humans (Hartman 2017).

Vaccines currently available are:

1. The live attenuated Smithburn vaccine, derived from Smithburn's original neurotropic strain, which is safe for use in cattle, sheep and goats (Barnard 1979). Side effects are seen in pregnant females, in which fetal abnormalities or

abortion can occur. This vaccine has successfully been used many times for the control of RVF in Eastern and Southern Africa and, more recently, in the Middle East (OIE 2016).

2. The Clone 13 vaccine is a naturally attenuated strain, carrying a large deletion in the NSs gene, which encodes the main virulence factor (Muller et al. 1995). The risk of reversion is considered unlikely and side effects were not seen in experimental vaccine trials in sheep (Hunter and Bouloy 2001; Dungu et al. 2010), although recent investigations have demonstrated that this attenuated virus is able to cross the sheep placental barrier and to cause fetal infection, malformations and stillbirths (Makoschey et al. 2016). Clone 13 vaccines have successfully been used in goats without adverse effects in pregnant females (Lo et al. 2015).
3. Inactivated RVFV vaccine is produced by formalin-inactivation using a field strain of RVFV adapted to growth in cell culture (Barnard 1979). The main disadvantage is that inactivated RVF vaccines require an initial vaccination, 3–6 months boosters and annual booster as well (OIE 2016).

In endemic areas, the goal is the control and prevention of epizootics and epidemics, contributing, at the same time, to the improvement of livestock production. In these endemic areas prioritized vaccines would be those at one dose (with a long-lasting immunity of at least one year) or, secondly, a life-long immunity after a limited number of doses, while in non-endemic or free areas, if potential risk is present (animal or animal products movements from infected areas) vaccines can be used for the prevention of the disease or, even, to control the introduction of the virus (OIE 2016).

Concerning vector control, strategic larvicidal agents used in the mosquito breeding habitats is highly useful. We can use both treatments, hormonal inhibitors such as methoprene and larvical toxins (for example produced by *Bacillus thurigiensis*) with positive effects, which are commercially available (FAO 2003).

Regarding the animal movements and their control, these do not appear to have any effect when an outbreak is detected within an infected country. However, movements of animals between infected and non-infected areas, regions or countries is very relevant because the arrival of viremic animals within the incubation period could disseminate the disease into new territories, particularly in the presence of large populations of mosquitos (rainy season) (FAO 2003).

20.3 Peste Des Petits Ruminants

20.3.1 Background

PPR (also see Chap. 13 of volume 1), caused by a *Morbillivirus* belonging to *Paramyxoviridae* family, is one of the most important diseases of sheep and goats around tropical and subtropical regions. PPRV has been considered as a variant of rinderpest virus but adapted to small ruminants (Albina et al. 2013). In the past two decades, PPR has spread greatly and nowadays affects Africa (with the exception of the southern countries), the Middle East, Turkey, West and South Asia, and China as well (FAO/OIE 2016). With a morbidity and mortality rates close to 100% and 80–90%, respectively, PPRV originates enormous economic losses for the small ruminant production in the world (FAO/OIE 2016). Clinically is characterized by high fever and inappetence in acute form of disease, followed by congestion of oral, ocular and nasal mucosae showing serous discharges that progress to more mucopurulent and abundant (Roeder and Obi 1999), bronchopneumonia and diarrhea also appear commonly within 5–10 days after the onset of clinical signs, causing high mortality (Diallo 2006). Abortions are commonly seen during PPR outbreaks, which can be directly caused by PPRV or in combination with other abortive pathogens (Kulkarni et al. 1996; Abubakar et al. 2008). PPRV produces immunosuppression in the patients and opportunistic pathogens often complicate the clinical signs (Kerdiles et al. 2006); however, surviving animals develop a strong life-long immunity acting on the virus (Albina et al. 2013). The transmission is usually by direct contact between infected and non-infected small ruminants because PPRV is inactivated within a few hours in the environment (Albina et al. 2013). However, the environment can be important in the epidemiology of the diseases in goats, since it has been demonstrated that PPRV can be excreted in the feces, at least, during two months after a natural infection (Ezeibe et al. 2008; Abubakar et al. 2012). PPRV seems to affect goats more severely than sheeps (Lefèvre and Diallo 1990), although different seroprevalences have been found in affected goats and sheeps in outbreaks occurred in Turkey (Özkul et al. 2002), Ethiopia (Abraham et al. 2005), Tanzania (Swai et al. 2009) or Tunisia (Ayari-Fakhfakh et al. 2011). Some factors could explain these serological differences; i.e. the management systems, animal density or strain virulence (Couacy-Hymann et al. 2007), but also affected species and breed (Diop et al. 2005). Thus, some authors have indicated that Sahelian goats would be more resistant than Guinean dwarf goats and that experimentally infected Alpine goats would show a very high sensitivity (Hammouchi et al. 2012). PPRV is considered as non-pathogenic to cattle or buffaloes; nevertheless, some evidences point out that camels could be susceptible (Roger et al. 2000; Khalafalla et al. 2010) and may act as reservoirs of the virus.

After the successful global eradication of rinderpest in 2011, the next challenge for the international animal health organizations seems to be to fight definitively against PPR. The 'International Conference for the Control and Eradication of peste des petits ruminants (PPR)', held in Abidjan in April 2015, approved the PPR Global Control and Eradication Strategy (PPR GCES), which would be developed jointly by FAO and OIE, and whose main purpose was to eradicate the disease by 2030. This Resolution on the Global Control and Eradication of PPR was definitively went on by the delegates in the 84th General Session of the OIE World Assembly in May 2016 (FAO/OIE 2016). The four fundamental pillars that support the global PPR eradication programme were: (i) availability of effective prevention and control tools/measures; (ii) scientific and technical feasibility of eradication over a 15-year period; (iii) a benefit/cost ratio estimated at 33.8; and (iv) international consensus in favour of PPR eradication. However, the feasibility of the PPR eradication will depend on lessons learnt from the rinderpest eradication, such as stated in the 2017–2021 programme, but also other many epidemiological, financial or organizational aspects (Albina et al. 2013).

Diagnostic procedures in the field are based on suspected clinical signs, post-mortem lesions and histological findings. However, virus should be detected by molecular biology techniques such as RT-PCR or one-step RT-PCRs, which are the most sensitive methods (Bao et al. 2008; Kwiatek et al. 2010). In laboratories where molecular techniques are not available, ELISA can be performed (Libeau et al. 1994). When an outbreak occurs, isolation and growth in cell cultures are required to characterize PPRV strain involved.

20.3.2 Control Strategies and Eradication

In the 5-year FAO/OIE programme on PPR GCES (2017–2021), four components are clearly established: (i) promoting an enabling environment and reinforcing veterinary capacities; (ii) support to the diagnostic and surveillance systems; (iii) measures supporting PPR eradication; and, (iv) coordination and management. Different competencies at Global, Regional and National levels are also established, having been identified nine regions in PPR GCES. Programme approach includes (i) diagnosis system; (ii) surveillance system; (iii) prevention and control system; (iv) framework for PPR prevention and control system; and, (v) stakeholders' involvement in PPR prevention and control. The programme will be completed in a four-stage period, whose phases are: (i) assessment stage; (ii) control stage; (iii) eradication stage; (iv) post-eradication stage.

When an outbreak occurs in a PPR free territory, standard measures to control an animal disease must be implemented, such as quarantine, ban of animal movements, sanitary slaughter and cleaning and disinfection given that the virus is sensitive to most disinfectants. Once PPRV has been detected, mass vaccinations of goats and sheeps seem to be the most effective measure to control the outbreak. Available homologous vaccines conferring a life-long immunity after a single immunization, which was developed with attenuated Nigeria 75/1 strain in the 1980s (Diallo 2003). However, its low thermal stability (half-life of 2–6 h at 37 °C after reconstitution) (OIE 2013a) is the main limiting factor. In that sense, the vaccine has been improved mixing the train with cryoprotectant containing trehalose, extending preservation to 5–14 days at 45 °C in the lyophilized form, and 21 h at 37 °C after reconstitution (Worrall et al. 2000; Silva et al. 2011).

20.4 Goat Pox

20.4.1 Background

Goat pox virus (GPV), belonging to genus *Capripoxvirus*, family *Poxviridae*, affects mainly domestic goats with enormous impact in endemic regions (also see Chap. 13 of volume 1). The other two species of genus *Capripoxvirus* are lumpy skin disease virus and sheep pox virus, which affect cattle and sheep, respectively. Sheep pox virus and GPV were once misclassified and were considered two strains of the same virus, but genetic sequencing has demonstrated that they are separate viruses (Hosamani et al. 2004). Most strains are host specific affecting goats or sheep, but some strains infect both species with evidences that recombination between strains occurs in the field (Gershon et al. 1989).

GPV is endemic in Central and North Africa, the Middle East, India, China, Vietnam and Chinese Taipei (Fig. 20.2) (OIE 2010). Infected goats develop fever, macules in the skin, rhinitis, conjunctivitis and sialorrhea. Macules are progressively enlarged and develop into papules and scabs later. Pox lesions can occupy over 50% of the skin surface in naive animals; however, in enzootic areas lesions would be restricted to a few nodules under the tail and must be detected in a careful examination (Babiuk et al. 2008). Internal organs, particularly the lung, can also be affected showing the characteristic pox-like lesions. In severely affected goats, respiratory distress and finally death occur (Babiuk et al. 2008). Concerning transmission, infected sheep and goats shed virus in oral, nasal and ocular

Fig. 20.2 Worldwide distribution (grey areas) of sheep pox and goat pox (Madhavan et al. 2016)

secretions and transmission occurs through aerosols and direct contact (Bowden et al. 2008); thus, mechanical transmission by insect vectors would not be required; however, experimental studies have demonstrated that *Stomoxys calcitrans* is able to infect sheep (Kitching and Mellor 1986).

The characteristic skin and visceral pox lesions are indicative of GPV, but definitive diagnosis requires laboratory confirmation by PCR or by the identification of typical capripox virions using the transmission electron microscope. However, electron microscopy cannot differentiate among *Capripoxvirus* (Kitching and Smale 1986), which is particularly relevant for Sheep pox virus because it can affect goats as well. The virus can also be cultured in ruminant origin tissue (Binepal et al. 2001), causing intracytoplasmic inclusions clearly identified using Hematoxylin and Eosin staining (OIE 2010). The current gold standard for determining anti-capripoxvirus antibodies is virus neutralization, but requires live capripoxvirus, it is slow and labour intensive (Babiuk et al. 2008). Other reported serological methods are ELISA (Rao et al. 1997) and western blotting assays (Chand et al. 1994), but there are not validated ELISA for *Capripoxvirus* and the latter is difficult to perform and interpret (Babiuk et al. 2008).

20.4.2 Control Strategies

No specific treatment against GPV has been reported.

Sanitary prophylaxis includes the euthanize of infected animals (and proper destruction of carcasses), isolation of infected animals (and herds) for at least 45 days after successfully recovery, cleaning and disinfection of facilities and equipment, quarantine of newly introduced animals into disease-free herds, and control of animal and vehicle movements within affected zones (OIE 2010).

Medical prophylaxis includes live and inactivated vaccines, taking into account that all strains of capripoxvirus so far examined share a major neutralization site and will cross protect. Thus, vaccination would be the most effective measure to control the spread of GPV (Tuppurainen et al. 2017), although only live attenuated vaccines are available in the market nowadays. These vaccines confer immunity up to two years. Currently, a new generation of capripox vaccines is being developed using capripoxvirus genome as a vector for the genes of other ruminant pathogens (OIE 2010).

20.5 Contagious Caprine Pleuropneumonia

20.5.1 Background

CCPP is a highly contagious disease of goats caused by *Mycoplasma capricolum* subsp. *capripneumoniae*, which was designed as F38 until 1976 (MacOwan and

Minette 1978). The disease affects many African and Asian countries, but given that diagnosis is very difficult other mycoplasmas showing clinical signs and lesions resembling CCPP (*Mycoplasma mycoides* subsp. *capri*) are erroneously attributed to causing the disease. In fact, about 40 countries in Africa and Asia have reported clinical evidences of CCPP, but *M. c. capripneumoniae* has only been detected in 20 of them because not all laboratories have available technology and experience to isolate and identify mycoplasmas (Nicholas et al. 2008).

Despite CCPP is typically a goat disease, when an outbreak in mixed goat and sheep herd occurs, sheep can be infected as well (Bölske et al. 1996); even *M.c. caprineumoniae* has been isolated from healthy sheep (Litamoi et al. 1990). Thus, the role of sheep as a reservoir for the disease is under reappraisal (OIE 2014). Other wild ruminants have been infected in outbreaks occurred in Qatar and the United Arab Emirates (Nicholas and Churchward 2012), hence the role of wild ruminants as potential reservoirs should also be considered. The disease is transmitted by close contact between infected and non-infected animals, through the expulsion of infected droplets during coughing. The disease is highly contagious, and for a successful transmission, only a brief period of contact is needed (Thiaucourt and Bölske 1996).

CCPP is considered as one of the most severe diseases of goats (Thiaucourt and Bölske 1996), is extremely contagious and frequently fatal, and in East Africa and the Middle East, where CCPP is endemic, causes enormous economic losses (OIE 2014).

Diagnostic methods to confirm CCPP, *M. c. capripneumoniae* should be by isolated or strongly supported by serology, lesions restricted to pleura and lung and based on pleuropneumonia and, at lung level, enlargement of the interlobular septa does not occur (OIE 2014).

20.5.2 Control Strategies

As an urgent measure to face an outbreak of CCPP, the successful treatment of the affected animals can be achieved using effective antibiotics as tetracyclines, fluoroquinolones or the macrolide family like tylosin in the first stages of the disease (Hassan et al. 1984; Ozdemir et al. 2006). Nevertheless, this measure does not imply the complete elimination of the bacterium and, after treatment, the animals are considered as potential carriers (Nicholas and Churchward 2012).

Common sanitary prophylaxis through quarantines, movement controls, euthanize of infected and exposed animals, and cleaning and disinfection of the facilities should be adopted as soon as possible (OIE 2014).

Vaccination is the best way to eradicate successfully CCPP. In fact, it was achieved in Southern Africa in 1889 by applying immunization of the animals through preparations containing pleural fluid or affected lungs homogenates, in combination with the slaughter of the affected animals (OIE 2014). The current available CCPP vaccine contains inactivated *M. c. capripneumoniae* suspended in saponin has a shelf life of at least 14 months and provides protection for over one year (Rurangirwa et al. 1987).

20.6 Heartwater

20.6.1 Background

Heartwater (formerly cowdriosis) is an infectious disease caused by *Ehrlichia ruminantium*, order *Rickettsiales*, family *Anaplasmataceae* (Dumler et al. 2001), which is transmitted by *Amblyomma* ticks (Bekker et al. 2002).

Heartwater is found in practically all the sub-Saharan African countries where *Amblyomma* ticks are present, including the islands of Madagascar, Reunion, Mauritius, Zanzibar, the Comoros Islands and Sao Tomé (OIE 2008). Heartwater has also been described in the Caribbean islands of Guadeloupe, Antigua and Marie-Galante (Perreau et al. 1980), supposing a serious threat to America continent (OIE 2008). Ruminants are the affected species, particularly domestic ruminants (cattle, sheep and goats) are the most susceptible hosts for *E. ruminantum*, except those local breeds raised in endemic areas, which are more resistant. Wild ruminants are also affected, being under consideration their role as reservoirs in the epidemiology of the disease (Peter et al. 2002). *E. ruminantium* has also been associated with human and canine infections, but further characterization studies are necessary prior we can consider a possible pathogen in species other than ruminants (OIE 2008).

Indigenous goat breeds of endemic areas present high resistance to infection, however, imported goats (especially Angoras) are highly susceptible (Yunker 1996). Clinical signs in goats will depend on clinical form of the disease and the strain of *E. ruminantium* involved. In most cases, heartwater is an acute febrile disease and may involve neurological signs and respiratory distress, showing a high mortality (Yunker 1996). However, subacute heartwater with less pronounced signs, and also peracute heartwater with sudden death, can also occur (OIE 2008).

Diagnosis is based on clinical symptoms taking into account the different clinical forms of the disease, and also by post-mortem examination with hydropericardium (from which the disease' name is derived) as most characteristic macroscopic lesion, but also petechiae on the epicardium and endocardium, hydrothorax, pulmonary edema, intestinal congestion, the mediastinal and bronchial lymph nodes edematous, congestion of the brain, or moderate splenomegaly are observed (Yunker 1996; OIE 2008). Identification of *E. ruminantium* can be achieved by observing bacterium colonies in the brain or intima of blood vessels (brain smears once air-dried, fixed with methanol and stained with Giemsa) and also using PCR. Serological tests to detect *E. ruminantium* antibodies are ELISAs and western blot. However, cross-reactions with *Ehrlichia* spp. are expected when the whole *E. ruminantium* is used as antigen, and for that, serology has limited diagnostic applications (OIE 2008).

20.6.2 Control Strategies

Heartwater outbreaks are usually controlled with quarantines, euthanasia of infected animals and tick control. It is important to remark that *E. ruminantium* is not able to survive outside a living host for just a few hours, so transmission occurs after importing infected animals, subclinical carriers and by ticks. Clinically affected animals can be treated with tetracycline (oxytetracycline at 10 mg/kg or doxycycline at 2 mg/kg), being more effective during the early stages than in later stages (OIE 2008).

No commercial vaccines are available in the market currently. The only method to immunize the animals against *E. ruminantium* is the 'infection and treatment', administering infected blood followed by tetracycline in reacting animals (Bezuidenhout et al. 1994). Currently, this method is still in use in some endemic areas, but it is expected to be replaced by attenuated or inactivated vaccines in the next future (OIE 2008). Some interesting research on vaccinations in goats and based on inactivated *E. ruminantium* have been reported, particularly the use of Freund as adjuvant (Martínez et al. 1994), or in Montanide ISA 50 oil adjuvant with similar results (Martínez et al. 1996), and whose dose can do so low as 35 μg of antigen without decreasing of the protective effect, 28-fold lesser than the initial reported dose (Vachiery et al. 2006). This fact can do cheaper the final cost of vaccine per animal. Some advances have also been made on vaccines based on attenuated *E. ruminantium*, which confer a strong long-lasting protection against a homologous isolate but poor protection against heterologous. The extraordinary inestability requiring their storage in liquid nitrogen and their administration by intravenous route is the weakest points (OIE 2008). Some other research on recombinant vaccines shows promising results in mice (Nyika et al. 2002) and in sheep (Collins et al. 2003), but recombinant vaccines are not expected to be applied in the field in the future (OIE 2008).

20.7 Trypanosomosis

20.7.1 Background

Trypanosomes are flagellate protozoans belonging to order *Kinetoplastida*, genus *Trypanosoma*, family *Trypanosomatidae* that invade the blood plasma, the lymph and various tissues of their hosts (OIE 2013b). Trypanosomosis supposes a serious constraint on ruminant livestock production in many areas of Africa, Asia and Latin America. Goats, among other ruminants, can be affected by different trypanosome species, affecting adversely the economic efficiency in endemic areas (OIE 2013b). Trypanosomes are classically divided into Stercoraria and Salivaria sections, based on their life cycle in the insect vector. Salivaria section includes species only transmitted by tsetse flies (*Glossina* spp.), like *Trypanosoma congolense* and *T. brucei*, while others may be either cyclically transmitted by tsetse flies, or mechanically transmitted by other hematophagous insects (*T. vivax*), or only mechanically (*T. evansi*) or sexually transmitted (*T. equiperdum*), this latter affecting equines exclusively.

An important aspect to be considered in Africa is the trypanotolerance of some ruminant species and breeds, which is better understood in cattle breeds like N'Dama and West African Shorthorn than in small ruminants, whose mechanisms of tolerance are not well understood. About 43% of the goats in Central and West Africa are considered as trypanotolerant, and hence, the exploitation of the genetic resistance to trypanosomosis by using indigenous breeds is one approach to the control of the disease (Agyemang 2005). Thus, West African Dwarf (WAD) goats or Sea goat breeds (Kenya) are considered as trypanotolerant, although variations occur according to trypanosome species (*T. congolense* and *T. vivax*) and strains (Bengaly et al. 2002). Nevertheless, genetic introgression has been demonstrated making some breeds into WAD goats more susceptible to trypanosomosis, which explains the higher trypano susceptibility seen recently and put the light on the preservation of the genetic purity of trypanotolerant goat breeds in Africa (Geerts et al. 2009).

Diagnosis of trypanosomes are based on identification of the agent particularly in blood samples, using wet or dry-stained thick or thin blood films, concentration methods like micro-hematocrit centrifugation technique (Woo technique), which increase sensitivity, or PCR, the method of choice to identify the parasite genus, species or subspecies (OIE 2013b). Serological methods commonly used in cattle are ELISA and indirect fluorescent antibody test, but information about goats is limited.

Tsetse trypanosomes is a disease complex caused by *T. congolense*, *T. vivax* and *T. brucei brucei* affecting livestock in the tsetse belt of Africa and causing a disease in animals known locally as 'Nagana'. Although cattle is a specially affected host, small ruminants are also infected in that areas (OIE 2013b). Thus, *T. congolense* is the most common trypanosome of goats in Africa, and these animals serve as reservoirs of this parasite for other species. The trypanotolerance to *T. congolense* of WAD goats is similar to its F1 crosses with the Sahelian breed (trypanosusceptible) (Faye et al. 2002), and also to its F1 crosses with Saanen goats (trypanosusceptible) (Dhollander et al. 2005). Experimental infection in WAD goats affected reproductive performance with abortions, premature births and perinatal losses, although transplacental transmission of *T. congolense* or lesions in placenta could not be demonstrated (Faye et al. 2004). Specific diagnostic methods for *T. congolense* described are a PCR using GOL as primer set (Pereira de Almeida et al. 1998) and an indirect ELISA (Lejon et al. 2003). *T. vivax* is the second most common trypanosome of goats in Africa, extending its distribution beyond tropical zone because of its transmission by other hematophagous insects. Introduced in South America in 1830, goats have been recognized as reservoir hosts for *T. vivax* in many countries in the region (Gardiner and Mahmoud 1992). *T. brucei*, causing natural infection in goats, has sporadically been reported in the literature, concretely in WAD goats in The Gambia (Osaer et al. 1999). Goats are relatively resistant to

T. brucei gambiense, the causative agent of West African human sleeping sickness, but they have been implicated as reservoir host of the parasite (Makumyaviri 1991). Goats have also been suggested as reservoirs of *T. brucei rhodesiense*, the causative agent of East African human sleeping sickness (Robson and Rickman 1973).

T. evansi, the causative agent of surra, a disease of camel and horses that produces important economic losses in endemic areas, has also been described in goats causing subclinical, moderate and severe infection (Gutiérrez et al. 2006). Diagnosis based on blood smears is commonly difficult due to low parasitemia that usually occurs in goats; thus, more sensitive methods to detect *T. evansi* would be PCR (Ashour et al. 2013), or mini anion exchange centrifugation technique (Gutiérrez et al. 2004a). Serological methods like ELISA (Olaho-Mukan et al. 1992), indirect immunofluorescence (IFI) (Jacquiet et al. 1993) or by a direct card agglutination test (CATT/*T. evansi*) and an indirect latex agglutination test (LATEX/*T. evansi*) (Gutiérrez et al. 2004b) have been reported.

20.7.2 Control Strategies

Budd (1999) cited by Agyemang (2005) proposed the term 'trypanosomiasis control' for those strategies based on therapeutic compounds that kill trypanosomes in the host or by use of resistant livestock breeds to survive in infected areas and, the term 'tsetse control' referred to reduce the tsetse flies as indirect measure. When strategy is focused to remove completely tsetse flies from a determined area, the term is 'tsetse eradication' and, consequently, the diseases transmitted by them.

The use of trypanocides to control trypanosomosis has widely been used until now, in fact, about 25% approximately of all affected cattle in Africa have been protected by this method (Budd 1999 cited by Agyemang 2005). Despite its beneficial use, emerging drug-resistance of many *Trypanosoma* spp. strains has been observed, particularly to isometamidium, diminazene and homidium bromide, being the three trypanocides most commonly used (d'Ieteren et al. 1998). This fact seems to affect entire regions of West and East Africa (Agyemang 2005). The enormous difficulty to develop vaccines against trypanosomes due to the antigenic variations showed by these parasites suggests a rationale use of these drugs in the frame of an integrated disease management strategy (Geerts and Holmes 1998). In general, curative doses used in cattle can also be applied for goats (Ilemobade 1986). Thus, diminazene aceturate and quinapyramine dimethyl sulfate are considered as very effective trypanocides in goats, although relapses of trypanosomes have been described using diminazene aceturate, probably caused by the re-emergence of the parasites from the central nervous system because the drug is not able to cross the blood–brain barrier (Whitelaw et al. 1985). Isometamidium chloride is also an effective trypanocide but signs of shock or death in goats have been reported when given intravenously at doses greater than or equal to 0.5 mg/kg (Schillinger et al. 1985). Homidium chloride or homidium bromide is effective against *T. vivax* and *T. congolense*. Goats experimentally infected with *T. evansi* were cured after a single dose of a melarsamine (Cymelarsan®) at 0.3 mg/kg in acute stage (Zweygarth et al. 1992) or at 0.5 mg/kg in chronic stage (Gutiérrez et al. 2008). New research using diamidine compounds in goats infected with *T. evansi* seems to be promising (Gillingwater et al. 2011).

Regarding tsetse control, after the mass use of insecticides affecting environments and forest in the past, nowadays more 'friendly' techniques such as trapping, the use of odour-baited targets (Jordan 1986) and the treatment of animals with insecticide (Bauer et al. 1992) are being carried out. However, these techniques can only be developed in limited areas, are costly in preventing the re-invasion and possible resistance in non-tsetse targets like ticks, to pyrethroids as common insecticide product, which is also commonly used on livestock (Agyemang 2005).

20.8 Concluding Remarks

Many tropical and subtropical animal diseases are currently threatening the survival of livestock and people in those affected regions, and efforts must be made to alleviate their effects in terms of morbidity, mortality and animal product quality for a better development of rural communities in the poorest regions of the world.

The tropical diseases considered in this chapter should be combated from all possible approaches, particularly controlling the outbreaks by means of (a) sanitary measures (e.g. immobilization of the infected animals/herds, euthanize of unrecoverable animals, cleaning and disinfection of the facilities); (b) prophylactic measures (vaccination if available); (c) therapeutic measures (using proper antimicrobials); and, (d) post-therapeutic measures for a long-time period for screening the animals to check the disease status until the complete recovery of the animals. This includes regular serological checking to estimate the evolution of specific antibodies untill the complete seroconversion, in which an outbreak can be considered as definitively eradicated. Many of these diseases are zoonotic and, consequently, protective measures must be taken by personnel handling infected animals and materials.

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Chapter 21
Microbiological Safety of Goat Milk and Cheese: Evidences from a Meta-Analysis

Vasco A. P. Cadavez, Vânia Rodrigues and Ursula A. Gonzales-Barron

Abstract This chapter synthesizes published information concerning the incidence of zoonotic pathogenic microorganisms—*Listeria monocytogenes*, *Staphylococcus aureus* and shigatoxin-producing *Escherichia coli*—in raw goat milk and cheese. Meta-analytical data were extracted from primary studies undertaken in Brazil, China, Czech Republic, Germany, Iran, Italy, Malaysia, Mexico, Norway, Portugal, Spain, Sweden, Switzerland, Turkey and USA. In both raw goat milk (overall incidence 42.6%; 95% CI: 23.0–64.8%) and cheese (overall incidence 26.4%; 95% CI: 10.8–51.6%), *S. aureus* was found to be the most frequent contaminant bacterium, which suggests that control measures during milk handling are still to be reinforced. In addition, the high frequency of detection of generic *E. coli* in raw goat milk cheese (overall incidence 11.9%; 95% CI: 3.8–31.6%) is another indicator of hygiene deficiencies during production. Moreover, *E. coli* strains with virulence genes have been very frequently detected in raw goat milk (overall incidence 10.5%; 95% CI: 5.3–19.6%). *L. monocytogenes*, a pathogen that mainly affects the susceptible population, presented a high incidence in both raw goat milk (overall incidence 3.4%; 95% CI: 2.2–5.1%) and goat milk cheese (overall incidence 8.5%; 95% CI: 4.9–14.6%). In conclusion, the present meta-analysis confirms that raw goat milk and cheese are important vehicles of transmission of foodborne diseases. Further research work towards improving the current microbiological quality of these products, particularly in traditional production units, is essential.

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21.1 Introduction

In 2015, the amount of milk produced by EU member states was approximately 168.2 million tonnes. Production of cow milk represented 96.8%, milk from ewes 1.7%, goat milk 1.3% and buffalos' milk only 0.18% (EUROSTAT 2016). Despite goat milk composition is similar to cow milk, goat milk is either transformed into cheese, mostly in Mediterranean countries and Latin America, or consumed raw or acidified in Africa and South Asia. Goats' production systems are mainly small-scale enterprises; thus, the milk processing techniques employed present a wide variation from country to country and/or region to region, according to local traditions and market's demand.

If compared to cow milk, goat milk has some interesting properties such as the smaller size of protein micelles, the smaller fat globules and also the higher levels of short- and medium-chain fatty acids, which are responsible for its easier and higher digestibility (Roberts 1985). However, raw milk is an excellent medium for the growth of microorganisms; hence it is very perishable and requires careful handling. Raw milk is susceptible to pathogenic microorganisms, which have been found to be responsible for several foodborne diseases associated not only to raw milk but also to products thereof. Hence, milk processing is an essential step to ensure its preservation, and to reduce milk spoilage and foodborne illness in consumers.

When goats present healthy udders, the milk secreted can be considered as non-infected, and natural inhibitors, such as lacto-ferrin and lacto-peroxidase, prevent the growth of bacteria, at ambient temperatures, during the first three or four hours immediately after milking (Ay and Bostan 2017). Hence, during this initial period, milk ought to be cooled to 4 °C so as to preserve its original quality. Even, in regions with poor hygienic standards, the use of lacto-peroxidase system is recommended to control the microbiological quality of raw milk (Ay and Bostan 2017; Codex Alimentarius 2007).

Raw goat milk has a mixed microflora (bacteria, virus, fungi, yeasts and parasites) derived from several sources (FSANZ 2009), including direct transfer from blood (FSANZ 2009; Verraes et al. 2015) and environment, such as exterior surfaces of the goat, feces, milk-handling equipment and personnel (FSANZ 2009; Verraes et al. 2015). The routes of contamination of raw goat milk can be classified (FSANZ 2009) into: (i) animal factors: animal health and husbandry; (ii) environment factors: housing, faeces, feed, soil and water; and (iii) milking practices: milking methods, personnel, equipment, storage, packaging and delivery.

The hygienic quality of raw goat milk is the primary key to produce good-quality and safe milk and milk products to consumers; thus, good hygiene practices throughout the dairy goat's chain are essential to assure goat milk quality. Foodborne pathogens pose a major threat to public health, as can be seen by the reported hospitalization and fatal cases due to zoonoses in 2015 in the EU: 5901 cases of Shiga toxin-producing *E. coli* (STEC) infections, 2206 cases of listeriosis and 94625 of salmonellosis (EFSA 2016). It is expected that the number of cases be considerably higher as many foodborne illnesses remain unreported. This is especially relevant in rural developing regions where raw milk is normally consumed and the public health organizations have poor reporting systems (Oliveira et al. 2011).

A broad range of microbiological hazards has been identified from previous research studies; refer to FSANZ (2009) and Verraes et al. (2015) for an overview of human pathogenic microorganisms that are the main microbial hazards associated with raw goat milk consumption. However, there is only a small number of research studies focused on the quantification of human pathogenic microorganisms in raw goat milk and thereof products. For this chapter, data concerning the frequencies of detection of foodborne hazards were collected for raw goat milk and cheese. In raw milk, frequencies of occurrence were found for: *Listeria monocytogenes*, *Staphylococus aureus* and *E. coli* O157:H7; and in cheese, frequencies of detection were found for: *L. monocytogenes*, *S. aureus* and general *E. coli*, as hygiene indicator. Thus, for this meta-analysis compilation work, we focus on the aforementioned biological hazards which are the most recurrent microorganisms reported in research papers concerning raw goat milk and products.

21.2 Meta-Analysis

The objective of this meta-analysis study was to estimate the overall incidence of foodborne pathogens in raw goat milk and cheese. For this, searches on electronic public libraries, using the Scopus and Scielo databases, were carried out to find published articles and official reports, summarizing the occurrence of microbiological hazards in these products. The bibliographic searches were undertaken using the following formulas:

Scielo: [('occurrence') OR ('prevalence') OR ('incidence') OR ('concentration') OR ('contamination') OR ('count') OR ('survey') OR ('sampling')] AND [('*Listeria*') OR ('STEC *Escherichia coli*') OR ('*Staphylococcus aureus*') OR ('*Salmonella*') OR ('*Campylobacter*') OR ('*Brucella*') OR ('*Mycobacterium*')] AND ('goat milk') AND NOT [('artificial') OR ('meta-analysis') OR ('systematic review') OR ('extract') OR ('livestock') OR ('spiked') OR ('feed')];

Scopus: [TITLE-ABS-KEY ('occurrence') OR TITLE-ABS-KEY ('prevalence') OR TITLE-ABS-KEY ('incidence') OR TITLE-ABS-KEY ('concentration') OR TITLE-ABS-KEY ('contamination') OR TITLE-ABS-KEY ('count') OR TITLE-ABS-KEY ('survey') OR TITLE-ABS-KEY ('sampling')] AND [TITLE-ABS-KEY ('*Listeria*') OR TITLE-ABS-KEY ('STEC *Escherichia coli*') OR TITLE-ABS-KEY ('*Staphylococcus aureus*') OR TITLE-ABS-KEY ('Salmonella') OR TITLE-ABS-KEY ('*Campylobacter*') OR TITLE-ABS-KEY ('*Brucella*') OR TITLE-ABS-KEY ('*Mycobacterium*')] AND [TITLE-ABS-KEY ('goat milk') AND NOT [TITLE-ABS-KEY ('artificial') OR TITLE-ABS-KEY ('meta-analysis') OR TITLE-ABS-KEY ('systematic review') OR

TITLE-ABS-KEY ('extract') OR TITLE-ABS-KEY ('livestock') OR TITLE-ABS-KEY ('spiked') OR TITLE-ABS-KEY ('feed')].

The occurrence of microbial hazards in raw goat milk and cheese is a binary trait (i.e. a sample tests either positive or negative for the pathogen), thus the parameter to measure the effect size is the raw proportion p (or incidence, being calculated as the number of successes, i.e. positive samples, s, divided by the total sample size, n). In order to restrict the range of the effect size or pathogen's incidence from 0 to 1, and to stabilize the variance, the logit transformation of the raw proportion was used as the effect size measure θ as proposed by (Viechtbauer 2010). For more details concerning the meta-analysis of pathogens' occurrence data refer to Xavier et al. (2014).

After assessing all the information presented in every study, a total of 24 primary studies were considered appropriate for inclusion in this meta-analysis study for having used approved microbiological methods and presenting sufficient and extractable data. The meta-analysis study for raw milk were based on 18 primary studies (Jamali et al. 2013; Abou-Eleinin et al. 2000; Guerra et al. 2001; Foschino et al. 2002; Muehlherr et al. 2003; Albarracin et al. 2008; D'Amico and Donnelly 2010; Vyletělová et al. 2011; Cupáková et al. 2012; Farzan et al. 2012; Spanu et al. 2013; Soto Beltran et al. 2015; Bogdanovičová et al. 2015; Cavicchioli et al. 2015; Durmaz et al. 2015; Bogdanovičová et al. 2016; Marozzi et al. 2016; Xing et al. 2016), while the ones for cheese were based on eight primary studies (Perez et al. 1998; Guerra et al. 2001; Moreno-Enriquez et al. 2007; Akineden et al. 2008; Brito et al. 2008; Rosengren et al. 2010; Jakobsen et al. 2011; Soto Beltran et al. 2015). From each of the primary studies (j), the number of samples (s) experiencing the event of interest (i.e. testing positive for a pathogen) and the total number of samples (n) were extracted. Information such as pasteurization, production stage (if applicable) and year of the survey was also annotated from every primary study. For the research papers, a total of 55 observations of incidence (s/n) of foodborne pathogens were extracted from the 24 primary studies. The simplest random-effects meta-analysis model (Viechtbauer 2010) was used to evaluate the variability (i.e. heterogeneity) among the true effects estimated by the primary studies.

21.3 Occurrence of Foodborne Pathogens in Raw Milk

In spite of the broad knowledge concerning the huge negative impact that food-borne diseases can represent for goats' producers, data concerning the microbial pathogens occurrence in goat milk and milk products are limited. For instance, in the last EFSA report (EFSA 2016), there is very little information on biological hazards in goat milk and thereof products.

The results of the meta-analysis study for the incidence of *L. monocytogenes*, *S. aureus* and *E. coli* O157:H7 in raw goat milk are presented in Table 21.1. Mean effect size, standard error (S.E.), confidence intervals, between-study variability (τ^2) and tests for heterogeneity (Q) are compiled.

Table 21.1 Meta-analysis results for the occurrence of *L. monocytogenes*, *S. aureus* and Shigatoxin-producing *E. coli* (STEC) raw goat milk

Value	*L. monocytogenes*	*S. aureus*	STEC
Effect size	0.034	0.426	0.105
S.E.	0.5547	0.6138	0.5924
[95% CI]	[0.022–0.051]	[0.230–0.648]	[0.053–0.196]
Pr > |t|	<0.001	0.518	<0.001
Q stat	1.881 (d.f. = 6)	138.5 (d.f. = 13)	7.744 (d.f. = 4)
P-value	0.930	<0.001	0.101
τ^2	0.0	2.684	0.3304

S.E. standard error; *CI* confidence interval; *Q* stat test for heterogeneity; τ^2 between-study variability; *d.f.* degrees of freedom

The forest plot of the meta-analysis model on the occurrence of *L. monocytogenes* in raw goat milk is shown in Fig. 21.1. As illustrated, *L. monocytogenes* was detected in raw goat milk with frequencies varying between 0.8% in the study of Foschino et al. (2002) and 3.8% in the study of Abou-Eleinin et al. (2000). The meta-analysis model indicated that the overall incidence of *L. monocytogenes* in raw goat milk was 3.4% (95% CI: 2.2–5.1%). A random-effects model was not fitted to this data partition since the between-study variability turned out to be non-significant (test of heterogeneity $Q = 1.881$; $P = 0.930$ in Table 21.1). In spite of being a rare disease, listeriosis causes severe illness (Durmaz et al. 2015) with a high mortality rate in the susceptible population, i.e. young, pregnant, immunocompromized and elderly people). Hence, the presence of *L. monocytogenes* in raw goat milk represents a microbiological hazard for the cheese industry, and inactivation methods are then essential to control the *L. monocytogenes* before manufacturing soft goat milk cheeses based on the use of unpasteurized goat milk (Abou-Eleinin et al. 2000).

The forest plot of the random-effects meta-analysis on the occurrence of *S. aureus* in raw goat milk is shown in Fig. 21.2. The meta-analysis model indicated that the incidence of *S. aureus* in raw goat milk is 42.6% (95% CI: 23.0–64.8%), and the between-study variability was significant as shown by the test of

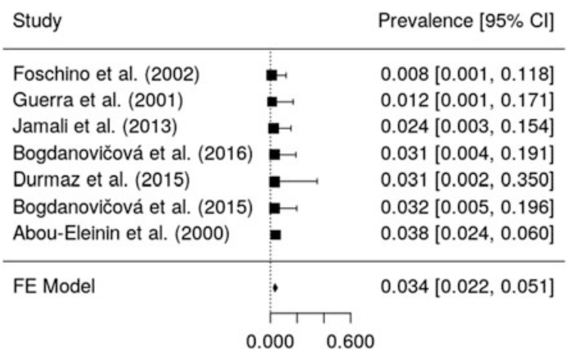

Fig. 21.1 Forest plot of the fixed-effects (FE) meta-analysis model of incidence of *L. monocytogenes* in raw goat milk

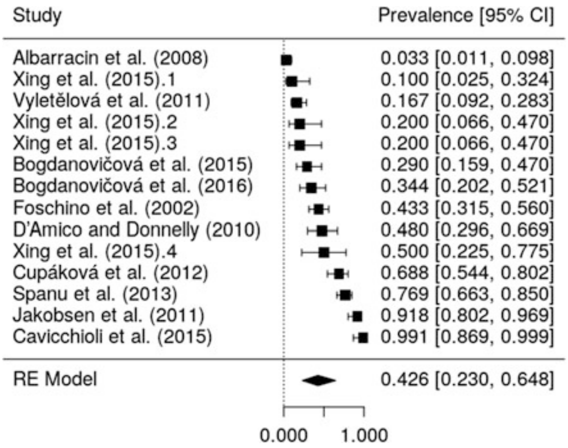

Fig. 21.2 Forest plot of the random-effects (RE) meta-analysis model of incidence of *S. aureus* in raw goat milk

heterogeneity (Q = 138.5; $P < 0.001$ in Table 21.1). As illustrated in Fig. 21.2, *S. aureus* was found in raw goat milk with frequencies between 3.3% in the study of Albarracin et al. (2008) up to 99.1% in the study of Cavicchioli et al. (2015).

The contamination with *S. aureus* is particularly relevant since it can produce enterotoxins and therefore cause foodborne intoxication in milk consumers (Oliveira et al. 2011). The results from this study show that raw goat milk is frequently contaminated with *S. aureus*. The lack of proper hygienic measures during milk handling is the major risk of contamination (Akineden et al. 2008). Even if milk is pasteurized, its contamination by *S. aureus* should be taken into consideration since staphylococcal enterotoxins are thermostable (Oliveira et al. 2011; Cavicchioli et al. 2015).

The forest plot of the random-effects meta-analysis model on the occurrence of *E. coli* O157:H7 in goat raw milk is shown in Fig. 21.3. The bacterium *E. coli* is commonly found in the intestinal microflora of humans and warm-blooded animals, and is generally used as hygiene indicator in the food industry. However, it may become a pathogenic organism such as the O157:H7 serotype. The meta-analysis model indicated that the incidence of *E. coli* O157:H7 in raw goat milk is 10.5% (95% CI: 5.3–19.6%), and the between-study variability was significant as shown by the test of heterogeneity (Q = 7.744; $P < 0.001$ in Table 21.1). The occurrence

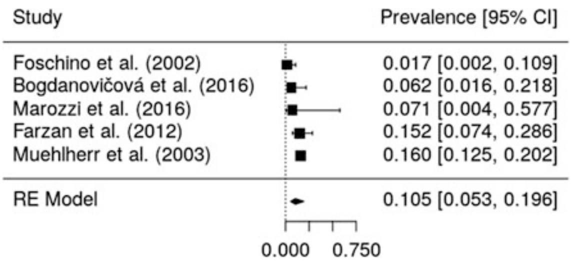

Fig. 21.3 Forest plot of the random-effects (RE) meta-analysis model of incidence of *E. coli* O157:H7

frequencies in raw goat milk varied between 1.7% in the study of Foschino et al. (2002) and 16.0% in the study of Muehlherr et al. (2003).

21.4 Occurrence of Foodborne Pathogens in Cheese

The circumstances of production and storage of dairy products made from raw milk determine the behavior (i.e. growth, survival or inactivation) of the microorganisms that are potentially present in the raw milk. The pathogens can grow, survive or be inactivated. The growth of the lactic acid bacteria (LAB) reduces the growth possibilities of the pathogens, on the one hand, by competition and, on the other hand, by a decline in the pH. Thus, the effect of starter cultures producing bacteriocins and the addition of potassium or sodium nitrate is especially aimed at inhibiting the growth of pathogenic bacteria (Verraes et al. 2015).

The results of the meta-analysis study for the logit-transformed incidence of *L. monocytogenes*, *S. aureus* and general *E. coli* in raw goat milk are presented in Table 21.2. Effect size, standard error (S.E.), confidence intervals, between-study variability (τ^2) and tests for heterogeneity (Q) are presented.

Forest plot of the random-effects meta-analysis model of occurrence of *L. monocytogenes* in goat milk cheese is shown in Fig. 21.4. The meta-analysis model indicated that the incidence of *L. monocytogenes* in goat milk cheese is 8.5% (95% CI: 4.9–14.6%). The between-study variability was not significant as shown by the test of heterogeneity (Q = 6.546; P = 0.162 in Table 21.2).

L. monocytogenes in raw goat milk and cheese presented comparable incidence rates. This foodborne pathogen is commonly associated with cheese and other ready-to-eat products, which has been responsible for several outbreaks in industrialized countries. In Portugal, an outbreak of human listeriosis seemingly associated with dry and semi-dry cheese occurred in 2010 affecting 39 people (Guilherme 2012).

Table 21.2 Meta-analysis results for the occurrence of *L. monocytogenes*, *S. aureus* and general *E. coli* in goat milk cheese

Value	*L. monocytogenes*	*S. aureus*	*E. coli*
Effect size	0.085	0.264	0.119
S.E.	0.5764	0.6353	0.6514
[95% CI]	[0.049–0.146]	[0.108–0.516]	[0.038–0.316]
Pr > |t|	<0.001	0.6270	<0.001
Q stat	6.546 (d.f. = 4)	150.1 (d.f. = 15)	27.22 (d.f. = 7)
P-value	0.162	<0.001	<0.001
τ^2	0.201	4.185	1.820

S.E. standard error; *CI* confidence interval; Q stat test for heterogeneity; τ^2 between-study variability; *d.f.* degrees of freedom

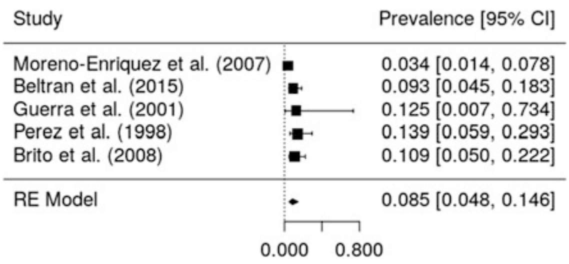

Fig. 21.4 Forest plot of the random-effects (RE) meta-analysis model of incidence of *L. monocytogenes* in goat milk cheese

Forest plot of the random-effects meta-analysis model of occurrence of *S. aureus* in goat cheese is shown in Fig. 21.5. The meta-analysis model indicated that the incidence of *S. aureus* in goat cheese is 26.4% (95% CI: 10.8–51.6%), and the between-study variability was significant as shown by the test of heterogeneity ($Q = 150.1$; $P < 0.001$ in Table 21.2).

There was a significant heterogeneity in the occurrence of *S. aureus* between pasteurized and non-pasteurized cheeses [$F(\text{d.f.1} = 2,\ \text{d.f.2} = 14) = 3.4565$; $P = 0.0603$] with an intra-class correlation (I^2) suggesting that ~90.4% of the total variability in measured occurrences in *S. aureus* can be attributed to the variability induced by pasteurization. Even after cheeses were categorized into 'pasteurized' and 'unpasteurized', there was some remaining between-product variability (residual QE = 134.0; $P < 0.001$). The heterogeneity in the occurrence of *S. aureus* reveals the variability in hygiene between the cheeses produced with unpasteurized milk. The high occurrence of *S. aureus* in cheeses produced with unpasteurized milk is an indicator of hygiene deficiency during processing.

Forest plot of the random-effects meta-analysis model of occurrence of the general *E. coli* in goat milk cheese is shown in Fig. 21.6. The meta-analysis model indicated that the incidence of *E. coli* in goat cheese is 11.9% (95% CI: 3.8–31.6%), and the between-study variability was significant as shown by the test of heterogeneity ($Q = 27.22$; $P < 0.001$ in Table 21.2).

With regards to *E. coli*, the heterogeneity between pasteurized and non-pasteurized cheeses was also significant [$F(\text{d.f.1} = 2,\ \text{d.f.2} = 6) = 12.6040$; $P = 0.0071$] with an I^2 suggesting that ~21.4% of the total variability in measured occurrences in *E. coli* can be attributed to the variability induced by pasteurization. When cheeses were categorized into 'pasteurized' and 'unpasteurized' (Fig. 21.6), the between-product variability became negligible (residual QE = 7.69; $P = 0.262$).

Since the traditional cheese production from raw goat milk, usually in small processing industries, may pose a substantial risk for the presence of pathogenic bacteria (D'Amico and Donnelly 2010); special attention should be given to placing effective processes to control the currently high prevalence of pathogens in raw goat milk and traditional cheeses (D'Amico and Donnelly 2010). There are limited research works focused on the prevalence of pathogenic microorganisms of goat

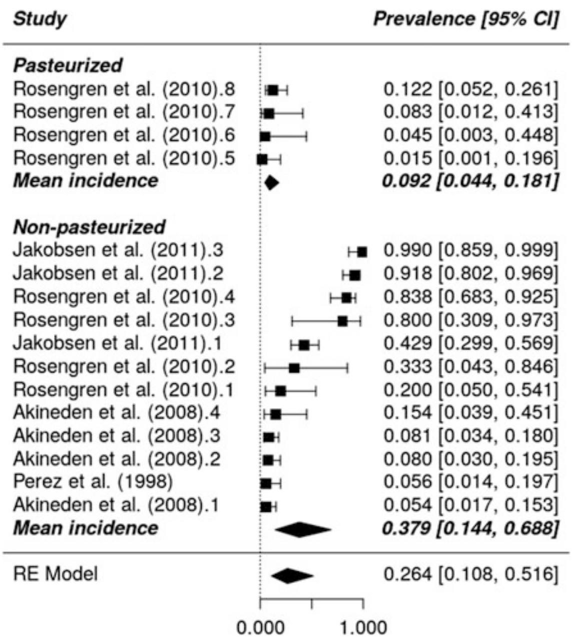

Fig. 21.5 Forest plot of the random-effects (RE) meta-analysis model of incidence of *S. aureus* in goat milk cheese

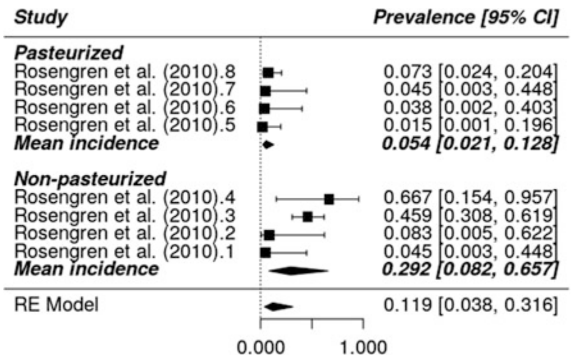

Fig. 21.6 Forest plot of the random-effects (RE) meta-analysis model of incidence of general *E. coli* in goat milk cheese

milk cheese; yet *L. monocytogenes* has often been recovered at the end of ripening even at levels above the maximum stipulated by Regulation EC No. 1441/2007. The scarcity of published data is particularly true for *L. monocytogenes* and *E. coli* (pathogenic and generic), which can be inferred from the uneven distribution of observations within the funnel plots of the two hazards (Fig. 21.7), signalling the likely presence of publication bias.

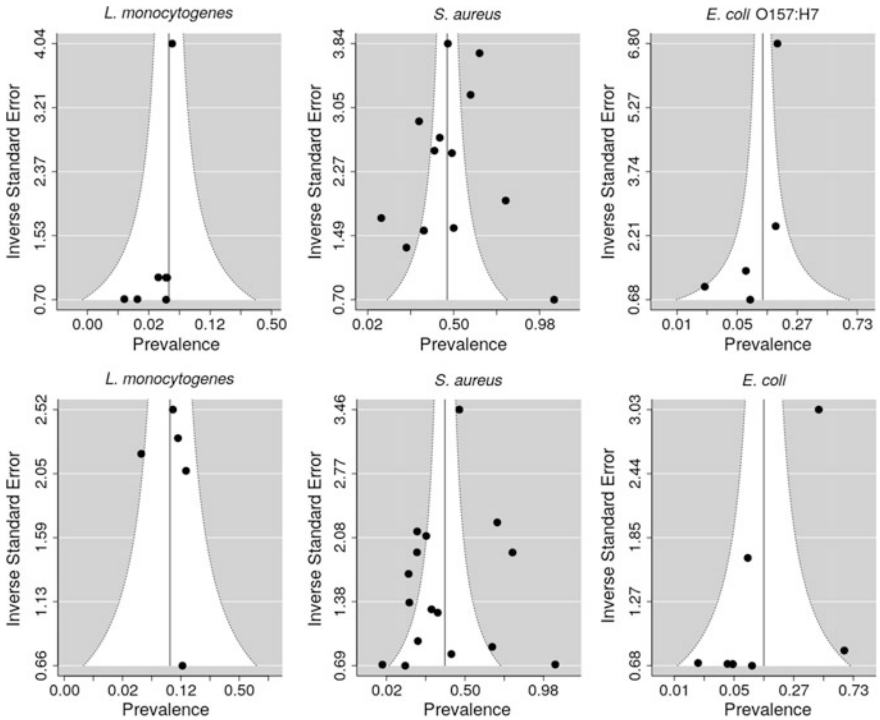

Fig. 21.7 Funnel plots of the meta-analysis models of incidence of microbial hazards in raw goat milk (top three) and goat milk cheese (bottom three)

21.5 Conclusions

This systematic review and meta-analysis indicated that currently, the information on the level of occurrence of foodborne pathogens in raw goat milk and cheese is limited. Data gaps still exist pertaining to the concentration of pathogens in the raw goat milk and thereof products.

Hence, further research is essential to support the food safety authorities to estimate the impact and magnitude of foodborne diseases resulting from consumption of raw goat milk, as well as to assess the impact of the control measures developed to mitigate the foodborne diseases. The frequency of official controls for raw goat milk and milk products is very low, and microbiological control analyses of these products delivered by EU member states to EFSA (2016) are scant.

This meta-analysis study confirmed that consumption of raw goat milk and milk products bears health risk to consumers. Thus, milk pasteurization is the best processing technique to ensure safety of goat milk. However, a better knowledge of the current microbiological quality of the goat milk is essential to plan further research work in order to improve the quality of raw and pasteurized goat milk.

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Part V
Climate Change, Environmental and Nutritional Stressors, and Goat Welfare

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Chapter 22
Climate Change and Goat Agriculture Interactions in the Mediterranean Region

Nazan Koluman (Darcan), Nissim Silanikove and Ahmet Koluman

Abstract Currently, even countries located within the temperate zone are affected by changes in global warming. These changes are associated with unprecedented events of extreme high ambient temperature, above 40 °C, and seasonal changes. The number of days with temperature humidity index above a specific comfort threshold (>68) has noticeably increased in recent years in the Mediterranean region. The rate of global warming, including in the temperate zone, is expected to continue to vulnerable in coming years. The economic importance of goat production has been increased during the last decades all over the world, predominantly in countries that are routinely exposed to harsh environment. Goats have numerous advantages that enable them to maintain their production under extreme climate conditions. Moreover goats emit less methane than other domestic ruminants. Based on these advantages, it can be said that goat breeding will play an important role in mitigating and adapting to climate change (CC) in harsh environments. The impacts of CC on goat production could be assessed analyzing the direct or indirect effects of climatic factors. The CC is expected to create indirect impacts on quality and amount of goat feeds, feeding strategies, seasonal usability of grasslands, genetic improvements (hybridization and others) and on the goat population. The interaction between goats and their environment in relation to their physiological stage, use of natural resource, waste management and crop production are direct effects of CC on goat production. In this chapter the direct and indirect effects and interactions of CC-animal-environment will be determined.

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22.1 Introduction

Climate change (CC) is a global phenomenon in which triggers global warming, droughts, flooding and depletion of natural resources (Naqvi and Sejian 2011). The environment of livestock production, agricultural crops and related management practices developed over the past 10,000 years is significantly changing due to human-induced CC. Currently, even countries located within the temperate zone are affected by changes in global warming. Developing countries are highly vulnerable to climate change since their economy predominantly relies on rain-fed agriculture that totally depends on natural factors. Traditional farming systems, which have low technological capacity, cannot help to adapt and mitigate drastic climate change (Tubiello 2012). Agricultural production from crops and livestock, and thus global food security, is already affected by CC and will continue to be influenced by global warming. Thus, these changes will continue to affect the goat farming, among others, directly and indirectly.

Heat stress (HS) imposed by high ambient temperature in temperate zones such as Germany, northern Italy or the United States was identified in recent years as a major factor which has a negative impact on milk production, reproduction, and the optimum health score of dairy cows. HS has also shown to increase appreciably the cow's mortality in those areas. On the other hand, there is no evidence that dairy goat production in temperate zones is affected so far; though evidence for such effects was noticed in deserts and Mediterranean countries (Silanikove and Koluman 2015).

Certain applications, particularly those intended for improving the environment and genotype, will become important. An ability to lessen the impact of climatic conditions would be closely associated with goat's milk and meat production capacity and the economic trait of production (Darcan and Güney 2002; Darcan and Çankaya 2008). Thus, two factors, genetic capacity and mitigation of HS, will dictate to large extent the level of productivity per goat and the number of goats in a particular environment. Therefore, actions to decrease environmental stress should be put into practice by taking current changes in CC into account. Some studies (Güney et al. 2006; Koluman et al. 2011) have demonstrated that applying methodologies to mitigate climatic stress, such as ventilation and sprinkling, improved productivity of goats. Additional approach which demonstrated positive effects was an improvement in the genetic structure to optimize goats adaptation along with increasing their productivity level under certain conditions (Darcan 2000; Darcan and Güney 2002; Silanikove and Koluman 2015). Thus, we see a great scope for goat in the future in harsh environments on the basis of: (i) the ability for better performances under these harsh environments; (ii) to benefit from feed resource, which aren't used by other ruminants (Boyazoglu and Morand-Fehr 2001); (iii) to benefit from the superior thermoregulation capacity and ability to cope with water shortage (Devendra 1987; Silanikove 2000) and, (iv) to benefit from their capacity to emit less methane (Silanikove and Koluman 2015).

Goat production systems and considerations on strategies of adaptation to global warming and climate change, which are in mutual interaction with each other, have become recently a popular subject on the public agenda and scientific literature (Silanikove and Koluman 2015). Among domestic ruminants, goats are the most adapted species to imposed HS in terms of production, reproduction and resistance to diseases. The main conclusions that can be made is that uttermost scenarios of climatic change will negatively affect the dairy industry and that the contribution of goats to the dairy industry will increase in proportion to the severances of changes in environmental temperature (Silanikove and Koluman 2015).

The impacts of CC on goat production could be assessed analyzing the direct or indirect effects of climatic factors (Silanikove and Koluman 2015).

22.2 Direct Effects of Climate Change on Goat Farming

The interaction between goats and their environment in relation to their physiological stage, use of natural resource, waste management and crop production become prominent. Reviews on this subject have shown that goat are superior to other ruminants in adverse environments (Silanikove 2000; Silanikove and Koluman 2015). However, a common mistaken belief concerning to decrease the greenhouse gas emissions led to political, social and economic sanctions and repressed goat production (Steinfeld et al. 2006).

In regard with goat production, efforts should be made to improve the genetic capacity in relation to the type of goat and increasing the production level per animal. The biological environmental conditions should be taken into consideration in terms of pollution to be led by preferring conventional methods in the use of natural resources. In order to increase production in the unit area which will lead the issues of protecting the natural life and organic production to become more significant. Furthermore, the negative effects on livestock farming, which derives from uncontrolled use of substances, could cause the emergence of new diseases that inflict humans (Steinfeld et al. 2006).

The main factors that need to be taken into account in considering the effect of climatic change on goat production are:

- Feed-grain production, availability, and price;
- Pastures and forage crop production and quality;
- Animal production, health, and reproduction;
- Disease and pest distribution;
- Water scarcity;
- By-products using and soil infertility;
- Biodiversity, loss of genetic and cultural diversity;
- Increase energy consumption.

We have to expect that the goat production systems based on grazing and the mixed farming systems will be more affected by global warming than the industrialized system. This would be due to the negative effect of lower rainfall and more droughts on crops and pasture growth, the direct effects high temperature and the solar radiation on animals (Nardone et al. 2010). Pasture and forages in temperate zones are expected to be affected by CC, but relatively less in comparison to other climatic zones (Sautier et al. 2013). This effect would be depending of the geographical conditions (e.g., mountainous and forest area) and the balance between increase in growing season length and damage caused by floods in winter draught in summer (Sautier et al. 2013).

Global grain production, particularly in hot spots (Teixeira et al. 2013), grain production in the US, and the larger world exporter of food/feed grains is expected to be substantially negatively affected by CC (Thompson et al. 2005). Local production of grains in temperate European countries, is expected to decline and being vulnerable to erratic CC (Teixeira et al. 2013).

However, what will happen if food prices will start to rise by the CC and their consequences on animal production? It is possible that under extreme scenarios, drought reduces the amount of quality forage available to grazing dairy animals. Due to limited sourced the grains could be used for only human diet. These changes will be associated with restructuring of the dairy animal sector, particularly with increase in the proportion of dairy goats. Even the need to reduce greenhouse gas emission per unit of product is further necessity to increase the efficiency of animal production. This can be achieved by (i) increasing biological efficiency, (ii) technological efficiency and (iii) economic efficiency (Babinszky et al. 2011).

22.3 The Contribution of Livestock to the Greenhouse Effect

A better understanding of the advantageous and disadvantageous of local goat breeds and crop production within a regional projection is highly desirable to implement adaptation programs in the long run. Applying genetic and biotechnological approaches are also means to improve adaptation to CC. However, in the present chapter we would like to emphasize on the local gene resources, which offer resistance and endurance to local extreme environmental conditions. Methane emissions of the local goats should also be put forth in such approach. A pilot study concerning on this subject (Görgülü et al. 2009) is described below. The estimated methane emissions from ruminants in Turkey is summarized in Table 22.1. According to Table 22.1, the majority of greenhouse gas (CH_4, CO_2 and nitrous oxide) produced by livestock originates mainly from the digestion process in the rumen, while the minority part comes from manure and feed production. It is estimated that the methane emission by ruminants in Turkey is approximately 1 million ton and more than 85% of that is of enteric origins (Table 22.1).

Table 22.1 The annual methane emission of the cattle, sheep and goats in Turkey with origins of enteric and manure

Species	Enteric (ton)	Manure (ton)	Total (ton)	Enteric (%)	Species (%)
Cattle	675,394	108,457	783,850	86.2	76.5
Sheep	203,800	6114	209,914	97.1	20.5
Goat	29,600	888	30,488	97.1	3.0
Total	908,794	115,459	1,024,252		

Adapted from Görgülü et al. (2009)

Furthermore, it was concluded that 76% of total emission is caused by the cattle population. This estimation represents an increase in methane emission in comparison to that made earlier by the State Institute of Statistics' (DSI) Branch Office of Environmental Statistics in 2000. According to this source, the methane release caused by enteric fermentation totaled 692,000 tons and the emission caused by fertilizes totaled 37.6 tons (TUIK 2009).

It's known that the methane emission is related to goats' dry matter consumption (Görgülü et al. 2009). The native breeds with lesser live weights and productivities also have lesser methane emissions, which will become an advantage in the future by using these breeds for production purposes.

Greenhouse gasses have capacity to raise earth's temperature and are indirectly responsible for climate change and global warming (Steinfeld et al. 2006). After CO_2, CH_4 is the second important gasses which contribute to global warming. Different species originate greenhouse gasses and their effect can be determined by different methods.

Since atmospheric methane is currently increasing at a rate of about 30–40 million tonnes per year, stabilizing global methane concentrations at current levels would require reductions in methane emissions or increased sinks for methane of approximately the same amount. This reduction represents approximately 10% of current anthropogenic emissions. The major agricultural sources of methane are flooded rice paddies, enteric fermentation and animal wastes. Decreasing methane emissions from these sources by 10 to 15% would stabilize atmospheric methane at its present level and is a realistic objective. In 1990, agricultural emissions of methane in the EU-15 were estimated at 10.2 million tonnes per year and were the greatest source (45%) of methane emissions in the EU. Of these, approximately two-thirds came from enteric fermentation and one third from livestock manure (Moss et al. 2000). According to Johnson and Johnson (1995), 80 million Mt of CH_4 is produced by livestock enteric fermentation annually, of which 730 g/kg is attributable to cattle. In comparison, goat husbandry is responsible for approximately 2.5–4% of total greenhouse effects and sheep and goats account for about 200 g/kg of emission from enteric fermentation. CH_4 is not only an important greenhouses effect but also indicates loss of energy intake (Johnson and Johnson 1995).

To calculate methane emission rate from sheep and goats, different regression equation can be used such as that of Blaxter and Clapperton (1965) and different parameters can be used in these equations depending on species and conditions. Blaxter and Clapperton (1965) equation is shown below:

$$E_{CH4} = 1.3 + 0.112D + L\,(2.37 - 0.05D)$$

Where E_{CH4} is CH_4 energy of gross intake (%), D is digestibility of gross energy intake (%), L is level is the level of feeding.

Some researchers have reported that when condensed tannins, acacia, *Calliandra calotthyrsus* or *Lespedeza cuneate* were supplemented to the goat diet a reduction of CH_4 emissions at different rates was observed (Carulla et al. 2005; Puchala et al. 2005). Thus, the ability of goats to exploit efficiently natural resources (mainly brows) including tanniferous-rich compounds (Silanikove 2000) is an advantageous characteristic of goats over other ruminant species in methane emission.

Developing feeding strategies trying to minimize CH_4 emission will redound in a short-term economic benefits as well.

According to Macfarlene and Howard (1972), water turnover is proportional to feed intake. McDowell and Woodward (1982) noted that goats have certain advantageous traits in situations where water resources were limiting. These were higher heat tolerance to dehydration, less susceptibility to respiratory rates and fewer metabolic disorders than cattle and sheep. Goats have a lower water turnover rate compared to camel, followed by sheep and cattle (Macfarlane 2006), and since as a rule they prefer semi-arid and sub-tropical climates where ambient temperatures are high and rainfall relatively low. Nicholson (1985) reported that camels have the lowest turnover, zebu cattle and sheep have comparable rates, while goats have the highest turnover. This statement contrasts with Macfarlane (2006) findings. Large animals with a lower metabolic rate per unit weight and a low surface-to-volume ratio would be expected to have correspondingly low water turnover rates, and in this respect cattle appear to be the least efficient users of water. They have developed several adaptations to cope with scarcity of especially water and also feed (Devendra 1987). According to Robertshaw (1982) in draught conditions the goats have identified four adaptations:

(1) Ability to desiccate the feces;
(2) Ability to concentrate the urine and thereby reduce urine volume;
(3) Ability to reduce evaporative water loss;
(4) Utilization of the rumen as a water reservoir.

These characteristics were identified as important traits in the adaptation of goats to harsh environments (Silanikove 2000).

22.4 Indirect Effects of Climate Change on Goat Production

The CC is expected to create indirect impacts on quality and amount of goat feeds, feeding strategies, seasonal usability of grasslands, genetic improvements (hybridization and others) and on the goat population (Silanikove and Koluman 2015). The quality and quantity of goat feed is important with regard to the rations prepared. The grain (wheat, barley, maize) which is used as goat feed and oily seed residues (cottonseed residues, sunflower seed residues) ensure that the rations are prepared with the lowest cost without losing any nutritional value (Koluman Darcan et al. 2009).

The CC impacts on goat production in some ways; these are physical environment, biologic environment, climate and chemical environment as represented in Fig. 22.1.

The physical environmental conditions appear with possible changes in the feeding conditions. The sheltering becomes more costly due to extreme climate conditions (i.e., too warm or too cold) and certain qualities aimed at performance such as milk and meat productivity are likely to lag behind. Studies conducted under extreme climate conditions have demonstrated an impact on goats in terms of the milk quality and quantity and cause a decrease in the lactation period in dairy goats (Chase and Sniffen 1988; Bucklin et al. 1991; Alnaimy et al. 1992). Studies on the reproduction performance found that the fertility decreases (Alnamier et al. 2002; De Rensis et al. 2002). The estrous could not be clearly determined and thus the interval to first insemination (days) increases and the pregnancy rate decreases (Alnamier et al. 2002; De Rensis et al. 2002). Blood flow to the uterus decreases under high ambient temperature, which increase the body and, indirectly as well, the uterus temperature. Consequently, decrease in fertilization rate limits the embryonic development and aggravate early embryonic fatalities (De Rensis et al.

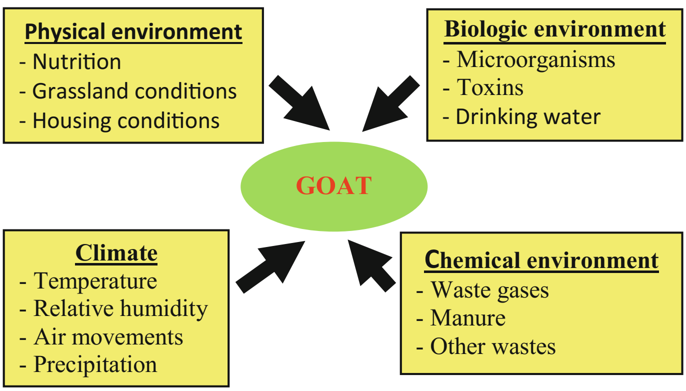

Fig. 22.1 Classification of expected effects of climate change on goat production (Koluman Darcan et al. 2009)

2002). In young goats the growth and development are negatively affected by these conditions (Darcan 2005; Koluman Darcan et al. 2009). Furthermore, it was reported that high environmental temperature reduces voluntary feed intake, feed efficiency and extend the fattening period (Silanikove 2000; Davis et al. 2001).

The grassland or crop production and its quality would slump down due to decrease in water resources and the land availability for crop production. There will be tendencies toward producing foods which are aimed at firstly feeding human on available lands, as the lands appropriate for crop production will shrink due to the increasing sea-water level, drought or salinity (Silanikove and Koluman 2015). The competitive power of the goat feed production would decrease due to economic reasons and priorities of general agricultural and industrial activities. Accordingly, a decrease in the competitive power can emerge as the first situation to be caused by the emergency of feeding problems in goats. As the precipitation regime changes, some agricultural lands would suffer drought, whereas some others will experience salinity. Thus there will be competition between the feed crop and alternative plants on lands consisting of agricultural production and the cost will be a prominent issue at this point. Furthermore, short, woody and leafy plant species with long roots appropriate for water storage which are resistant to salinity and draught would become prominent in vegetation. These plant species are among special ones which could be greatly utilized by goats in an effective way (Silanikove 2000; Koluman Darcan et al. 2009; Silanikove and Koluman 2015).

The studies on genetic improvement of farm goats in terms of production qualities and productivity have always been under discussion. But local goats' capacity of maintaining their productivity in all circumstances and their advantageous situation with regard to negative environmental impacts should be taken into consideration. Therefore, the work on genotype should be based on selection. The qualities of local gene resources such as length of life, goat health and productivity have an impact on the greenhouse gas emission, and thus they will be able to maintain their advantages over hybrid stocks even under climate changes. Furthermore, they are less affected by short heat waves due to their anatomic and advanced thermoregulation capacity enabling them to easily excrete the extra heat (Silanikove and Koluman 2015). Besides the productivity level, the length of life could also be affected by climate changes. An increase in such incidents as droughts, floods and epidemic diseases is expected due to the climate change (Silanikove and Koluman 2015). Therefore, it is important to start genetic selections with goats, which are resistant particularly to droughts and diseases. Important traits in such selection schemes are skin and hair type, sweat gland capacity, reproduction rate, ability to maintain productivity in difficult conditions, resistance to local diseases and parasitic infestations, metabolic heat production, tolerance to draught, anatomic or morphologic structure are some important impacts that likely derive from climate changes (Koluman Darcan et al. 2009).

A serious threat in stockbreeding will be reflected by certain goat diseases that would increase treatment expenses, productivity losses and immunity, such as blue tongue and gastroenteritis. Many factors like easier spread of disease vectors and an increase in atmosphere temperature due to shorter cold seasons with temperatures above 15 °C will play a role in the emergency of these diseases (Steinfeld et al. 2006). Indigenous goats possess higher resistance to diseases and external parasites. Thus, indigenous breeds are also likely to be more resistant to disease vectors, which are expected to change under the drought and extreme climate conditions in the future. The native goats are able to use the plants rich in lignin effectively by consuming less feed and water (Silanikove 2000). The ability of goats to resist disease and exploit more efficiency natural resources should be considered as part of the healthy society perspective (Koluman Darcan et al. 2009). These aspects endue local gene resources to be more advantageous than exotic breeds, particularly in terms of resistance to diseases, ability to utilize poor vegetation and endurance to drought.

Food-goat feed-fuel supply interactions are another factor that may have negative impacts on the goat feed sector in near future because it will become less profitable. The possibility to use plant residues in bio-diesel production to meet energy needs could cause shortage of these by-products in the goat production in the future. The low atmosphere temperature is one of the most important factors creating negative impacts on the dry matter content of grassland feed crops, particularly in springs. This, it is expected that water holding capacity of soil will fall with decreasing precipitation, which will lead to a decrease in the dry matter content in plants. Besides, the biomass of by-products which are used in goat production would be greatly influenced by the climate change and the nutritional value could decrease. Therefore, the silage and fodder production will lag behind (Koluman Darcan et al. 2009).

The genetic diversity in farm goats is important with regard to food safety and rural development. The applications that are carrying out towards these ends by Research Institutes and governments will provide stockbreeders with the advantage of goat selection and new genotype development according to climate change, varying market opportunities and turning towards new fields which are needed by people. FAO (2007), reported that a great number of goat stocks in the world were under the threat of perishing. The majority of these goats are raised at small enterprises with low inputs, where agriculture and goat production based on grasslands is performed simultaneously.

Climate impacts differ, depending up on such factors as a goat's age, gender, productivity level and products. The goat adaptation to climate conditions can also depend on the age of the goats; younger goats may even perish under conditions in which grown animal endures. For example, in rainy and mild climates the mortality rate in young goats decreases whereas in extremely high heat and cold conditions decrease their survival. Therefore, the sheltering conditions gain considerable attention in goat production (Koluman Darcan et al. 2009).

Goats are also more resilience than other ruminants (Silanikove 2000). Resilience is defined as 'the ability of a species to survive and recover from a perturbation' (Williams et al. 2008). Both, adaptive capacity and resilience, are influenced by species ecology, physiology and genetic diversity (Silanikove 2000). Goats have low body mass, and low metabolic requirements, which is an important asset to minimize their maintenance and water requirements, in areas where water sources are limited. An ability to reduce metabolism allows goats to survive even after prolonged periods of severe limited food availability. A skillful grazing behavior and efficient digestive system enable goats to attain maximal food intake and maximal food utilization in a given feeding situation. An effective urea recycling to the rumen allows goats to effectively digest low-protein feeds (Silanikove 2000). The specious rumen volume of goats plays an important role in the evolved adaptations by serving as a huge fermentation and water reservoir. The water stored in the rumen is utilized during dehydration, and the rumen serves as a container, which accommodates the ingested water upon rehydration. Goats, when possible, eat diets composed of browse (tree-leaves and shrubs) that ensure a reliable and steady supply of food all year around, albeit with a low to medium quality. One of the most remarkable features of goats is characterized by short-term or seasonal anatomical acclimatization to changes in forage quality (Silanikove 2000). The corresponding morpho-physiological adaptations are: (i) larger salivary glands; (ii) higher surface area of absorptive mucosa than in grass and roughage eaters; and, (iii) a capacity to increase substantially the volume of the foregut when fed high-fibrous food. This grazing strategy in combination with the anatomical and physiological adaptations described above makes goats the most efficient desert-dwelling species among domestic ruminants. Desert goats are very resilience to the effect of HS (Silanikove 2000). Goats are superior in reproductive traits in comparison to cows as reflected by their higher fertility and short generation interval (Devendra 1987).

However, how CC will affect goat industry in temperate zones is unknown, no direct information is available. To analyze this question, we can consider the effect of HS in breeds that are relatively adapted to HS under relevant climatic situations. Limited information on this line exists, particularly for goat breeds commonly raised under Mediterranean and subtropical conditions. Based on the basic interrelationship between an animal and its environment and also based on the above-mentioned information on cow and goat response to HS, we summarized the HS risk classes according to Livestock Weather Safety Index of Normal (no effect), Alert (modest effect), Danger (severe effect) and Emergency (collapse of the system, animal may die) for goats and cows (Silanikove 2000). Goats are much more adapted and resilient than cows to the effect of HS, meaning that they will much less affect than cows to climatic changes. Although, little information is available, it can be safely assumed that goat will be able to maintain higher reproduction and resist better diseases under HS (Silanikove 2000; Escareno et al. 2013).

With the advance of severity of CC, more and more areas will become dryer and subjected to increase HS during longer summers (EEA-JRC-WHO 2008). Thus, it is likely that the situation which now favorite the flourishing of goat industry like in Mediterranean zone will be extend to areas currently defined as temperate zones, such as central Europe.

Of course, under some of the harsh CC scenarios, even goats will not be able to prevent the entire negative impact of CC on dairy goat production: First, because they are also influenced by HS and partially depended on feed price. Typical milk goat production nowadays when maintained on Mediterranean rangelands varies between 600 and 2000 L per year (Castel et al. 2010) for intensive and semi-intensive production systems, whereas typical milk production of cows ranges from 6000 to 10,000 L per year (Gaully et al. 2013). Thus, a second major limitation is imposed by the lower body size and milk production per unit in goats in comparison to cows and consequential limitations on practical herd size, particularly associated with farm workload (particularly milking). In some countries, namely, Greece, Albania and some of the central and eastern European countries (Bulgaria, Bosnia and Herzegovina, Croatia) the contribution of goats and sheep to dairy production is sizable, around 40%, and in some of them (e.g., Greece) exceeds that of cows (FAO 1998; Haenlein 2001). The main reason seems to be the ability of goats to uniquely and effectively exploit vast scrub- and wood-land that characterize those countries (Silanikove 2000). Thus, the level of about 40% of total dairy production may represent the upper limit of contribution of dairy goats to total dairy production in those regions.

The best scenario would be that in opposite to the catastrophic predictions on the effect of CC, or that the severity of changes will be milder than expected (increase of 0.7 °C), which will allow adaptation to the change (Gaully et al. 2013). However, if the devastating impact of CC on Human wellbeing and livestock production is unavoidable, the best strategy would be to prepare to those changes and to do the best to lessen the impact. Because economic adjustments may be slow, more accurate models for prediction of the impact of CC on dairy cows and goat production are necessary. This will allow deriving accurate predictions of the optimal replacement value between goats and cows under variable scenarios, which likely be found helpful in making the necessary adaptive transitions more effective and less painful. Thus, continuation of monitoring the effect of CC on dairy cow and goat production and improving our ability to model them will be important part of science in coming years.

22.5 Concluding Remarks

Goats have ability to maintain productivity in changing climate. Low metabolic heat production, tolerance to water deprivation, anatomic and morphologic structure which enable efficient utilization of low quality feeds, skin and hair type, sweat gland capacity, reproductive capacity and, resistance to diseases and parasites, were identified as important characteristics of goats to adapt CC conditions for future.

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Chapter 23
Impact of Adverse Environmental Stress on Productive and Reproductive Performance in Osmanabadi Goats

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Abstract Among the livestock species, goats have notable characteristics that make it peculiar to outshine competently in harsh tropical and subtropical environments. Osmanabadi goat breed is a dual purpose (meat and milk) hardy goat breed native to the states of Maharashtra and its adjoining states belonging to the tropical semiarid regions in India. The results from the available literatures indicate the extreme adaptive capability of Osmanabadi goats to the extreme climatic condition. It has been proved that if nutrition is not compromised, Osmanabadi goats were found to cope with heat stress (HS) challenges without compromising production. In males, HS impacts reproduction directly by reducing the semen volume, sperm motility, higher sperm defects, and reduces libido. These impacts were aggravated when feed scarcity coupled with HS. Further, the various experimental findings established that the Osmanabadi goats possessed superior adaptive capability to counter HS through their ability to alter the behavioral, physiological, endocrinological, and different thermotolerant gene expression patterns. In addition, lying time, drinking frequency, respiration rate, rectal temperature, plasma heat shock protein 70 (HSP70), and peripheral blood mononuclear cell HSP70 gene were reported to be the ideal biological markers to quantify the impact of environmental stress in Osmanabadi goats. Also, higher expression of toll-like-receptor

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8 (TLR8) and TLR10 in heat-stressed Osmanabadi goats indicated that these two genes could be the immunological markers for HS in goats.

23.1 Introduction

Goats play a key role in the livelihood security of the poor landless, small, marginal farmers and for rural women providing nutrition in the form of milk, meat, as well as income. In some developed countries like France, goats play a relevant role in the milk industry and they are raised to produce high-quality products, for example, special cheese (Dubeuf and Boyazoglu 2009). The population of goats in the world was estimated to be 924 million in 2011. Within the past three decades (1980–2011) their population has been doubled in the world (FAO 2014). This doubling in the population might be due to their ability of adapting to harsh weather conditions. The goat population succeeds the cattle population and holds the second position in India, whose census in is 135.17 million goats based on the 19th livestock census, 2012. However, the goat population in India has decreased by 3.8% in comparison with the previous census published in 2007.

Indian goats are classified based on:

(a) Agroecological zones (Acharya 1982):

- Western Himalayan region—Hairy breeds;
- Eastern Himalayan region has the nondescriptive goats;
- Dry Northern region has 11 predominant goat breeds;
- Eastern region which receives high rainfall has two goat breeds (Ganjam and Bengal goats);
- Southern arid/semiarid regions where mixed farming is practiced has good meat-type breeds like Osmanabadi, Sangamneri, Kanni Adu, Malabari, and Attapady;
- Southern Eastern coastal region having mostly non-descript goats with fusion of goat breeds of the Southern arid region.

(b) Production type (Khan and Rai 2000):

- Milch/meat breeds (Jakharana, Jamunapari, Beetal, Barbari, Sirohi and Surh);
- Meat/milch breeds (Sanamnri, Kutchi, Zalawadi, Gohilwali, Mehsana, and Osmanabadi);
- Meat breeds (Bengal, Ganjam, Malabari, and Kanni Adu);
- Fiber/meat (Gaddi, Marwari, Chengthengi, and Chegu).

(c) Body weight (Khan and Rai 2000):

- Large (Beetal, Jamunapari, and Sirohi);
- Medium (Barbari, Marwari, and Osmanabadi);
- Small breeds (Bengal).

India harbors 23 well-recognized goat breeds which are well adapted to different agroecological zones, although other nondescriptive breeds are also present. Natural selection and selective breeding based on their adaption to their respective agroecological zones have helped them to evolve into distinct breeds through ages. Indigenous goat breeds have gained importance due to their high disease resistance ability and high adaptability to thrive in harsh weather. They are able to reduce their metabolism in order to sustain a prolonged period of limited feed supply through their ability to digest feed efficiently coupled with their browsing habit (Chaidanya et al. 2017). Among the 23 descriptive goat breeds in India, Osmanabadi breed falls under medium sized breed with a long body and long legs. It is widely distributed in Maharashtra state and other adjoining southern states like Karnataka and Andhra Pradesh.

Among the livestock species, goats have notable characteristics that make them peculiar to outshine competently in harsh tropical environments. Thus, one of the main objectives of promoting goat species is to counteract the pessimistic consequences of climate change in a design to improve and sustain productivity. Physiological, behavioral, and morphological responses let the goats thrive effectively in unfavorable and challenging climate change induced environmental conditions (Assan 2014). These responses are important in coordinating the goats to specific environmental conditions and assuring a sustainable level of production. In the increasing substance of climate change, promoting and propagating goat production may be a feasible mitigation strategy. Due to its peculiar feeding behavior, better endurance to diseases, heat tolerance, and resilient features, goats serve as a key species of livestock in minimizing the growing concern of climate change on livestock production system. This chapter is targeted towards the impact of different climate change related environmental stresses which hampers the productive and reproductive performance of Osmanabadi goats. Emphasis was also given to highlight the adaptive capability of Osmanabadi goats to different environmental stresses.

23.2 Origin, Location, and Distribution of Osmanabadi Goats

Osmanabadi goat breed has its origin from Latur, Tuljapur, and Udgir taluks of the Osmanabad district, Maharashtra state, India (also see Chap. 28) (Yadav and Singh 2016). Osmanabad district falls under Marathwada region of Maharashtra state, at latitude of 18.18 N and longitude of 76.04 E in India, which is generally dry with an average rainfall of 730 mm. However, the Osmanabadi breed has spread in the neighboring and adjoining districts of Osmanabad like Parbhani, Ahmednagar, Solapur of Maharashtra and adjoining parts of Karnataka, Andhra Pradesh, and other states too. The goats are known for their high adaptive characteristic features to harsh environment, with high prolific ability even under poor management conditions.

In the 19th All India Livestock Census (2012) conducted by Department of Animal Husbandry, Dairying & Fisheries, Ministry of Agriculture, showed that the total Osmanabadi pure breed population in India was 2.48 million. Out of 135.04 million indigenous goats in the country, Osmanabadi goat breed forms 2.3%. The graded breed of Osmanabadi in India was approximately 3.066 million in 2012. The total population of male and female in Osmanabadi pure breed is approximately 0.54–1.94 million respectively, whereas in the graded population the male and the female population was approximately 0.13–0.45 million, respectively.

Among the states, Maharashtra has the highest Osmanabadi goat population (both pure and graded breed) with 2.15 million followed by Karnataka with 0.4565 million. Gujarat has a very less Osmanabadi goat population. However, in the 18th census (2007) the goat population was also seen in Kerala. Osmanabadi goat is also found in Goa as it is one of the popular breeds of the state (Das et al. 2014). In addition, Kumar (2007) stated that the breed has also spread to Madhya Pradesh. So, based on the information the Osmanabadi breed were also found in Goa, Madhya Pradesh, Kerala, and Gujarat in addition to the predominant states like Maharashtra, Karnataka, and Andhra Pradesh (Andhra Pradesh and Telangana). The farmers primarily prefer Osmanabadi goats for rearing due to their breed characteristics. Though the goat population has decreased from 18th to 19th census in India by about 4%, concretely from 140.5 million in 2007 to 135.04 million in 2012, the Osmanabadi population has raised from 1.55 million to 3.06 million approximately, which is an increase by 50%. This indicates the preference of the farmers in rearing them. Moreover, the spread of the goat population from Maharashtra to Karnataka and the adjoining states like Andhra Pradesh (Andhra and Telangana) Kerala, Goa, and Madhya Pradesh indicates the animal's adaptability to thrive in different agroecological zones also. The distribution patterns of Osmanabadi goats in Maharashtra, Karnataka, and Andhra Pradesh states in India are 19.8, 2.5, and 2.5% respectively. Figure 23.1 represents the map of the country remarking the states with Osmanabadi goats.

23.3 Salient Phenotypic Production and Reproductive Traits of Osmanabadi Goats

The phenotypic characteristics of Osmanabadi goats are described in Table 23.1.

Osmanabadi goats are an efficient breed and it takes 14–15 months for kidding twice. The first kidding occurs approximately at 450 days of age in an organized farm and at 506 ± 18 (±S.E.M.) days under field conditions (Harikrishna et al. 2013). The kidding and twinning percentage in Osmanabadi goat breed were found to be 55.9 and 10.5%, respectively, based on the data collected from 1999 to 2004

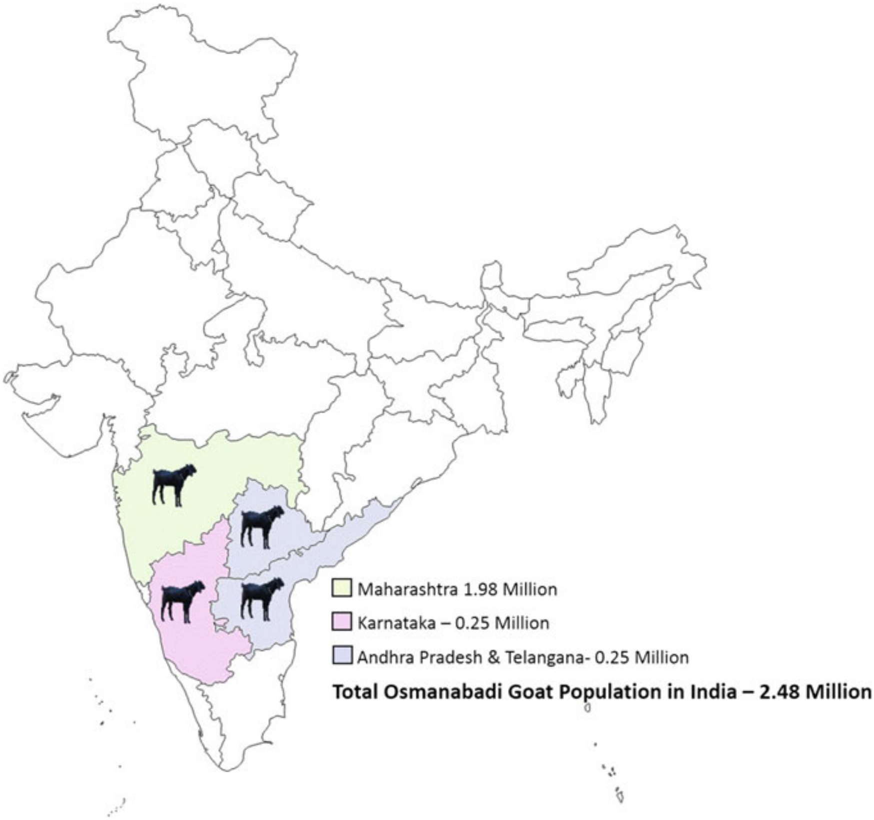

Fig. 23.1 The distribution pattern of Osmanabadi goats in major states in India

in Vidarbha under farm condition (Sahare et al. 2009). Triplets and quadruplets are seldom reported in this breed. Average kidding interval is about 297 ± 35 days. Under well-managed field conditions, the animals are able to give milk yield ranging from 0.7 to 1.5 kg with a lactation length of 130–150 days. Study (Harikrishna et al. 2013) conducted on 396 birth records of Osmanabadi goats for a period of 6 years (2003–2008) showed that maximum percentage of birth occurred during the winter season (October–February). The kidding percentage during summer and rainy seasons were 33.7 and 17.4%, respectively. However, the mean birth weight was more in the rainy season followed by summer and the least during the winter season. The average birth weight of Osmanabadi male kids is 2.60 ± 0.01 kg while the female kids is 2.35 ± 0.01 kg (Harikrishna et al. 2013). Table 23.2 describes the growth performance of Osmanabadi goats according to different age groups.

Table 23.1 Description of salient characteristics of Osmanabadi goats

Characteristic	Description
Body size	Medium to large
Skin color	The breed is predominantly black in color (75%). Rest of the breed is found in white, spotted, or brown color
Horn	The horns are usually either straight or curved. Straight horns are comparatively more in number than the curved horns. In this breed, males are usually horned while females are poled
Ear	Ears are mostly pendulous with very few having horizontal ears
Head	Mostly convex type. Concave and flat headed animals are also documented
Wattles	Absent
Tail	Curved with either slender or bunchy in nature
Noteworthy facts	Highly disease resistant, drought resistant, and heat tolerant
Average body weight (Male)	32–36 kg
Average body weight (Female)	30–32 kg
Birth weight of male kids	2.6 kg
Birth weight of female kids	2.4 kg

Source Deokar et al. (2006, 2008), Harikrishna et al. (2013)

23.4 Environmental Stress as an Important Factor Influencing Osmanabadi Goats

Stress is the consequence of any alterations in the environmental forces constantly acting upon animals which disrupts the homeostasis and results in initiation of adaptation mechanisms (Binsiya et al. 2017). Among the ruminant livestock species, goat is the best adapted to harsh environments, especially the indigenous goats, which perform better than other domesticated ruminants (Silanikove 2000). Since, lower basal heat production, larger salivary glands, and the capacity to significantly increase the volume of the foregut when fed with high fibrous feed are the major morpho-physiological characteristics that allow goats to more easily adapt to harsh environments (Bernabucci et al. 2010). The survival and productivity of animals in tropical regions depend on the existence of certain adaptive characteristics and their capability to sustain their core body temperature within a certain range. The maintenance of homeothermy is the key priority for animals to overcome the productivity such as milk yield and reproduction (Souza et al. 2014). Osmanabadi goats show HS during hot weather with high temperatures and relative humidity where the ambient temperature is a major factor that negatively affects the goats' performance (Shilja et al. 2016). Extreme heat load causes hyperthermia which consequently affects physiological responses and ultimately leads to reduced

Table 23.2 Growth parameters (mean ± S.E.M.) of Osmanabadi goats

Age groups (months)	Sex	Number of observations	Height at withers (cm)	Chest girth (cm)	Body length (cm)	Body weight (kg)	Heart girth
0–3	M	91	41.3 ± 0.2	38.4 ± 0.2	33.2 ± 0.2	6.0 ± 0.1	31.1 ± 0.2
	F	179	40.6 ± 0.1	37.6 ± 0.2	32.6 ± 0.2	6.3 ± 0.1	30.5 ± 0.2
4–6	M	47	55.2 ± 0.2	52.7 ± 0.3	45.4 ± 0.3	15.4 ± 0.1	56.7 ± 0.8
	F	82	54.3 ± 0.2	52.1 ± 0.2	45.4 ± 0.2	15.2 ± 0.9	55.0 ± 0.7
7–12	M	40	62.8 ± 0.4	59.9 ± 0.5	50.4 ± 0.3	19.2 ± 0.2	–
	F	72	62.28 ± 0.3	59.5 ± 0.3	49.5 ± 0.3	19.0 ± 0.1	–
13–36	M	74	74.6 ± 0.4	73.6 ± 0.4	60.9 ± 0.3	31.3 ± 0.2	–
	F	148	71.1 ± 0.3	69.7 ± 0.3	58.8 ± 0.2	29.6 ± 0.2	–
>36	M	18	74.2 ± 0.8	73.9 ± 0.6	62.8 ± 0.4	32.4 ± 0.2	–
	F	49	72.5 ± 0.5	73.6 ± 0.4	62.2 ± 0.3	32.6 ± 0.3	–
Reference		Mule et al. (2014)	Mule et al. (2014)	Mule et al. (2014)	Mule et al. (2014)	Mule et al. (2014)	Nimbkar (2014)

production performance (Sejian et al. 2015). In extreme conditions, both physiological and behavioral responses are elicited to combat the HS and they are highly essential to provide optimum nutrition to improve the adaptive capability of Osmanabadi goats to HS (Shilja et al. 2016). However, usually, the feed resources are very scarce during summer months leading also to severe nutritional stress which hampers both the productive potential as well as the thermoregulatory mechanisms necessary to adapt to the tropical environment.

23.4.1 Impact of Heat Stress on Goat Production

HS affects the physiological responses which lead to a reduction in feed intake, redeployment of blood flow, depression of the immune system and altered endocrine functions that negatively affect the productivity and reproductive performance of the goat (Marai et al. 2007).

The thyroid hormones play important roles in the adaptation of animals to the environmental changes by their regulation and general metabolism (Nazifi et al. 1999). Increase of core body temperature in a heat-stressed goat is associated with significant depression in thyroid gland activity which results in a reduction of thyroid hormones level (Silanikove 2000; Al-Samawi et al. 2014).

The goat kids born during rainy season were reported to grow faster coupled with higher body weight gain in comparison to kids born during summer (Phillips 2004). Hamzaoui et al. (2012) reported the reduction in feed intake and body weight gain during HS without any changes in the level of blood nonesterified fatty acids in goats. Goats are able to sustain the basal level glucose but lactose secretion decreases by 5% where some of the blood glucose is spared to synthesize lactose during HS (Hamzaoui et al. 2012). Wheelock et al. (2010) reported the body muscle degradation under HS and the consequential amino acids which are used for gluconeogenesis. Dairy goats under HS reduce their feed intake by 22–35% and produced 3–10% lower milk yield with lower fat, protein, and lactose concentrations (Salama et al. 2014).

In a study conducted on Osmanabadi goats, Bagath et al. (2016) reported significantly lower body weight when these goats were on restricted feeding during the summer season. These authors attributed this decrease in body weight to both heat as well as nutritional stress. The same authors also established that apart from reduction in body weight, increase in growth hormone (GH) concentration and lower insulin-like growth factor 1 (IGF-1) also indicated the compromised productive performance in Osmanabadi goats. Further, in a study conducted on Osmanadi bucks, Niyas (2015) reported that significantly reduced body weight in heat-exposed Osmanabadi bucks being attributed to reduced feed intake during HS condition. Figure 23.2 describes the experimental Osmanabadi goats both in the controlled condition inside the shed as well as the heat exposed animals in the outside environment.

Fig. 23.2 Experimental Osmanabadi goats inside the shed (A: control) and outside the shed (B: heat stress) which present a lower body score. The THI values inside (**a**) and outside (**b**) the shed were 23.3 °C (74 °F) and 27.2 °C (81 °F), respectively (Provided by V. Sejian)

23.4.2 Impact of Heat Stress on Goat Reproduction

HS affects the fertility and reproductive performance of livestock species through compromised physiological function of the reproductive tract, disturbances in hormonal balance, decreased oocyte quality in addition to decreased embryo development and embryo survival (Gendelman and Roth 2012). The poor quality oocyte and embryo results in decreased conception rate with more days open in the tropical and subtropical regions during the hot season (Collier et al. 2006).

The high ambient temperature and relative humidity affect directly the reproductive performance by altering or impairing various tissues or organs of the reproductive system (Das et al. 2014). HS alters steroid secretion in goats by decreasing the ovarian LH receptors and reducing the follicular responsiveness to LH (Kanai et al. 1995; Ozawa et al. 2005). The reduction of the preovulatory surge of LH results in delayed ovulation in goats (Siddiqui et al. 2010). Moreover, HS also reduces the circulating concentrations of inhibin and increases the FSH secretion (Roth et al. 2000). Figure 23.3 describes the generalized hypothetical impacts of HS on the reproductive performance of Osmanabadi goats.

Hyperthermia also affects cellular function in various tissues of the female reproductive tract, including the follicle, oocyte and the embryo (Wolfenson et al. 2000; Hansen 2009). The increase in plasma cortisol levels as a result of activation of the hypothalamic-pituitary-adrenal (HPA) axis during HS and block the estradiol-induced sexual behavior (Singh et al. 2013). Further, the reduced aromatase activity and viability of granulosa cells result in poor estradiol secretion and, in turn, the low level of estradiol suppresses the signs of estrus, gonadotropin surge, ovulation, transport of gametes and ultimately reduces the fertilization rate (Wolfenson et al. 2000; Das et al. 2014). Wilson et al. (1998) suggested that the HS inhibits the follicular growth during the preovulatory period of proestrus and thus reduces the level of estradiol. Hence, the decrease in estradiol secretion from the

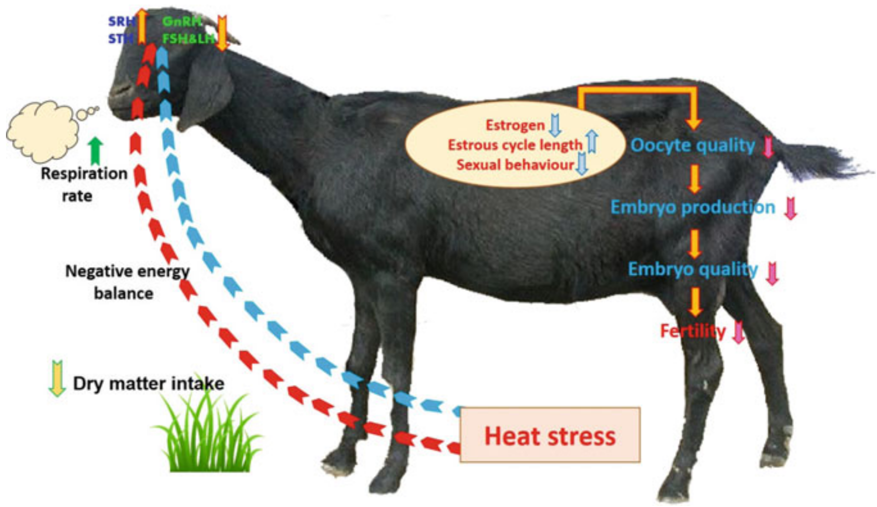

Fig. 23.3 Hypothetical model depicting the impact of heat stress on Osmanabadi goat reproductive efficiency. (*FSH* Follicle stimulating hormone; *GnRH* Gonadotropin releasing hormone; *LH* Luteinizing hormone; *SRH* Somatotropin releasing hormone; *STH* Somatotropic hormone)

dominant follicle may cause poor expression of estrus signs (Wolfenson et al. 1997).

In males, HS impacts reproduction directly by reduced semen volume, sperm motility, higher sperm defects and reduces libido (Farshad et al. 2012). Further, the high ambient temperature influences the pH of semen and the chronic HS may lead to irreversible testicular degeneration (Salles et al. 2017). The scrotal-skin temperature exhibits highly negative correlation with serum testosterone, libido, sperm motility, sperm concentration, and conception rate and positively associated with dead and total abnormal sperm (Ruediger et al. 2016). In a recent study conducted in Osmanabadi bucks, Niyas (2015) established lower mass motility, progressive motility, and plasma testosterone in both heat and combined (heat and nutritional) stressed groups indicating the sensitivity of reproductive performance of this breed to environmental stresses. Further, in the same study, it was also established that the expression of HSP70 messenger ribonucleic acid (mRNA) was higher in testicles of heat-stressed Osmanabadi bucks. In addition, the highest loss of spermatid density indicating decreased spermatogenesis was also recorded in stressed groups when compared to control animals (Niyas 2015). These findings indicate that the reproductive performance is being compromised in Osmanabadi goats while they are trying to adapt to environmental stress challenges.

23.4.3 Nutritional Stress Impact on Goat Production

The potential of livestock is being compromised due to climate change induced stressors that commonly include a shortage of feed and fodders and water scarcity. The detrimental effect of climate change on livestock production compels for the selection of well-adapted livestock species that have inherent ability to endure the inevitable climate change effects. Furthermore, due to accelerated climate change, the short, woody, and leafy plant species with long roots that are appropriate for water storage, which are also resistant to saltiness and limited water resources, will become prominent in vegetation (Darcan et al. 2009). Within this structure, a goat's interaction with environment originated from its behavioral features in better utilization of harsh vegetation, natural resource, and waste management become almost perfect. It continues to perform remarkably better than any other livestock species under extreme conditions, gain advantage from feeding resources which aren't readily used by other livestock species and release less methane emission in return.

23.4.4 Effect of Nutritional Stress on Digestive Health

As a consequence to stress, the DM intake is reduced either due to nutritional inadequacy or thermal stress. Reduction during thermal stress helps to maintain core body temperature by decreasing the heat generation by ruminal fermentation and nutrient metabolism. Feeding of poor quality feed and fodders that are low in protein and high in lignocellulose content result in lower digestibility, decreased rate of passage, and hence the lower feed intake. Decreased rumen motility due to thermal and nutritional stress along with increased water intake result in gut-fill that in turn reduces feed intake (Beede and Collier 1986). Decreased DM intake is more prominent in animals fed with roughage-based diet than in animals fed with concentrate diet, the effect being much worse in animals fed mainly with roughages.

Lower volume of saliva due to less feed intake disturbs the acid-base balance of the metabolic system (Nardone et al. 2010). The lowering of rumen pH leads to acidosis, laminitis, and reduction in milk fat content. The maintenance requirement for stress is increased and the absorption of the nutrients is considerably reduced, finally resulting in reduced net energy supply for production. In a recent study on Osmanabadi bucks, Chaidanya et al. (2017) reported that the rumen parameters varied between the HS, nutritional stress and combined (heat and nutritional) stress groups. The extracellular, intracellular, and the total activity of carboxymethyl cellulase in rumen fluid were established to be significantly lower in stressed Osmanabadi bucks as compared to control animals. Further, these authors also reported the lowest concentration of ammonia nitrogen in the combined stress group. In addition, lower concentrations of total nitrogen, trichloroacetic acid precipitable N, propionic acid, butyric acid, and valeric acid were observed in nutritionally stressed bucks (Chaidanya et al. 2017). Furthermore, the ratio of acetate to propionate in rumen fluid was also significantly higher in combined and nutritionally stressed bucks. In contrast, the expression of rumen HSP70 was higher in combined stress group bucks indicating the severity of cumulative environmental stress in Osmanabadi bucks (Chaidanya et al. 2017).

23.4.5 Effect of Nutritional Stress on Goat Reproduction

Inadequate nutrition, particularly energy, depresses the reproductive performance of extensively or intensively managed goats. Adequate and optimum feeding is required for attaining early sexual maturity. The energy stimulates estrus activity within the normal breeding season, ovulation rate, fertilization, and survival of ova and the maintenance of embryos. Ovarian activity is reduced during feed scarcity, which is reflected by lower conception rates during the dry seasons. Chronic or severe feed restriction impairs hypothalamic gonadotropin pulse generator. However, improvement in doe nutrition increases the systemic LH secretion, which restores the ovarian activity (Kusina et al. 2001). Restriction in energy intake during pre-mating period causes loss of body weight in doe and hence reduces the incidence of twin birth. Niyas (2015) also reported that the nutritional deficiency during exposure to HS had a detrimental effect on the reproductive performance of Osmanabadi bucks. This signifies the importance of optimum nutrition to counter HS impact in this breed.

Nutritional stress causes abortions or metabolic disorders such as pregnancy toxemia in pregnant does (Steele 1996). The lower level of glucose in the maternal blood triggers the hyperactivity of adrenal gland of the fetus, which then releases the estrogenic precursors that leads to expulsion of the live fetus and, hence, abortion occurs. Pregnancy toxemia is a condition characterized by mobilization of fat body reserves, by an undernourished pregnant doe, which is channeled to growing fetus. The reproductive performance of nutritionally stressed pregnant does after kidding is adversely affected. The negative energy balance (NEB) during early lactation and loss of fat body reserves delay the resumption of *postpartum* estrus in lactating does. The late resumption prolongs the service period that ultimately affects the kidding interval. Reducing the *postpartum* anoestrus period and proper feeding of does result in decreasing the kidding interval. Chikura (1999) found that goats kidding in the dry season had a longer kidding interval (382 ± 90 days) than those that kidded during the wet season (265 ± 40 days), which was attributed to the nutritional stress experienced during the dry season. Puberty is delayed in kids reared by underfed goats due to delay in desirable body weight at which puberty occurs (Rhind 1999). The indigenous nonseasonal goat breeds can kid when they are 1 year old but the fluctuating plane of nutrition suppresses early occurrence of estrus and increases the age at first kidding.

23.4.6 Water Stress Impact on Goat Production

Water forms an important constituent of the animal's body by contributing to 50–80% of their live weight. Consumption of water is much crucial than living without feed or fodder. Sufficient water intake by the animals ensures animals' production and health. Decrease in the amount of drinking water could not recuperate the loss of water in the body through milk, urine, sweat, respiration, and dung (Schlink et al. 2010). Further, for maintenance, production, growth and pregnancy water forms an essential component in goats. These animals were not only the first to be domesticated but also the first to be domesticated in dry, hot arid regions of the world. During the dry summer season, the goats can withstand the dehydration's effects for several days because of their adaptable and tolerance capability (Silanikove 1994, 2000). Their adaptation mechanisms have helped the animals to thrive in such harsh environment by minimizing the body water losses (Silanikove 2000). With limited available water, maintenance can be achieved in goats, which shows their superior capacity to alleviate the detrimental effects of water scarcity (Alamer 2009).

During water stress condition, the milk production decreases in goats (Hossaini-Hilali et al. 1994; Mengistu et al. 2007). Milk production needs the highest water requirement as the water content present in the milk is more than 88%. Goats have high withstanding capacity of water restriction even during lactation, though milk production decreases, the total solids tend to remain at the same levels (Alamer 2009). The lactating goats undergo weight loss during water stress condition, given that water forms 50–80% of the body weight of an animal. Water scarcity affects directly to resupply the water back to the animal. During water deprivation hemoconcentration will occur, which affects the blood flow to the mammary gland, affecting the milk secretion as well. During water stress, the cortisol concentration is increased, activating the plasmin system to release the protease peptone with channel blocking activity (PPCB) from ß-casein. Further, the lactose secretion is also inhibited in mammary tissue leading to decrease in the milk production (Silanikove 2000). Water deprivation up to 60% in goats caused significant elevations in serum concentration of triglycerides, albumin, total proteins, and cholesterol. See the next chapter for more details regarding water metabolism.

23.5 Adaptive Capability of Osmanabadi Goats

The domestic goat (*Capra hircus*) often referred as the poor man's cow, is considered as the backbone of rural economy with 95% of the goat population concentrated in the developing countries. Goats are prolific, resilient, distributed widely around the globe, able to thrive in different agroecological zones and harsh environments because of their adaptive capability (Webb 2014). HS is identified as a crucial climatic anomaly to impose severe economic losses on goat production. Despite the superior adaptive performance, HS can hamper the production efficiency in Osmanabadi goats by debilitating their adaptive capability (Shaji et al. 2016). Figure 23.4 describes the various adaptive mechanisms of goats to HS challenges.

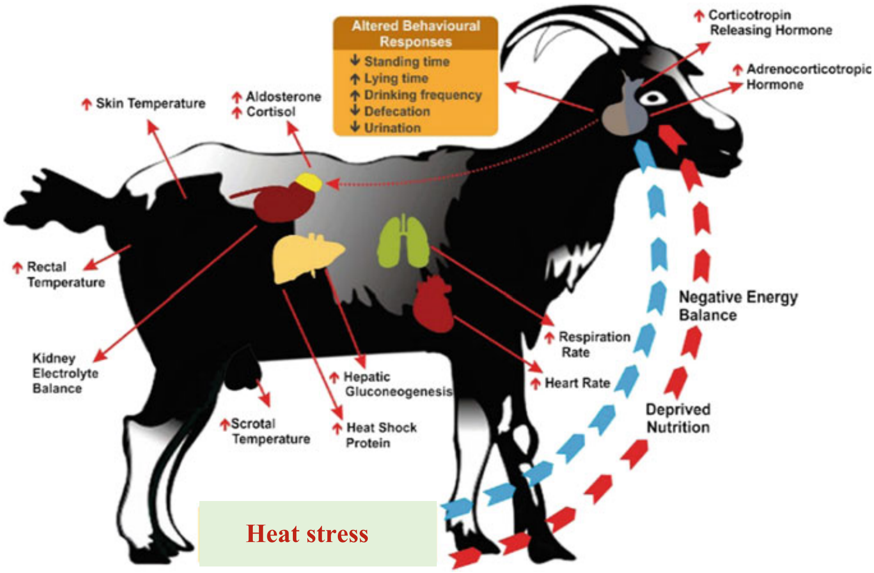

Fig. 23.4 Impact of heat stress on Osmanabadi goat adaptive capabilities

The recent studies on Osmanabadi goats by Shaji et al. (2016, 2017) clearly established the superior adaptive capability of this goat breed to the agroclimatic conditions from which they were originated (Shaji et al. 2016). This was evident from the alterations in their behavioral, physiological, blood-biochemical, and endocrine responses which were subjected to HS (Shaji et al. 2016, 2017). Further, the impact of HS on the immune response in Osmanabadi goats was established based on the different toll-like receptors (TLRs) expression pattern in liver and spleen (Sophia et al. 2016a, b).

The Osmanabadi goat subjected to HS exhibited lower body temperature in the forenoon as an adaptive response to cool the body in excess during night hours to cope with the afternoon HS (Shaji et al. 2017). Further, the influence of HS on behavioral response showed increased standing time and decreased lying time as an adaptive mechanism to reduce heat gain from the ground. Paulo and Lopes (2014) reported similar results in Saanen goats. Further, reduced feed intake and increased drinking frequency in the heat-stressed goats indicated the adaptive response to reduce metabolic heat and to conserve body water, respectively. Significant reduction in defecation frequency and urinating frequency reported in the Osmanabadi breed was also attributed to its effort in conserving the body water as an adaptive mechanism to prevent dehydration (Shaji et al. 2016).

Physiological adaptation in the goats is expressed by alterations in respiratory rate (RR), pulse rate (PR) and rectal temperature (RT). The RR and RT have been established as the reliable indicators to assess HS in animals (Sejian et al. 2013). On Osmanabadi bucks, Shaji et al. (2016) established RR and RT as important biological markers to quantify HS in these goats. Further, they observed a significant interaction between the treatment (HS) and experimental days (35 days) for both RR and RT indicating the significance of these parameters for adapting to HS challenges in Osmanabadi goats. Similar increased RR in heat-stressed goats have also been reported by many researchers, establishing the role of RR for homeostatic relevance in enhancing the heat dissipation and in reducing the body temperature (Kumar et al. 2011; Rahardja et al. 2011). In addition, it was generally observed that PR significantly increased in heat-stressed goats and this response was generally believed to be an adaptive mechanism to enhance vasodilation to increase the blood flow to the extremities activating the heat dissipation mechanisms (Hooda and Upadhyay 2014). Similar heat stressed increase in PR was also observed in Osmanabadi goats (Shaji et al. 2016). This study also established the significance of skin temperature in the head, flank, and scrotum regions to stimulate the vasodilatation process to increase the blood flow to the skin surface to facilitate heat dissipation.

Plasma cortisol is the major stress-relieving hormone in livestock species and the influence of HS on cortisol is well documented in small ruminants (Indu et al. 2014). The cortisol has been identified as a reliable biomarker to quantify HS in Osmanabadi goats (Shaji et al. 2017). Furthermore, Osmanabadi goats exhibited superior adaptive traits indicated by nonsignificant variation in the plasma glucose level during HS. This was ascribed to the enhanced hepatic gluconeogenesis to ensure regular glucose supply for the thermoregulatory activities. The adaptive nature of Osmanabadi breed was indicated in the same study by significant variations in the triglyceride level between the HS and control group goats. Moreover, a significant reduction in plasma protein and cholesterol was recorded in heat-stressed Osmanabadi goats in order to support the process of supplying sufficient energy through hepatic gluconeogenesis. Similarly, the significantly lower plasma albumin, globulin, and protein in heat-stressed Osmanabadi goats were established to be the adaptive mechanisms to favor the hepatic gluconeogenesis process (Shaji et al. 2017). HSP70 has been established as a molecular chaperone for environmental stress tolerance and adaptation in goat (Gupta et al. 2013; Banerjee et al. 2014). Plasma and peripheral blood mononuclear cell (PBMC) HSP70 mRNA expression were significantly higher during HS condition in goats (Banerjee et al. 2014; Shaji et al. 2016) indicating the reliability of using it as a confirmatory biomarker to quantify HS in goats. In addition, the adrenal HSP70 was also identified as an important biomarker to assess HS in Osmanabadi goats (Shaji et al. 2017). During HS, the immune responses of the animals are hampered (Sophia et al. 2016c). In a study conducted on Osmanabadi goats fed ad libitum, the HS significantly increased the expression pattern of hepatic TLR1, TLR3, TLR6, TLR7, TLR8, and TLR10 (Sophia et al. 2016a). The increased expression pattern of these genes indicated the superior adaptive capability of Osmanabadi goats; the increased expression patterns of TLRs were associated with increased ability to maintain immune status. These results also indicated that when nutrition is not compromised, heat-stressed animals are able to sustain their immune functions (Sophia et al. 2016a). However, in the same study different expression patterns of TLRs were obtained in the spleen. The higher spleen TLR 1, 2, 3, 6, 7, 8, 9, and 10 mRNA expression was established in Osmanabadi goats subjected to both heat as well as nutritional stress (Sophia et al. 2016b). The difference in expression patterns of different TLRs in liver and spleen could be attributed to the fact that spleen is a primary lymphoid organ, while the liver is considered to be the secondary lymphoid organ. The activated splenic innate immune functions in terms of different increased TLR expressions during combined stress indicate the Osmanabadi goat's adaptation and disease resistance mechanism under extreme environmental conditions. The significantly higher expression of TLR10 in liver and TLR1 and TLR8 in the spleen of heat-stressed Osmanabadi goats as compared to thermoneutral animals established that these genes could be ideal immunological markers for HS in goats (Sophia et al. 2016a, b). Table 23.3 describes the impact of HS on different adaptive parameters of Osmanabadi goats. The aforementioned results on the adaptive performance of Osmanabadi goat during HS put forth the relevance of concentrating future research efforts on indigenous breeds such as Osmanabadi and suggest indigenous goat production as a worthy investment platform.

Table 23.3 Impact of heat stress on different adaptive parameters (mean ± S:E.M.) of Osmanabadi goats

Parameter	Control	Heat stress
Behavioral responses		
Standing time (min) period	235.5 ± 13.5	254.2 ± 15.1
Lying time (min) period	124.5 ± 13.5	105.8 ± 15.1
Drinking frequency (no. of times)	2.5 ± 0.2	3.1 ± 0.3
Defecating frequency (no. of times)	3.1 ± 0.2[a]	2.0 ± 0.3[b]
Urination frequency (no. of times)	3.0 ± 0.3	2.0 ± 0.2
Water intake (L/day)	1.3 ± 0.1[a]	1.6 ± 0.1[b]
Physiological responses		
RRM (breath/min)	25.1 ± 1.2	23.0 ± 1.0
RRA (breath/min)	31.9 ± 1.4[a]	69.2 ± 5.3[b]
PRM (beats/min)	61.6 ± 1.9	59.2 ± 1.4
PRA (beats/min)	69.6 ± 1.8[a]	79.2 ± 2.4[b]
RTM (°C)	37.7 ± 0.1	37.6 ± 0.1
RTA (°C)	38.7 ± 0.1[a]	39.1 ± 0.1[b]
Skin temperature differences		
STHM (°C)	30.1 ± 0.5	29.8 ± 0.2
STHA (°C)	35.0 ± 0.2[a]	37.7 ± 0.8[b]
STSM (°C)	32.7 ± 0.2	32.1 ± 0.2
STSA (°C)	33.7 ± 0.2	34.5 ± 0.2
STFM (°C)	31.0 ± 0.2	30.3 ± 0.2
STFA (°C)	34.9 ± 0.2[a]	36.5 ± 0.4[b]
Blood-biochemical responses		
Glucose (mg/dL)	55.1 ± 2.1	56.2 ± 2.4
Total protein (g/dL)	6.1 ± 0.1	6.2 ± 0.1
Albumin (g/dL)	2.6 ± 0.1	2.6 ± 0.1
Globulin (g/dL)	3.5 ± 0.1	3.6 ± 0.1
Total cholesterol (mg/dL)	61.3 ± 3.4	55.6 ± 3.8
Cortisol (µg/dl)	5.3 ± 1.1	8.7 ± 1.3
Aldosterone (pg/mL)	77.2 ± 2.8[a]	103.3 ± 7.8[b]
Plasma HSP70 (ng/mL)	0.9 ± 0.2	1.3 ± 0.2
Triglycerides (mg/dL)	17.7[a] ± 0.9	8.5 ± 1.3[b]
Urea (mg/dL)	61.3 ± 2.2	62.1 ± 1.7
PUN (mg/dL)	27.4 ± 1.0	29.8 ± 0.9

(continued)

Table 23.3 (continued)

Parameter	Control	Heat stress
Gene Expression Patterns		
Hepatic HSP70 gene	1[a]	1.50[b]
Adrenal HSP70 gene	1[a]	1.65[b]
PBMC HSP70 gene	1[a]	1.65[b]
Hepatic TLR10	1[a]	2.29[b]
Spleen TLR-1	1[a]	3.25[b]
Spleen TLR-8	1[a]	3.23[b]

Source Shaji et al. (2016, 2017), Sophia et al. (2016a, b)
All a versus b values within a row differ significantly with each other ($P < 0.05$). HSP70 heat shock protein 70; *PRA* Pulse rate afternoon; *PRM* Pulse rate morning; *PUN* Plasma urea nitrogen; *PUN* Plasma Urea Nitrogen; *RRA* Respiration rate afternoon; *RRM* Respiration rate morning; *RTA* Rectal temperature afternoon; *RTM* Rectal temperature morning; *STFA* Skin temperature scrotum afternoon; *STFM* Skin temperature flank morning; *STHA* Skin temperature head afternoon; *STHM* Skin temperature head morning; *STSA* Skin temperature scrotum afternoon; *STSM* Skin temperature scrotum morning; *TLR* Toll-Like-Receptor

23.6 Concluding Remarks

The significance of Osmanabadi goats in meeting the socioeconomic security of poor and marginal farmers is principally due to their superior adaptive capability to the tropical environment.

This chapter reviews the impact of different environmental stresses on both the productive and reproductive performance in Osmanabadi goats. The literature clearly suggests that HS alone does not bring significant impact on the productive potential of this breed. This indicates that when nutrition is not compromised, Osmanabadi goats are able to withstand HS without compromising production. The rumen fermentation pattern and metabolites are also found to be drastically altered in Osmanabdi goats during the different environmental stress exposure. Further, it is also established that Osmanabadi goats possessed superior adaptive capability to counter HS through their ability to alter the behavioral, physiological, endocrinological, and different thermo-tolerant gene expression patterns. On the other hand, lying time, drinking frequency, RR, RT, plasma HSP70, and PBMC HSP70 gene expression may act as ideal biological markers to quantify the impact of environmental stresses abilities in Osmanabadi goats. The significantly higher expression of TLR8 and TLR10 in heat-stressed Osmanabadi goats indicates that these two genes could be the immunological markers for HS in goats. More detailed studies are required to have a clear understanding of all these associations at a mechanistic level and if we are fully exploiting the potential of nutritionally manipulated productive performance in Osmanabadi goats during HS condition. These efforts may further help to identify potential biomarkers for optimum production and adaptation in Osmanabadi goats which may be used in breeding programs using marker assisted selection to further refine this breed. This crucial step must be performed before disseminating them to the farmers in the agroecological zones they are reared to ensure their livelihood security.

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Chapter 24
Heat Stress Effects on Water Metabolism of Goats in Harsh Environments

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Abstract Goats play a predominant role in the economies of millions of people, and they have been a source of meat, milk, skin, wool, and fiber since ages. Goats undergo various kinds of stressors under many different conditions, i.e., physical, nutritional, chemical, and physiological and heat stress (HS). Among all, thermal stress is the most concerning nowadays in the ever-changing climatic scenario, which supposes a serious long-term challenge faced by small ruminant owners worldwide. HS results in decreased growth, reproduction, production, and milk quantity and quality. Thus, HS results in economic losses, emphasizing the necessity to objectively assess animal welfare. The hot climate is a serious threat to agriculture business, including goat production. The ability of sheep and goats to cope with HS without affecting their welfare and productive performance has been often overrated. To date, little attention has been paid to comprehensive detailed data on the adverse effect of HS on small ruminants. Among domestic ruminants, goats are renowned for their ability to tolerate water and energy restriction. However, some basic questions regarding their ability to endure water restriction under HS are still open. Therefore, a definition of heat stress and its effects on water metabolism on goats will be the scope of this chapter.

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24.1 Introduction

HS is described as the cumulative detrimental effect of a variety of factors on the health and performance of goats, in our case, or it is the magnitude of forces external to the body which tend to displace its systems from their ground state (Yousef 1985). Goats undergo various kinds of stressors, i.e., physical, nutritional, chemical, physiological, or HS. Among all, HS is the most concerning nowadays in the ever-changing climatic scenario (Silanikove 1992), and it is one of the most important stressors especially in the tropical, subtropical (Marai et al. 2007), semiarid (Al-Dawood 2015; Silanikove 2000a), and arid (Silanikove 1992) regions of the world. CC supposes the most serious long-term challenge faced by small ruminants' owners globally since it impacts goat production and health. Environmental factors such as ambient temperature, solar radiation, and relative humidity have direct and indirect effects on goats (Collier et al. 1982). High environmental temperature is considered as the major concern that challenges the goat's ability to maintain energy, thermal, water, hormonal, and mineral balance (Silanikove 1992). The intergovernmental panel on climate change predicts that by the year 2100, the increase in global surface temperature may be 1.8–4.0 °C (IPCC 2007), and it is expected that 20–30% of livestock might be at the risk of extinction (FAO 2007). There is evidence that climate change, especially elevated temperature, has already changed the overall abundance, seasonality, and spatial spread of farmed small ruminants (Van Dijk et al. 2010).

The degree of HS, experienced by animals, is estimated by temperature–humidity index (THI) that includes both ambient temperature and relative humidity (Marai et al. 2001). Measuring the heat load imposed on an animal using air temperature (dry bulb temperature) can be misleading. A more useful measure is the wet bulb temperature, which takes relative humidity into account (Sparke et al. 2001). Thereby, THI $\leq$ 74 is considered normal, 75–78 is an alert status, 79–83 is a danger status, and THI $\geq$ 84 is an emergency status for animals (Helal et al. 2010).

24.2 Water Metabolism

Water is one of the most important nutrients required for the maintenance of life, and it is involved in many physiological essential functions for the performance of small ruminants. Water is essential for the adjustment of body temperature, growth, reproduction, lactation mechanisms, digestion pattern, nutrient exchanges and transport to and from cells in blood, excretion of waste products, and heat balance (Salem 2010). Water requirements are regulated by dry matter intake, environmental temperature, and loss of water from body tissues. Unlike feed nutrients, water does not receive adequate consideration to ensure optimal performance of ruminant animals, mainly those raised for milk or meat and under hot conditions. Small ruminants may experience moderate to severe water restriction during HS conditions, and their requirements for water in dry areas are high due to high temperatures and radiation load from the sunrays (Salem 2010).

There are two aspects of adaptation concerning metabolism and nutrition that are under discussion. One concerns fat. The goat has a lower fat reservoir in the body, more unsaturated fat in the tissues and plasma. In goats, less fat is mobilized by adrenalin than sheep. Whereas in sheep, fat is stored in adipose tissue and also intramuscularly, in goats the deposits are visceral (Devendra 1987). During the period of feed shortage or starvation, the mobilization of fat is associated with an increase in thyroxine and also adrenaline secretion rates (Silanikove 2000b). This mobilization of fat, mostly of oleic acid (C18:1) contributes more to survival than attrition of tissue protein (Silanikove 2000b). This is particularly evident in Black Bedouin goats than in the desert, which not only have a lower energy and water turnover rate compared to other goats but also a capacity to produce about 1.4 kg of milk yield/day (Shkolnik et al. 1980); the stored energy in fat must obviously have contributed to this ability (Devendra 1987). The second factor concerns water metabolism and water turnover rate. According to Macfarlane and Howard (1972), water turnover is proportional to feed intake. McDowell and Woodward (1982) have noted that goats have certain traits which were advantageous in situations where water resources were limiting. These have higher heat tolerance to dehydration, less susceptibility to respiratory alkalosis from high respiration rates, and fewer metabolic disorders than cattle and sheep. Goats have a lower water turnover rate compared to camels, followed by sheep and cattle (Macfarlane 1968), and since as a rule, they prefer semiarid and subtropical climates where ambient temperatures are high and rainfall relatively low. Nicholson (1985) reported that camels have the lowest turnover, zebu cattle and sheep have comparable rates, while goats have the highest turnover. This statement contrasts with Macfarlane (1968) findings. Large animals with a lower metabolic rate per unit weight and a low surface-to-volume ratio would be expected to have correspondingly low water turnover rates, and in this respect, cattle appear to be the least efficient users of water. Several adaptations to cope with the scarcity of especially water and also feed have been developed (Devendra 1987). Robertshaw and Dmi'el (1983) identified four adaptations in goats which are as follows (Fig. 24.1):

(a) Ability to desiccate the feces. This represents about 20% of total loss under thermoneutral conditions (Devendra 1987), and reduces fecal water loss by about 20–30% (Devendra 1987). However, because of a decline in total fecal output, there is an overall 61% reduction (Devendra 1987);
(b) Ability to concentrate the urine and thereby reduce urine volume. In dehydrated animals, urine volume usually declines by about 50% (Devendra 1987) and urine osmolality can rise 2800–3000 mOsm/L water giving a urine plasma ratio of 10, a level comparable to many desert ungulates (Schmidt-Nielsen 1983);
(c) Ability to reduce evaporative water loss. Several authors have confirmed that dehydration results in a marked reduction in evaporative water loss (Shkolnik et al. 1980). This means that there is reduced cooling. However, heat storage is not a phenomenon observed in goats (Devendra 1987). While this phenomenon

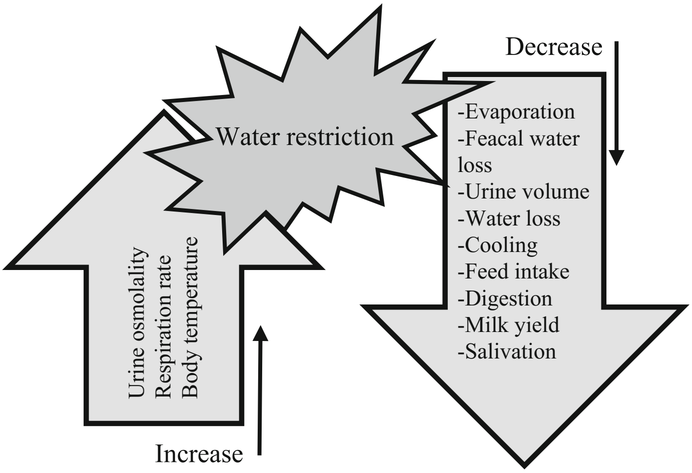

Fig. 24.1 Goats adaptation to water restriction

may be especially true in the arid and semiarid environments, in the humid regions, high humidity suppresses evaporative heat loss. Thus, non-evaporative heat loss is an important adaptive mechanism in these regions and goats such as the Katjang in Malaysia and Indonesia, or the dwarf goats in Nigeria and Zaire may have been subjected to natural selection for this feature in humid tropical climates (Devendra 1987);

(d) Utilization of rumen as a water reservoir (Devendra 1987). It is possible that the rumen acts as a reservoir of water and protects the vascular system from sudden dilution especially during rehydration following dehydration. Goats are known to live without water for several hours or days. Black Bedouin goats, for example, lose 25–30% of their body weight during water deprivation over 4 days due to a reduction in total body water and blood plasma volume (Shkolnik et al. 1980).

Although sheep and goats have colonized desert areas, they still need to drink almost daily, and they are better adapted to cope with periods without water than other farmed animals. In general, goats are better at conserving water than sheep and possibly due to their browse diet, may be able to obtain nearly all their water requirements from their food (Dwyer 2009). Overall, a water deprivation for 3 days or more would have detrimental effects on feed intake in lambs and ewes which exhibited reduced milk production (Aganga et al. 1990). However, goats kept under HS conditions doubled their water consumption (Salama et al. 2012; Caulfield et al. 2014). Increased water intake is mainly used by goats suffering from HS which is boosting heat loss by sweating and panting (Hamzaoui et al. 2013). In this regard, total water evaporation from water input was three times greater in heat stressed goats than the control ones (Hamzaoui et al. 2013). Insensible water loss by diffusion of water from the skin was two times higher at 35 °C than at 18 °C

(Shafie et al. 1994). Furthermore, sheep consumes 2 L water/kg of dry matter at temperatures between 0 and 15 °C, and this ratio increases three times at temperatures above 20 °C (Conrad 1985). In addition, water consumption is 9–11% of the total body weight during winter and 19–25% during summer in sheep (Ismail et al. 1995). Exposure of sheep to HS conditions induces a marked increase in water turnover and water intake (Ismail et al. 1995), and the increase in water turnover was 6% in winter and 7% in summer (Ismail et al. 1995).

24.3 Water Restriction Effects on Goats

Water restriction was extensively studied in ruminants over the past five decades in order to evaluate and understand the physiological basis underlying their capacity to endure water shortage, and the effects of water restriction on feed intake and utilization (Silanikove 1992). It is possible to maintain ruminants for long periods (e.g., for an entire season) on restricted water intake (Silanikove 1992). Hence, it is obvious that ruminants in general, and goats in particular, have the capacity to balance their water economy at a lower level than their normal water intake. Consequently, unlike in animals experiencing dehydration, the plasma tonicity and electrolyte concentrations may be in the steady state throughout the water restriction for a long period (Silanikove 1992). However, despite the above-mentioned extensive research, the existing information does not allow us to tell between two options that enable goats to maintain water balance under water restriction: (i) Reduced feed intake is linked to reduced energy metabolism and hence reduced water losses (Silanikove 1989). With this option, the goats maintain homeostasis without losing body water and without changes in plasma electrolyte composition in comparison to normal conditions; and (ii) water restriction induces losses in body water content in comparison to pre-restricted level and activates physiological responses to preserve water losses. In this case, the achievement of homeostasis of water fluids is associated by some loss of body water and increase in plasma electrolyte composition in comparison to pre-restricted conditions.

The mass of body water accounts for 60–70% of body weight and constitutes 99% of the molecules in mammalian body (Chew 1965). Maintaining homeostasis of body fluids is, therefore, an essential function in terrestrial mammalians. For maintaining homeostasis of body fluids, water, which is constantly lost through evaporation, urination, and fecal excretion, should be replaced. In addition, there is a need to maintain an essential minimal mass of water pools in order to preserve essential functions, such as cardiovascular flow, appropriate ion balance, and composition, as well as thermoregulation (Schmidt-Nielsen 1983; Silanikove 1994). Under thermoneutral conditions, food and water intake are highly related to each other in goats and other mammals (Silanikove 1989). Feed restriction or reduced energy intake is associated with proportional reductions in water intake without loss of body fluids and changes in blood plasma composition (Silanikove 1989, 1994). In contrast, water deprivation induces a decrease in body fluid content and an increase in its osmolality (Silanikove 1989). In order to maintain thermoregulation during periods of heat stress, animals may sweat and pant, causing loss of body water. The main general homeostatic responses to dehydration in mammals include reductions in fecal and renal water losses, reductions in metabolism and, hence, in evaporation, and protection of plasma volume (Schmidt-Nielsen 1983; Silanikove 1994).

From the above discussion, it appears that there are two types of drinking and water regulatory mechanisms: the first is the food intake-dependent drinking, in which homeostasis of body fluids is achieved without perturbation of body fluid volume and without significant changes in body fluids osmolality and ion composition; the second one is drinking in response to dehydration, which is also influenced by the physiological changes induced by water deprivation (Silanikove 1994).

When the water supply is unlimited, there is a close interrelationship between the amount of food consumed and the water ingested in ruminants as well as in other mammals (Chew 1965; Silanikove 1989). This relationship derives from the close interrelationship between energy and water fluxes in mammals (Silanikove 1989). Imposing reduction of feed intake of roughage diets to about 45% of the ad libitum intake was reflected by a similar reduction in water intake in the desert and non-desert goats (Silanikove 1989). Differently, in that experiment, the reduction in free feed intake upon restricting free water intake was proportionally much lower than the level of water restriction imposed. Similar moderate reduction in feed intake would be proportional to water restriction (33 and 67%), which was found in goat breeds of tropics (Abioja et al. 2010) and deserts (Alamer 2009). In cows, with 50% drinking water restriction, reduction in feed intake was 20% lower than during the water availability ad libitum (Burgos et al. 2001).

There should be no problem for goats to maintain body weight and energy balance on 30–40% reduction in free feed intake, and desert goats can maintain body weight even with 50–60% reduction of feed intake (Silanikove 1985, 1987). Thus, the loss of body weight found in the latter experiment cannot be explained by the modest reduction in feed intake, particularly if taking into consideration that the digestibility of the diet was most likely increased under the water restriction conditions (Silanikove 1985, 1992). The concentration of antidiuretic hormone increases under deficit in body fluids in order to preserve body water. Reduction in plasma volume is associated with an increase of sodium concentration, the main ion in extracellular fluids and with a parallel increase in antidiuretic hormone concentration (Andersson 1977; Maltz et al. 1984). Thus, lack of evidence for appreciable energy deficit and the evidence for reduced plasma volume in proportion to the level of imposed water restriction is the most probable explanation for the proportional increase in glucose, cholesterol, creatinine, and urea concentrations under water restriction. A similar increase in blood plasma metabolites upon water restriction was found by Casamassima et al. (2008) in sheep.

Exposure of goats and sheep to heat stress was found to be associated with a regulatory increase in body fluid volume and plasma volume (Silanikove 1988, 1992; Rahardja et al. 2011). Thus, a putative regulatory increase in body water and plasma volume when water was freely available may explain why the dehydration imposed by water restriction did not affect substantially feed intake and thermoregulatory responses of the goats. The imposed dehydration did not lead the goats to dehydration level, which would put at risk their cardiovascular and thermoregulation functions.

In another study, the water-restricted animals were subjected to higher heat stress than the goats having free access to water as reflected by the increase in the temperature in a very exposed area of the body to the sunrays, the head skin. Nevertheless, the increase in deep (rectal) and udder skin temperatures were quite modest in comparison to the animals exposed to severe HS (Silanikove 2000a), indicating that the HS under those conditions did not induce significant challenges on the thermoregulation capacity of the goats. For comparison, the daily mean of rectal temperature was 0.5–0.9 °C higher in dehydrated goats than in hydrated ones, which would be due to a reduced evaporative heat loss (Baker 1989; Jessen et al. 1998).

Imposition of water restriction enforced the animals to use different strategies, which implied a much more economic use of water for maintaining the water balance and thermoregulation. This switch was also reflected by a marked reduction in the water to feed intake ratio. Similar sharp reduction in this ratio in response to water restriction was also found by Abioja et al. (2010) in the West African tropical goats.

As summarized from above, the most notable physiological and behavioral responses in the water restricted animals were those associated with saving the water lost. The increase in body temperature allows goats to save the water losses; even under harsher conditions, the level of thermolability may be much higher than during rehydration (Baker 1989). Thus, the reduction in body water content contributes to reducing water losses. The main cause of water losses from the body is evaporation (cutaneous and respiratory), which is directly linked to the metabolic rate of the organism (Silanikove 1989). Heart rate in mammals is proportional to heat production (Brosh 2007). Thus, the reduction in heart rate in the water-restricted goats suggests that they reduced their metabolism to preserve water and to compensate for the reduction in feed intake.

The reduction in walking and standing is one of the factors that explains the more economized energy metabolism. Nevertheless, the increase in standing activity may reflect a thermoregulatory behavioral response: in the standing position, the goats may direct themselves to a position in respect to the sun, minimizing their body surface exposed to direct radiation (Silanikove 2000a). The reduction in feed intake under water restriction is consistent with the results of Burgos et al. (2001) in cows. The reduction in consuming feed may also explain the lower rumination in the water-restricted goats.

24.4 Concluding Remarks

To summarize the data given here, it is significant that climate changes will affect all environments worldwide. These changes will induce animal husbandry and livestock practices to be more flexible to changing scenarios. Goats seem to be more adaptive to these changes. Farming practices and guides should adopt new and emerging techniques to combat these harsh environmental changes.

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Chapter 25
Why and How to Measure Goats' Welfare

George Stilwell

Abstract Sustainability, animal welfare and environmental concerns have increased consumers' interest in knowing how, where and by whom food is produced and handled from 'farm to fork'. But even if consumers did not object to poor animal welfare, there is enough evidence that good welfare corresponds to better performance and higher quality products. It is well established that animals with poor welfare have suboptimal performances or demand artificial ways of maintaining health and production. Comprehensive welfare assessment is not easy as animal welfare is a multidimensional and complex concept. However, it can be achieved through well-built assessment protocols. These protocols are also excellent tools to discern and monitor disease prevalence (e.g. lameness) and to track changes within the same farm over time as a part of good farm management. Welfare protocols should be devised to fully cover four Welfare Principles (Welfare Quality®—WQ): good feeding; good housing; good health; and appropriate behaviour. This is achieved by including and testing different types of indicators. Currently, welfare assessment is established mainly on animal-based indicators or also called output measures, complemented with some resource-based indicators. The 'AWIN-animal welfare indicators' was a large European project dedicated to developing, integrating and disseminating animal-based welfare indicators for different farms species, including goats. From the work of one of its research teams resulted a welfare assessment protocol for intensively kept dairy goats that is an excellent basis for the building of protocols for other production systems. Designing an assessment protocol is a challenging and laborious process that should start by identifying valid, reliable and feasible welfare indicators for goats in different agro-systems. This chapter presents the basis for the construction of a welfare assessment protocol and suggests some indicators to be included in the assessment of goats extensively managed in arid, semi-arid or in poor environmental conditions.

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25.1 Introduction

Animal welfare is a multidimensional concept that can be defined as a state of complete mental and physical health and by which the animal is in harmony with its environment. In summary, good welfare = being fit and feeling good (Webster 2005). Several reasons are behind the increased concern with farm animal welfare: (1) consumers' interest in knowing how, where and by whom food is produced and handled from 'farm to fork'; (2) the need to reduce the use of antimicrobials and other substances intended to artificially keep animals healthy and producing; (3) the overwhelming scientific evidence that animal performance is deeply and irrevocably associated with welfare; (4) and the society ethical demand for animal rights including the opportunity to 'live a good life'. So, an increasing number of consumers worldwide want to have a say on how animals are produced, but many may think they are unable to judge good from bad practices. In response to these demands, assurance schemes and welfare legislation have multiplied all over the world in order to certify high-quality animal products, in terms of health, safety and respect for animal welfare.

It seems obvious that 'you can't control what you can't measure' (Grandin 2010) so it is essential to create an instrument that will enable stakeholders (e.g. farmers, retailers, consumers, veterinarians, legislators, etc.) to scientifically and objectively measure and monitor on-farm welfare standards for management decisions, benchmarking, certification, farm assurance and legal purposes. Thus, animal welfare assessment should be considered as one of the main pillars of any efficient and sustainable production system.

Because animal welfare is not limited to one feature or component, assessment requires a multidimensional approach corresponding to a multi-criteria evaluation. To develop a practical tool (e.g. a quality assurance scheme) that delivers an overall view of welfare, different specific indicators need to be integrated and tested as prototypes (Spoolder et al. 2003). The final result will be one welfare assessment protocol or an assessment system composed of sequential protocols (Battini et al. 2015a). However, it should be said that indicators that are valid for one system, species or breed may not be valid for others. This is particularly true for small ruminants and especially for goats due to the huge range of purposes, habitats, behaviours, breeds and systems that are associated with the production of this farm animal.

Being very difficult (impossible?) to list universal indicators that reflect the welfare of all goats, this chapter presents the basis for the building of a comprehensive, feasible and reliable protocol. The refinement and selection of the more specific indicators should be performed by specialists working on the field.

25.2 The Toolbox Approach

Two broad categories of indicators are usually used to assess animal welfare at farm level (Botreau et al. 2007; EFSA 2012): (a) animal-based indicators (e.g. behavioural measurements, disease signs, productivity and health records) and (b) resource- (e.g. manpower, installation details, stocking density, feedstuff quality, etc.) and management-based indicators (e.g. how and when animals are fed, moved and mixed with other animals, breeding strategies, how routine practices like tail docking or dehorning are performed, etc.). Animal-based indicators can further be divided into four categories: health-, physiological-, behavioural- and record-based.

Throughout the years, it became evident that good management and access to an adequate environment did not necessarily result in a high standard of welfare. So, a different approach was suggested by scientists and some regulatory organizations such as the European Food Safety Agency (EFSA), emphasizing the role of animal-based indicators as they seem more appropriate for measuring the way the animal is feeling and responding or coping with its surroundings. In risk assessment terminology, these responses are the consequences of the factors acting upon the animal. If they are negative, they are referred to as adverse effects and, if positive, they are referred to as benefits (EFSA 2012).

When building an assessment protocol, the first step is to study and validate a variety of measures or indicators and then collecting them into what has been compared to a *toolbox*. Some of these indicators are easily validated because their relation with welfare is simple and straightforward (e.g. lesions and signs of disease or pain), but for others finding a correlation is much more difficult (Anzuino et al. 2010).

After collecting all these validated indicators, we can choose those more appropriate to address a particular purpose. For example, one tool may be selected to assess feeding while another one will be selected to evaluate the incidence of disease or human–animal relationship. In contrast, one tool can give information on several aspects of welfare,—for example, bad hair condition may not only be associated with nutritional deficits but also with the presence of parasites or chronic disease, as it has shown for dairy goats (Battini et al. 2015b). These indicators have been called 'iceberg' because they stand for more than is apparent.

It is obvious that different circumstances or different settings will require different indicators (Blokhuis et al. 2010; EFSA 2012). For instance, classifying overgrown hooves will probably be of little value for goats in mountain pastures but is an essential indicator of management quality in intensive dairy farms. It is also evident that it is unnecessary and even unrealistic to use all the tools every time the welfare of an animal/farm is to be assessed, because some will have very low prevalence, some will give repeat information, some will need too much time to collect and some will demand complex interpretation.

25.3 Building a Protocol

On-farm assessment protocols must be based on scientifically proven measures of needs fulfilment that are crucial for the maintenance of a state of animal physical and mental well-being.

One of the first steps in building a welfare assessment protocol is to define what are the needs of the animals to be assessed, classically categorized into the 'Five Freedoms': (1) freedom from hunger and thirst; (2) freedom from physical and thermal discomfort; (3) freedom from pain, injury and disease; (4) freedom from fear and stress; (5) and, freedom to exhibit natural behaviour (Farm Animal Council 2009). From these Five Freedoms, the WQ® project (Welfare Quality 2009; Blokhuis et al. 2010) outlined four main areas of concern termed 'Welfare Principles', that were then split into 12 criteria, each of which corresponded to a key welfare dimension: (a) good feeding (appropriate nutrition and absence of prolonged thirst); (b) good housing (comfort around resting, thermal comfort and ease of movement); (c) good health (absence of injuries, disease and pain induced by management procedures); (d) and appropriate behaviour (expression of social behaviour, expression of other behaviours, good human–animal relationship and positive emotional state). It should be clear that because animal welfare is a multidimensional concept, the fulfilment of all criteria is important. For example, the ability to exhibit appropriate behaviour does not compensate for poor health, and good health does not compensate for behavioural problems.

The next step is to identify promising animal-based indicators that will reflect the accomplishment of each welfare criterion (Main 2009). This can be done by consulting experts or by reviewing existing scientific literature (Battini et al 2014; Llonch et al. 2015). It should be said that when a criterion is not satisfactorily addressed by an animal-based indicator, environment or management measures should be used.

Labelling an indicator as appropriate will depend essentially on the satisfaction of three conditions (Waiblinger et al. 2001; EFSA 2012):

- Validity—does the indicator really measures what we think it measures? Does it relate to the animals experience? Validity is determined by accuracy and specificity. Two things are important to mention: (i) an overall assessment system is only as valid as the indicators used to establish it; (ii) validity might be situation dependent—sometimes measures that are valid during one stage of the production cycle or in a certain production system are not applicable to other times or other conditions.
- Reliability—expresses the relative similarity of results when assessing one animal/farm on different occasions, being associated with repeatability. Would indicators be recorded in the same way by more than one assessor (intra-observer reliability)? Would the same assessor record indicators in the same way on more than one occasion (inter-observer reliability)?

- Feasibility—can the indicator be measured on farm in a reasonable manner (i.e. time, manpower, tools…)? Feasibility refers to the degree to which the evaluation or collection procedure is possible, practicable and worthwhile. The development of feasible indicators is one of the main challenges in welfare assessment research.

There are two other features that have to be considered when selecting indicators to be included in a welfare assessment protocol—transparency and fairness. Producing a protocol that is based on utopic and intangible thresholds, will not help the farmer and ultimately not even the animals, as it will be disregarded and even disputed by farmers. In summary, animal-based indicators must be robust, quantifiable and sufficiently objective.

After selecting quantity and quality appropriate indicators so as to cover the Principles and Criteria previously defined, the protocol should be tested for its overall feasibility. If possible, the testing should be repeated in several systems and with different breeds (Battini et al. 2016; Can et al. 2016). If important differences are identified or if feasibility is reduced for some indicators, other tools should be sought to substitute the ones not giving reliable data.

Finally, some recommendations on the material needed to assess large herds in outdoor conditions: recording sheets, tablet or smartphone, paper, pens/pencils, binoculars, camera with a good zoom, measuring tape, laser rangefinder or other means to measure distance and safety shoes/boots.

25.4 Main Constraints and Limitations

When designing a protocol for goats, one of the first difficulties encountered is the lack of validated indicators. This may be especially true for herds in extensive, arid and poor environments, where welfare research is seldom done. The best way to overcome this constraint is to select potential candidates from a list of indicators proposed by experts (including farmers) (Phynthian et al. 2011; Battini et al. 2014), although some will still need scientific validation. In the case of the worldwide scattered arid and poor environments, it may be difficult to gather a significant number of opinions so as to build a comprehensive list of goat indicators, because of the high variety of breeds, production systems, geographic and climatic elements, etc.

One easy solution would be to use indicators from other more studied systems (e.g. dairy goats in intensive systems) (Anzuino et al. 2010; Battini et al. 2014), but the question is: do they have the same meaning? It seems obvious that those related to disease/lesions (e.g. lameness) are almost universal but the significance of others, such as BCS, hair condition, signs of thermal comfort or relations with humans, cannot be extrapolated.

Another challenge for protocol application is to ensure reliability, as there is an associated level of subjectivity involved when using animal-based indicators. To achieve a high level of reliability, individual perception (and concern) of welfare should be avoided (Meagher 2009) and animal welfare assessment should be seen as a science (Webster 2005). To meet this prerequisite, intensive training of assessors is essential, although it may be a problem in certain regions.

Moreover, there are two shortcomings related to feasibility:

(i) Herd and animal related—goats are gregarious animals making it difficult to identify and isolate individuals for physical examination. They are also stoic and most times able to adapt quickly to adverse conditions. This means that behavioural signs may be subtle and further concealed by cohabitants, character or temperament.

(ii) System related—the assessment of welfare indicators is not easy even in housed animals, but will be particularly difficult when animals are scattered through large (and inaccessible?) areas. Additionally, facilities for handling animals are sometimes lacking, making it very difficult to perform close and individual assessment. Possible attenuation for this is to implement a two-step approach. A first more superficial assessment, that is targeted mainly at the herd and can be done at a distance, will include some iceberg indicators (BCS, lameness, hair condition, etc.). Those farms not fulfilling pre-determined conditions are then taken to a second level that includes a much more comprehensive assessment. This second level consists of a broader and more detailed assessment that requires individual assessment (e.g. clinical examination), but still trying to keep feasibility by ensuring that it is conducted in a reasonable amount of time. For very large herds or those that are scattered throughout a large area, it may be unfeasible to apply the protocol to all animals due to time, financial costs and physical limitations. For these reasons, a sampling strategy that gives a representative account of the herd's prevalence for different indicators is crucial. Tables to calculate the proportion of animals to be assessed is available in the published AWIN protocols for goats (Battini et al. 2015a).

Finally, it should be mentioned that some practical issues will surface when trying to grade the level of welfare. For example, data collected is often expressed on ordinal scales, which limit the use of weighted sums to aggregate them. Also, as welfare measures may vary in precision, relevance and their relative contribution to an overall welfare assessment, aggregation procedures should be aware that principles may not be equally important. To complicate things further, it is recognized that the weight assigning is not merely a technical process, but should also take into account ethical assumptions and societal concerns and values. In summary, benchmarking and systematic classification of herds should be done with caution.

25.5 Protocols Being Used in Goats

The AWIN protocol for dairy goats is now published (AWIN 2015; Battini et al. 2015a). The final 25 indicators selected (Table 25.1) covered all criteria and principles suggested by the WQ® project and were integrated into a welfare assessment prototype that was tested for its overall feasibility in 60 goat farms located in Portugal and Italy (Battini et al. 2016; Can et al. 2016).

The tested protocol combined 14 indicators at group level and 11 indicators at individual level, which were assessed in order to produce each indicator's prevalence. Assessments began with group-level observations registering the number of goats improperly disbudded, queuing at feeding/drinking place, abnormally lying or kneeling, with poor hair coat condition, showing oblivion behaviour or signs of thermal stress (either shivering or panting). After group assessment, Quality Behaviour Assessment (QBA) was performed[1] followed by human–animal relationship tests (latency to the first contact and Avoidance Distance tests) inside the pen. Finally, animal-based indicators in individual animals (e.g. BCS, cleanliness, overgrown claws and body discharges) were collected. Group-level observations were made in one single pen containing only adult lactating goats, with all the animals being evaluated. After the assessment, the farmer was asked to answer a questionnaire that would provide additional information and a few resource/management-based indicators.

After conducting this testing, the AWIN working group decided to propose the two-step strategy presented previously in this chapter. It was decided that the two-step strategy was the best way to avoid having to apply a very comprehensive, time-consuming and expensive protocol to all farms in one region. In this way, only farms with potential welfare problems have to be assessed in detail. In a second level assessment, all pens and animals should be evaluated.

The AWIN team also produced a specific app (AWINGoat, available on Google Play Store and App Store) for tablet or smartphone, in order to facilitate data collection and to provide a clear and immediate output. The AWINGoat app is the first tool developed to assess welfare of dairy goats on farm and it enables farmers, veterinarians and technicians to collect, store and download the indicators included in the first-level welfare assessment protocol.

The AWIN protocol has also been tested and adapted to small, family-run ovine/caprine dairy mixed herds. These farms generally use mountain natural pastures with very little supplementation. Several changes were introduced to the original protocol—for example, queuing at the feed trough was removed—but in general, it was concluded that a modified protocol is acceptable and useful. These farms are most times small cheese-producing units, that will profit by showing consumers that health and welfare are certified.

[1]QBA aims to assess, summarize and integrate different aspects of an animal's dynamic style of interaction with the environment and cohabitants, using descriptors such as calm, anxious, curious or confident (Wemelsfelder et al. 2001).

Table 25.1 The 25 indicators used in the AWIN protocol for goats and their meaning (AWIN 2015)

Body condition score	Goats that are too thin or too fat
Hair coat condition	Goats with matted, rough, scurfy, uneven or shaggy hair coat
Queuing at feeding	Goats that cannot reach the feed through to eat
Queuing at drinking	Goats that cannot reach the water trough or other source of drinking water
Bedding	Quality of bed material (softness and dryness)
Thermal stress	Goats that are patting or shivering or showing other signs of thermal discomfort (e.g. seeking shade or the protection of barriers)
Kneeling at the feeding rack	Animals seeking to reach food
Lameness	Goats that are severely lame
Claws	Goats with overgrown or deformed claws
Faecal soiling	Dirty perineum and hind legs
Nasal discharge	Mucous or mucopurulent discharge (uni- or bilateral)
Ocular discharge	Serous, mucous or mucopurulent discharge (uni- or bilateral)
Abscesses	Superficial abscesses anywhere on the head or body
Oblivion	Animals which are isolated, apathetic, lethargic, etc
Improper disbudding	Important in farms where goats are disbudded. Having goats with horns housed together with hornless animals may be because of welfare problems
Latency to the first contact test	Time to first contact with assessor inside a pen (min 0—max 300)
Qualitative behaviour assessment	Scale with several descriptors related to mental status of the herd

A two-step approach was later proposed to increase feasibility

25.6 Animal-Based Welfare Indicators for Goats

As written above, it is difficult or even impossible to advice on which indicators should be selected from the assessment toolbox to provide reliable information for each production system, for each region or even for each breed. In the following lines, some potential indicators showing how they were validated and how to use them will be listed. Some of these goat indicators were pictured in Fig. 25.1.

BCS is usually performed to estimate the nutritional status of goats. It is probably the most widespread method used across species to assess changes in body fat reserves. It is associated with the quantity of food, quality of the diet, presence of chronic diseases or parasites or with prolonged exposure to very low temperatures. So, it is strongly correlated with animal´s health, welfare and, therefore, to production. Traditionally goats' body condition scoring is based on visual appraisal and palpation of certain anatomic locations (lumbar and sternal regions) (Hervieu and Morand-Fehr 1999). These scales are usually complex and detailed, six points normally subdivided in 0.5 or 0.25 intermediate scores. The

Fig. 25.1 Illustrations of some individual welfare indicators in goats: claw overgrowth and fracture (**a**), wound due to trauma consequently to horn growth (**b**), low body condition score (**c**), nasal discharge (**d**) and kneeling (provided by G. Stilwell)

main drawbacks of these methods are time consuming, assessors need considerable training and experience and animal restraining is mandatory. However, for welfare assessment, only the identification of extreme conditions (very thin or very fat goats) is needed.

By photographing several anatomical regions of previously scored goats, we managed to correlate some rump measures with the actual BCS. From these pictures, a pictorial body condition scale (Fig. 25.2) was built using the rump contour as a cue for detecting the extremes in BCS in Saanen, Alpine and few other breeds (Vieira et al. 2015a). This way, BCS of many goats can be rapidly obtained by simply observing the goat's rump region profile from the back. However, the extent

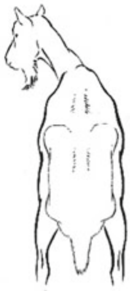
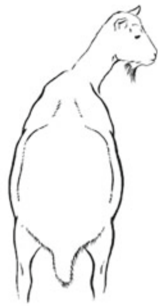
	Very thin	Normal	Very fat
General condition	Raw or slightly-raw boned goat, whit backbone and some ribs visible	Backbone not prominent but still visible and ribs difficult to assess visually	Backbone and ribs not visible. Goat has a rounded appearance, sometimes with abdominal fat deposits visible.
Rump region			
	Hip and pin bones are prominent.	Hip and pin bones still visible, but not prominent.	Hip and pin bones are difficult to identify.
	The line that connects the hip bone and the thurl assumes a markedly concave shape.	The line that connects the hip bone the thurl assumes a slightly concave or straight shape.	The line that connects the hip bone the thurl assumes a slightly or markedly convex shape.
	There is little muscle and/or fat between the skin and bone structures.	It is possible to realize some muscle and/or fat between the skin and bone structures.	All the rump region is coated by muscle and fat, contributing to the rounded appearance of the goat.

Fig. 25.2 Body condition scoring for dairy goats as proposed by Vieira et al. (2015a). Only extreme values are important in welfare assessment

to which the rump outline reflects the BCS of each animal depends on several factors such as breed, and so should not be extrapolated without further studies.

Lameness is a behavioural indicator of pain characterized by abnormal gait and positioning. It is considered one of the most important welfare problems in the dairy industry having a huge impact on production and on society (negative) perception of farming. The degree of lameness may range from slight to severe, and composite scoring tables have been produced for cattle but not for small ruminants. However, as for BCS, only moderate and severe cases need to be identified in a welfare assessment, because the correlation with overall lameness prevalence is fairly constant. Vieira et al. (2015b) suggested a visual analogue scale to increase validity and reliability of lameness scoring in goats, which is based on the simultaneous observation of three lameness signs that contribute to a final score:

(i) Abnormal gait: severe lameness can be described as goats having an irregular gait in time and space, sometimes leading to situations such as not bearing weight on one or more legs, 'goose' walking (limbs stretched), or moving on their knees (kneeling).
(ii) Head nodding: severe lameness is characterized by accentuated up and down movements of the head of goats while walking, whereas the head of non-lame goats head remains steady when walking.
(iii) Spine curvature: severe lameness is characterized by goats with an accentuated arched rump region, whereas on non-lame goats, no or just a slight, arched rump area can be noticed.

It should be recalled that ruminants are stoic animals that will frequently disguise pain and debilitating conditions. This is particularly true for lameness and so training is essential before trying to score goats.

In the AWIN protocol (AWIN 2015), severe lameness is assessed from inside the pen by making all animals walk for a few steps, but in the case of animals in extensive systems, the assessment may have to be done with binoculars or when bringing animals from pasture.

Hair coat condition is often related to health or nutritional problems or presence of endo- and/or ectoparasites (Battini et al. 2015b). Poor hair coat is often described as matted, rough, scurfy, uneven, shaggy hair coat, which is frequently longer than normal (AWIN 2015). To validate this indicator, a thorough clinical examination should be performed to goats with good and bad quality hair. It is common to find poor hair condition associated with chronic diseases, such as pneumonia, teeth problems or with diet imbalances. Hair coat assessment should include all of the body with the exception of the head and the distal parts of the limbs. Once more, assessment should take into consideration several factors such as breed and climate conditions.

Udder asymmetry has been defined as the cases in which one-half of the udder is 25% smaller than the contralateral. Although this can be genetically related or result from over-sucking of a preferred half by kids, it may also correlate with acute infection (affected half is larger) or chronic mastitis with gland atrophy (smaller half). Goats with udder asymmetry kick more often while being milked and are more often seen in an abnormal lying position, which may be related to higher sensitivity of the udder.

Thermal comfort—although goats are frequently described as rustic or highly adaptable animals, extreme heat or cold affect health, welfare and production. This is a particularly important indicator for goats in extensive systems, with little or no housing. Heat stress signs, associated with high temperature/humidity index, are panting and open mouth breathing. Animals may amass under shade. Careful attention should be given to animals with respiratory disease so as to differentiate it from heat stress. Cold stress, especially if combined with strong wind and rain, will be evidenced by shivering, erect hair on the back (horripilation) and arched back. Head and tail are usually kept down and animals tend to lie down close to each other. Thermal stress should be assessed from a distance as proximity of a person may disguise subtle behaviours.

Lesions and signs of disease should be carefully looked for as welfare is usually poor in these animals. Body, head and limbs should be examined. The type of clinical signs to register may depend on the prevalence of different diseases in each region or farm, but usually include (and indicate) nasal and ocular discharge (respiratory disease or inadequate ventilation); vulvar discharge (metritis or abortion); diarrhoea or soiling of the hind limbs (paratuberculosis or ruminal acidosis); swollen joints (trauma; lentivirus or mycoplasma infection); abscesses (Caseous lymphadenitis); etc. When possible, nasal and ocular discharge should be registered as uni- or bilateral as the meaning is usually different.

Human–animal relationship indicators will give an idea of the quality of handling. Gently handled animals are more inclined to approach people, and consequently, suffer less stress related to farm procedures. However, results should be analysed with caution as animals may be afraid of unfamiliar people, but extremely confident and friendly with herdsman. Also, breed and production system will influence behaviour regarding humans, without being necessarily related to bad handling. Two tests have been devised for this important criterion. The 'latency to the first contact' test in which the assessor (familiar or unfamiliar) will enter the pen and stand still with back to a wall or fence, recording the time until any animal does the first physical contact. The other test, called the 'flight distance test', will evaluate the minimum distance animals will allow the assessor to reach (from 2 meters to touch).

Qualitative Behavior Assessment (QBA) results from the ability of humans, that are used to observe normal animal behaviour, to integrate perceived details of behaviour, posture and movements, that can be defined as body language. Descriptors, such as 'relaxed', 'tense', 'agitated', 'playful' or 'curious', may be generated by the assessor or be selected from a list previously suggested for each species (Wemelsfelder et al. 2001). The use of QBA is a way of giving some importance to positive indicators (e.g. play, affiliative behaviour and curiosity). Such terms have an expressive, emotional connotation and provide information that is directly relevant to animal welfare and may be a useful addition to information obtained from quantitative indicators. QBA assessment should not be performed on individual animals, but on the group. It also should only be attempted after 10–20 min of observation, so as to give an overview of the mental state of the group and not an instant photograph. Observations should be done from a distance as the presence of the observer will undoubtedly change the behaviour.

25.7 Aggregating Indicators for an Overall Appraisal

Welfare is a complex and multifaceted state that is not easily defined by arbitrary thresholds. Assigning different weights to different indicators is challenging and controversial as it should take into account the appraisal objectives and the subjacent ethical values. For example, is fear more important than low body condition or lameness?

It would be foolish to try to define here the ideal recipe but a summary of existing methods for compounding welfare measures to make an overall assessment will be presented. One certainty is that the integration method has to be clear, transparent and repeatable so that certification and benchmarking is possible and credible. Additionally, the method should be feasible to be able to be used routinely on large number of animal units. Ideally, it should also be a path towards solutions.

One possible method is to grade each indicator (for example, as GREEN, YELLOW or RED) according to threshold previously defined. The overall assessment may then result from the number of indicators in each grade. For example, certification will only be awarded to farms with no RED indicator or no more than two YELLOW indicators. Additionally, the farm may be given a period of time to resolve the YELLOW issues. The problem with this method is how to establish the thresholds or minimal requirements. Solutions may come from benchmarking—use of prevalences from a reference population. In this way, critical indicators (e.g. mortality) may have a much lower acceptance value than more prevalent and less significant measures (e.g. overgrown claws). Although some flexibility may be introduced, this method also has the disadvantage of not distinguishing farms that have one RED from those having several 'REDS' or many YELLOWS. All would fail to reach acceptance but some would have more serious welfare issues.

Another method is to rely on the opinion of an expert or a group of experts (Sørensen et al. 2001) that make an overall appraisal of the indicators. This method is very simple and straightforward but is seen as very subjective.

Finally, scores given to different indicators can be summed. This method can be further improved by giving different weights to the measures allowing for an easy and relatively transparent ranking of farms. Also, partial score can be given to different criteria or principle (as a compound of many indicators) so that farm can more easily identify its' problems. A final score can be obtained (e.g. excellent, good or poor welfare) but certification may only be given if partial scores are above a certain limit.

25.8 Concluding Remarks

In conclusion, when establishing science-based, practical and suitable protocols, using animal-based indicators seem preferable. Although perhaps more subjective, these indicators seem to better reflect what the animal is feeling and the success of its coping with the environment. However, exceptional attention should be given to validity, reliability and feasibility studies.

Potentially, there are many different animal-based measures that can be used as tools to assess animal welfare. However, not all are applicable at all moments. Decisions on the selection from the toolbox and the way to employ these tools depend on the purpose of the assessment, the species and breed, the training and skills of the assessor, the conditions under which the indicator is to be gathered, the time available to collect it, the financial constraints, etc.

A welfare assessment protocol will only achieve its objective if it leads to a demonstrably beneficial impact on the well-being of the animals. This will only happen if harmful procedures are eliminated, management is improved and effective actions are actually implemented. Developing programmes for welfare assurance that are valued and trusted both by producers and by society should be the ultimate goal.

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Part VI
Conservation Priorities of Goat Populations

Chapter 26
Conservation and Utilization of Indigenous Goats and Breeding of New Breeds in China

Chao Yuan, Ting-ting Guo, Jian-bin Liu, Yao-jing Yue and Bo-hui Yang

Abstract There are nearly 58 indigenous goat breeds in China, which are an important part of biodiversity and have many excellent characteristics, such as high fecundity, strong adaptability, stress resistance, and also disease resistance, especially in the harsh ecological conditions. Meanwhile, under long-term natural and artificial selection of indigenous goat breeds in China, goats possess significant differences in their production characteristics, are more closely related to human beings and the production diversification are referred to meat, milk, wool, cashmere, fur, lambskin, and so on. However, some local goat breeds became threatened with extinction or have already disappeared before necessary conservation efforts could be performed. Therefore, it needs great strategic significance to strengthen the protection of goat genetic resources and to achieve reasonable and effective result on the sustainable development of animal husbandry, meet the needs of human development. The goat breed resources protectorate and isolation belts have been established taking into account different goat breeds and climatic ecological environment in China, also with enhanced technical guidance including molecular technology provided to breed protectors and breeding in scientific methods, avoiding any kind of hybridization. At the same time, it is also necessary that build conservation centers and core breeding groups combine conservation with selective dynamic breeding. Over the past few decades, six new goat breeds were successfully bred in China, namely Nanjiang Yellow goat, Shanbei White Cashmere goat, Chaidamu Cashmere goat, Jianzhou Big Ear goat, Guanzhong Dairy goat, and Jinlan Cashmere goat. It will also be benefit for conservation and utilization of breeding resource.

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26.1 Introduction

Indigenous goat breeds resources are the important part of biodiversity, which are closely related to the human beings. It is of great strategic significance to strengthen the protection of goat breeds resources and achieve a reasonable and effective result on the sustainable development of animal husbandry and to meet the needs of human development.

China goat breed resources have many excellent characteristics, such as adaptability, high fecundity, meat performance, and other characteristics (also see Chap. 4 of volume 2) (Sha et al. 2006; Li et al. 2012a, b). Some examples would be that Jining Green goat can show perennial estrus or kidding rate of this goat breed is 297.7% (He and Ma 2005). On the other hand, Matou goat, Shaanxi Southern White goat, and Guizhou White goat have outstanding meat traits in terms of adult body weight, carcass weight, slaughter rate, and net meat rate, with more than 40 kg, 20 kg, 50–63, and 40%, respectively (Jia 1999; Zhao 2001). In particular, Liaoning Cashmere goat is the highest cashmere yield breed in the world (Liu 2013).

Despite these exceptional traits, the production performance of indigenous goats in China is still relatively low (Luo and Wang 1998; Yang et al. 2004). In recent decades, due to the influence of various natural and human factors, the domestic and foreign market demands and other factors, the survival and development of local goat breeds are facing serious impact, whose consequences show population degradation and decrease trends (Qu 2005; Wang et al 2013).

In this chapter, strategies for conservation utilization of indigenous goat breeds in China are discussed, particularly focused on specific production aspects of several local goats, as well as the breeding development of new goat varieties (crossbreeding).

26.2 General Chinese Conservation Strategies

In order to strengthen the protection of local goat genetic resources in China, and according to the characteristics of goat breeds and climate and ecological conditions, the conservation farm of goat varieties have been established (Zhang 1994; Sun et al. 2014).

In the conservation farm, the breeding of core groups have also been set up (Li et al. 2012a, b). Unqualified goats were eliminated to optimize breed structure with hybridize different lines for reinforcing and enriching gene bank of prior traits (Bai et al. 2010). Thus, not only protection of indigenous goat genetic resources by using in vivo was done, but also the strengthening of the embryo bioengineering and molecular biotechnology in the conservation research and their applications. The establishment of the Chinese Livestock and Poultry Genetic Resources Information

System can understand and monitor the resources throughout the country to protect and to use the dynamic and timely grasp of resource changes (He and Ma 2005).

In ensuring the effective protection of the local varieties of goat in China, the application of hybridization and cultivation new goat varieties have also been carried out, which will promote the application and protection of these varieties. Giving priority to local breeds and importing other high-quality goat breeds, if necessary, will improve production performances. By improving the goat quality and reproductive performances, people income and living conditions can be raised (Cheng and Li 2011). At the same time, optimizing supporting technique like supplemental feeding, ecological farming, and grass silage will increase farmer's economic benefit (Li et al. 2009). Changing goat farming from traditional method to modernizing intensive management systems will be beneficial as well. The use of modern techniques for breeding, rotation grazing, and building artificially grassland can improve production efficiency. Changing goat breeding industry to more intensively and modernizing system is also needed (Hua 2004). It will also benefit for breeding resource conservation and utilization.

26.3 The Development of Products of Indigenous Goat Breeds in China

There are nearly 58 indigenous goat breeds in China (Zhang 1987; Du 2011; Zhao 2013), which show significant differences in their production characteristics, due to the geographical environment and the result of long-term artificial selecting improvements. According to their main uses, goats in China can be grouped into different types: dairy goats, fur goats, cashmere goats, kid leather goats, and meat goats.

26.3.1 Goat Wool

Goat wool is generally divided into two layers. Inner layer is composed of soft, slender, short, and curly wool, called cashmere (Chen and Pan 1998), which is one of the textile materials for China important export. The outer layer is thick, hard, and long, without curly wool, usually called goat wool. Because this latter is rough with no curl, and has poor holding capacity. It is difficult for spinning, being used in addition to part of the production for blankets, wool rope, and brush, often used as waste treatment. It can also be made of blended wool lining, because of its good elasticity, good dimensional stability, which is the production of high-grade suits of accessories (Yang and Zhang 2017).

The goat wool fiber is rough, hard, with no curl, but after using chemical treatment, local degeneration appears. The usual improvement methods for the goat wool performance are oxidation, reduction, enzymatic, and others. The main products are blended wool carpets and other similar ones. In view of the shortcomings of chemical treatment methods, using physical mechanical methods to improve the goat wool curling properties can increase from 0/25 to 14/25 mm, and does not affect the original properties of the goat wool. After this, goat wool can be purely spun wool top, which can produce up to 96% wool carpets (handmade carpets), Latex-back carpets and goat wool linings. It not only reduces the cost, but also improves the performance of finished products.

26.3.2 Cashmere

Cashmere is a thin layer of fine velvet that grows in the outer skin of the goat and covers the roots of the goat coarse wool. Cashmere textile is made of fine velvet and advanced material, which is with fine, light, soft, smooth wax, warm, and other fine features. Goat cashmere is produced in the annual April to May. To prevent the cashmere naturally fall off, usually grabbed in the cashmere when the fleece is lifted. Cashmere is a high-level wool raw materials, and according to their color can be classified as white cashmere, purple cashmere, etc. White cashmere is widely used in the textile industry. Cashmere is mainly used for pure spinning or blended with fine wool, to make cashmere sweaters, cashmere scarves, cashmere tweed, cashmere coat, and other high-grade appreciated textiles.

Cashmere fiber is irregular, thin, deep, and curl, composed of scales layer and cortical layer (Cao and Sui 2014). Cashmere is non-medullated fiber, and mostly coarse wool is medullated fiber. The density of Cashmere is 60–70 fiber/mm^2; fiber diameter is also finer than fine wool. The average diameter of Chinese cashmere is 14.5–16 μm. Fiber average length is 35–45 mm. The straight length is about three times of the natural length and the hygroscopicity is better than wool. Acid–alkali tolerance is more sensitive than fine wool, and the damage of cashmere fiber is very significant even at lower temperatures and concentrations, especially for chlorine-containing oxidants (Tian 2015).

Cashmere is a precious wool raw materials, being one of China traditional export commodities, highly renowned at international level. With the improvement of people's living standards, the high-quality wool products in the domestic market are progressively demanded. In recent years, to attend the growing world market demand, China annual output of cashmere has been 12,000 tons, accounting for 75% of the world cashmere (Yao et al. 1995). The quality is also considered as the best in the world. China cashmere habitat is mainly in Inner Mongolia, Xinjiang, Liaoning, Shanxi, Gansu, Shaanxi, Ningxia, Tibet, and Qinghai. The production of cashmere is about 200 g per goat annually.

26.3.3 Goat Fur

Kidskin (kid leather) and fur are the important products of goat industry, with high economic value. Kidskin refers to leather from aborted or 1–3 days-old kids, when the older than 1-month kid leather is called fur. Kid fur is not only the subsistence materials and by-production materials for farmers and herdsmen, especially for the national minority, but also it has played an important role to revitalize the local economy, promoting the development of export trade and maintaining the sustainable development of animal husbandry. As the kid fur clothes have a better resistance to cold environments, the gorgeous and high-end appearance, they are favored by domestic and foreign consumers. However, since the 90s of last century, with the impact of the world financial crisis, coupled with the introduction of animal welfare policy have limited the development of kidfur industry to some extent.

Goat leather board is another important product for farmers and herdsmen. The best time to obtain the skin is the late Autumn and early Winter because it will be hypertrophied, uniformly thick with fine surface, oily foot, and good elasticity, which is renowned at home and abroad. Goat leather board is made into leather by tanning, with a thin, supple, grainy, glossy, easy to lose surface, etc., which can be used for footwear and so on (Guo et al. 2013).

26.3.4 Goat Milk

Goat milk is known by many people as the "king of milk". Because the fat particles in goat milk are smaller than in cow milk, it is more appropriate for the human digestive absorption, Goat milk contains vitamins and trace elements in significantly higher level than cow milk (Yue 2013). In the USA, Europe, and some other countries, goat milk is considered as a high nutritional product (Yue 2013). Some experts have recommended it for people who are suffering from allergies, gastrointestinal diseases, bronchial inflammation or physical weakness, and particularly for babies because it is more suitable for drinking (Cao et al. 2007).Chemical components of the goat milk, such as ramic acid (C6:0), succinic acid (C8:0), and sunflower (C10:0), are mainly responsible for its special flavor (Wang et al. 2012; Chen et al. 2013).

26.3.5 Goat Meat

Meat is one of the main production performance of goats, particularly for those breeds selected for meat. China is the first goat meat producer in the world (Jiang et al. 2000). However, compared with developed countries or regions is still a low level of production and it still cannot meet the needs of people's lives. At present, the goat meat in China supposes less than 2% of the total meat production, and is mainly concentrated in the South of the country. With the improvement of people's living standards and modern dietary habits, the special nutritional value of the goat meat has promoted its higher consumption by the people in the country. Goat digestible protein content is high and carcass smell is light, in which kid is the top grade. The income gained by the selling kids is one of the main income of the herdsmen for a long time. In recent years, it is the second income behind the cashmere's income.

Chinese goat meat production is mainly located in the South of latitude 39° N, mostly concentrated in the South of Qinling Mountains-Huai River mostly in the southern provinces and cities, while the northern region produces less meat. The adult bucks weight of indigenous goat breeds in China is 25 ~ 60 kg. Adult goats weight 18 ~ 50 kg, the slaughter rate range from 40 to 60%, the kidding rate is 105 ~ 260%, and the kidding rate over 150% is taking up 55%. Additionally, China bred Nanjiang Yellow Goat, as a typical meat goat breed. Adult bucks are weighing up to 54 kg and adult doe goats up to 48 kg. Their slaughter rate is 55% and a net meat rate of 42%. The kidding rate of 180% (Wang et al. 1998).

Goat meat is divided into kid meat (8–10 months old), young goat meat (1–2 years old), and old goat meat (2–6 years old), according to the production age. The consumption of young goat is not very demanded in China and the optimum live weight to slaughter is 11 ~ 25 kg (Jiang et al. 2000).

The protein content in the goat meat is between 18.8 and 21.4%, which is higher than that of other livestock and poultry meat. The energy value is between 15.5 and 23.7 MJ/kg, which is lower than other livestock and poultry meat. Goats meat contains high protein and low fat, which makes it a highly recommendable for human nutrition. Amino acids, on the other hand, represent 55% of the total amino acids required. Compared with the ideal protein content, arginine, lysine, and methionine are in adequate level, the content of histidine, leucine, and valine is 80% more than the ideal protein content, indicating that goat meat is a readily absorbable amino acid source. The content of unsaturated fatty acids in goat meat is high, accounting for 55 ~ 70% of the total fatty acids, especially linoleic acid content, which is between 1.85 and 8.57%; and the cholesterol content is 60 mg per 100 g of meat, lesser than in sheep meat (70 mg), pork meat (74–126 mg), calf meat (106–140 mg), or chicken meat (70–90 mg), and rabbit meat (65 mg) (Shao et al. 2008).

26.4 Breeding New Goat Breeds Based on Special Indigenous Goat Breeds in China

In recent years, strengthen the protection of goat genetic resources has been made, and also works on the breeding of goat genetic resources and industrial development. In the past 10 years, after using modern breeding techniques and local varieties, a large number of new varieties and specialized lines were bred. Many special traits of indigenous goat breeds were maintained and greatly improved.

26.4.1 Nanjiang Yellow Goat

Nanjiang Yellow goat (Fig. 26.1) is the first cultured meat goat breed in China, which was the progeny from the crossbreed for more than 40 years using Nubian goat and Chendu Brown goat as male parents, and the native goats of Nanjiang goat and Jintang Black goat as female parents (Zhang 2005; CNCAGR 2011). The Nanjiang Yellow goat, which was on-site identified by the Sub-Committee of Sheep and Goats Variety Identification of the Chinese National Committee for the Management of Genetic Resources of Livestock and Poultry in October 13th, 1995, passed the review by the Chinese National Committee for the Management of Genetic Resources of Livestock and Poultry in December 14th, 1996, and was officially approved to definite designation by the Ministry of Agriculture of the People's Republic of China in April 17th, 1998 (Chang 1998; Wang et al. 2011). This breed is characterized not only by early sexual maturity, rapid growth and development, high fecundity, good meat production performance, strong adaptability, enduring roughage feeding and stable heredity performance, but also by tender and good palatability of meat and high quality of its fur (Wang 1997; Chen et al. 2012).

26.4.2 Shanbei White Cashmere Goat

Shanbei White Cashmere goat (Fig. 26.2), a Chinese domestic goat breed, is farmed to provide cashmere and other wool and meat as well. This breed is reared to improve cashmere production performance by Animal Husbandry and Veterinary Station of Shaanxi Province as well as Animal Husbandry Bureau (Station) in Yulin, Yanan, Hengshan, Jingbian, Yuyang, and other 14 counties (districts) using Laioning Cashmere goat as male parent and Shanbei Black goat as female parent.

This new breed in which simple bred hybridization was applied and undergone three stages of development: hybrid improvement, crossing fixed, and selection improvement to upgrade a dual-purpose variety upon cashmere and meat by the cooperation of governments, science and technology workers and producers for more than 20 years of unremitting efforts (CNCAGR 2011; Zhou et al. 2012). On-site identification of Shanbei White Cashmere goat was conducted by the experts of the Sub-Committee of Sheep and Goats Variety Identification of Chinese National Committee for the Management of Genetic Resources of Livestock and Poultry in April 2002 and it was officially approved for definite designation by the Ministry of Agriculture of the People's Republic of China in February 27th, 2003. Additionally, Shanbei White Cashmere goat has many peculiarities such as the

Fig. 26.1 Typical male **a** and female **b** of new Nanjiang yellow goat breed (provided courtesy of Zi-jun Zhang and Yu Chen)

(a) ♂

(b) ♀

followings: strong physique, slender cashmere fiber, high cashmere yield, enduring roughage feeding, strong adaptability, and stable heredity performance (Huang et al. 2015).

26.4.3 Chaidamu Cashmere Goat

Chaidamu Cashmere goat (Fig. 26.3), an exclusive cashmere goat which can adapt to the conditions of high-cold and drought, was successfully cultivated to be a multipurpose-type breed upon cashmere, milk, meat, and fur by Qinghai Institute of Animal Husbandry jointing professional and technical personnel and the majority of farmers in states and counties of Qinghai Province with more than 20 years of

Fig. 26.2 Typical male **a** and female **b** of new Shanbei white cashmere goat breed (provided courtesy of Xin-chun LI)

(a) ♂

(b) ♀

unremitting efforts using Liaoning Cashmere goat as male parent and Chaidamu goat as female parent (Lei 2002; CNCAGR 2011).

The new variety breeding which is characterized by enduring roughage feeding, strong resistance, pure white wool, high yield and good quality cashmere and stable heredity performance undergoes cross innovation, crossing fixed, selection improvement and other stages and it presents strong adaptation to harsh environment of the plateau.

Chaidamu Cashmere goat was identified as a new breed of livestock of Qinghai Province by Qinghai Livestock and Poultry Variety Identification Committee in 2001 and on-site identification was conducted by the Sub-Committee of Sheep and Goats Variety Identification of Chinese National Committee for the Management of Genetic Resources of Livestock and Poultry in June 2009. It was officially approved

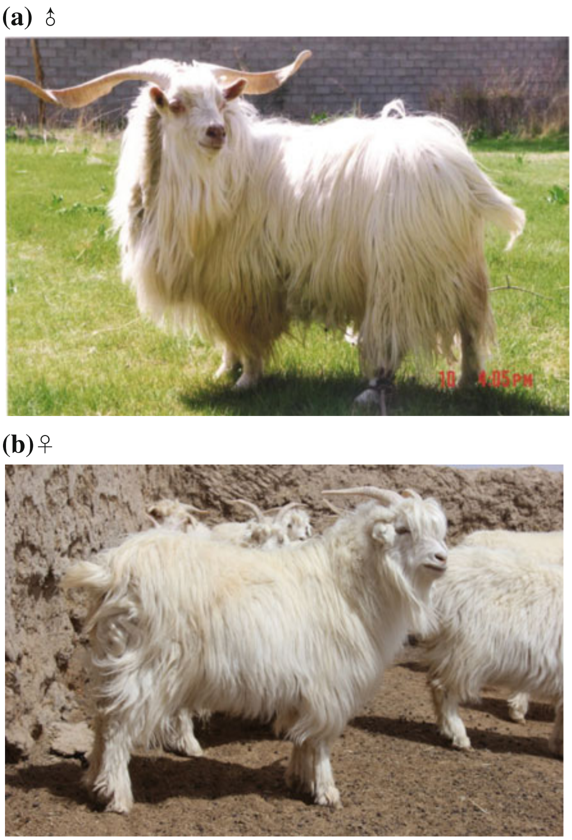


Fig. 26.3 Typical male **a** and female **b** of new Chaidamu cashmere goat breed (provided courtesy of Ma Zhuo)

to definite designation by the Ministry of Agriculture of the People's Republic of China in July 9th, 2010 (Lu and Ren 2006; Gu 2008; Za 2013).

26.4.4 Jianzhou Big Ear Goat

Jianzhou Big Ear goat (Fig. 26.4) was developed using Nubian goat as male parent and local Jianyang goat as female parent by the innovation teams belonging to Southwest Nationality University, Sichuan Institute of Animal Science, Sichuan Agriculture University, Jianyang Dageda animal husbandry Co. Ltd, and other institution.

The innovation teams successfully bred the new meat goat after 60 years of continuous efforts and broke through the new breed selection and matching technology of Jianzhou Big Ear goat undergoing cross innovation, crossing fixed, selection improvement, and other stages (Yi et al. 2012; Fan et al. 2013a, b).

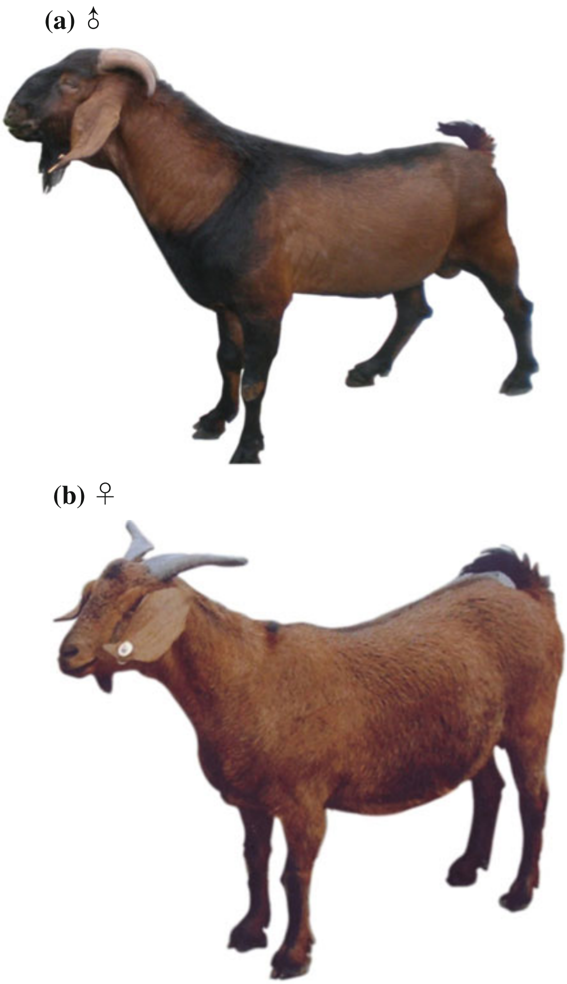


Fig. 26.4 Typical male **a** and female **b** of new Jianzhou big ear goat breed (provided courtesy of Yong Wang)

On-site identification was conducted by the Sub-Committee of Sheep and Goats Variety Identification of Chinese National Committee for the Management of Genetic Resources of Livestock and Poultry on October 13th, 2012 and definite designation was officially approved by the Ministry of Agriculture of the People's Republic of China on January 24th, 2013.

Jianzhou Big Ear goat, an excellent breed suitable for subtropical climate in South China, is characterized by large physique, rapid growth and development, superb meat quality, high fecundity, strong resistance, and enduring roughage feeding (Fan et al. 2013a, b; Xiong et al. 2013).

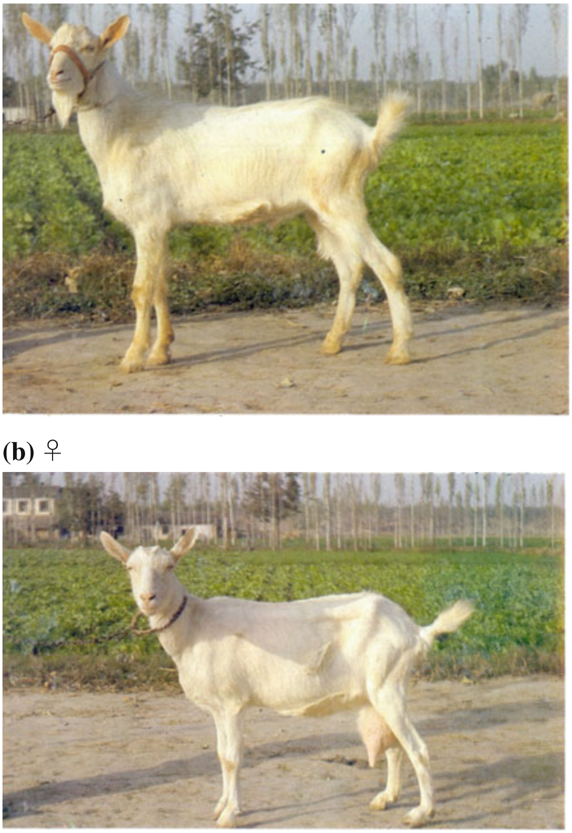
26.4.5 Guanzhong Dairy Goat

Guanzhong Dairy goat (Fig. 26.5) was developed to improve production performance by Northwest Agriculture and Forestry University jointed province, city, and county professional and technical personnel and the majority of farmers for more than 20 years of unremitting efforts using Saanen Dairy goat as male parent and Guanzhong Dairy goat as female parent (Qi et al. 2005; CNCAGR 2011). The new breed which was obtained by simple breeding hybridization, was on-site identified by the Sub-Committee of Sheep and Goats Variety Identification of Chinese National Committee for the Management of Genetic Resources of Livestock and Poultry in 1990 and was officially approved to definite designation by the Ministry of Agriculture of the People's Republic of China in 1991.

Guanzhong Dairy goat has many peculiarities such as strong physique, obvious dairy conformation with good milk production performance, strong disease resistant

Fig. 26.5 Typical male **a** and female **b** of new Guanzhong dairy goat breed (provided courtesy of Zi-jun Zhang)

(a) ♂ **(b)** ♀



ability, enduring roughage feeding, manageability, wide adaptability, delicious meat, and stable heredity performance (Li et al. 2010, 2012a, b).

26.4.6 Jinlan Cashmere Goat

Jinlan Cashmere goat (Fig. 26.6) was developed using Liaoning Cashmere goat as male parent and Lvliang Black goat as female parent by the Shanxi Agricultural Department unified organization of its province, city, and county departments as well as sheep and goats science and technology workers and farmers. The breeding team successfully bred the new meat goat after 30 years of continuous efforts undergoing three stages of hybridization improvement, crossing fixed and selection improvement and using the high efficiency breeding, high efficient regulation of reproduction, balanced nutrition regulation and other technologies (Zhang et al. 2012). The new breed was on-site identified by the Sub-Committee of Sheep and Goats Variety Identification of Chinese National Committee for the Management of Genetic Resources of Livestock and Poultry on October 19th, 2011 and was officially approved to definite designation by the Ministry of Agriculture of the People's Republic of China on November 14th, 2011.

Jinlan Cashmere goat is characterized by its high cashmere yield, good cashmere fineness, strong adaptability, and stable heredity performance (Qin 2014; Du et al. 2017).

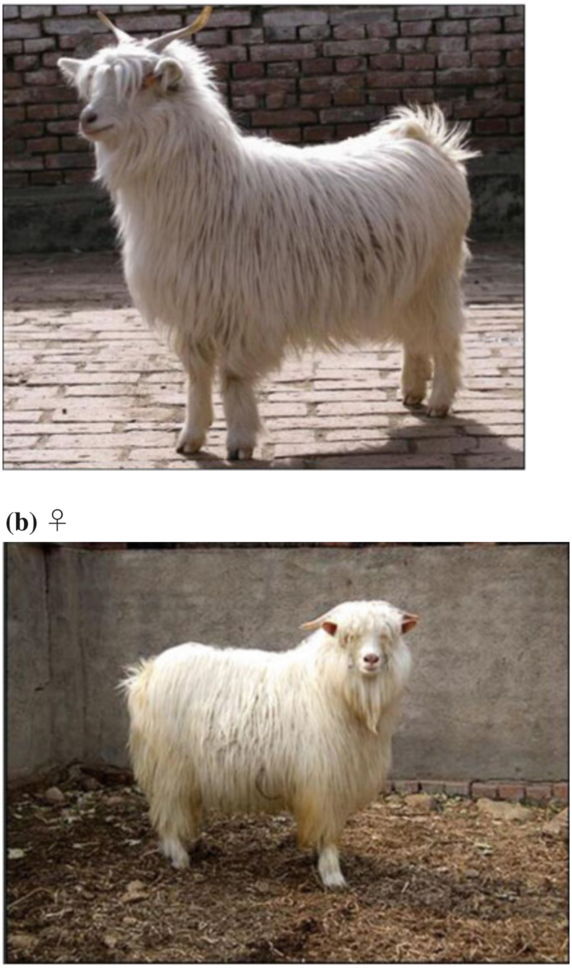
26.5 Concluding Remarks

Indigenous goat breeds resources are an important part of biodiversity, which are closely related to the human beings. In order to strengthen the protection and rational utilization of local goat genetic resources in China, and according to the characteristics of goat breeds and climate and ecological conditions, goat varieties of which conservation farm, core group, gene bank, and information monitor system have being established; and which can understand and monitor the resources throughout the country to protect and to use the dynamic, timely grasp of resource changes. On this basis, products indigenous goat breeds were developed, a large number of new varieties and specialized lines were bred, many special traits of indigenous goat breeds were maintained and greatly improved.

Nevertheless, because the influence of various natural and human factors, the domestic and foreign market demands the survival and development of local goat breeds are facing serious impact, whose consequences show population degradation and decrease trends. As a result, development and protection of indigenous goat breed resources should be balanced simultaneously. The challenges we face will be focusing on perfecting protection measures including ecosystems establishing,

Fig. 26.6 Typical male **a** and female **b** of new Jinlan cashmere goat breed (provided courtesy of Yang-yi Mao)

(a) ♂



(b) ♀

optimizing development of products, improving indigenous goat breeds, breeding new goat breeds, and others.

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Chapter 27
Genomics for the Improvement of Productivity and Robustness of South African Goat Breeds

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Abstract South Africa is one of the major goat-producing countries with over 6 million goats, 63% of which are farmed under smallholder communal farming systems where poor nutrition, disease infestation, and harsh climatic conditions are common. The Boer, Kalahari Red, and Savanna breeds were developed in South Africa and have turned out to be regionally and internationally relevant. Adaptation and tolerance to local conditions are crucial for survival of these goat genetic resources in suboptimal conditions. The full genetic potential of veld goat populations is not yet fully unraveled. Complete mtDNA sequencing and diversity analysis revealed multiple maternal lineages in South African goat populations that were shared amongst the breeds and populations with absence of population sub-structuring. Median joining network analysis using different mtDNA genes suggests that South African populations have multiple maternal lineages that are shared with other global populations. Caprine SNP50K panel data analysis highlighted elevated levels of genetic diversity in South African indigenous goats compared to industrial breeds as well as the utility of the genome-wide SNP marker panels in population genetic studies. Landscape genomic analysis suggests a strong role of environmental factors in shaping the genetic diversity of South African indigenous goats. Selected loci responsible for the adaption of goat populations to local production systems may be targeted in breed improvement programs particularly under marginalized communal production systems. Successful sequencing

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and analysis of the Tankwa and other South African goat genomes could screen for potentially numerous genomic variants such as copy number variants. Community-based breeding programs would be the appropriate tool for breed improvement allowing sharing of production capital, pooling of resources and services and enabling joint processes of decision-making. Genomics could complement breed improvement efforts by providing pedigree estimates and can be useful in monitoring and control of inbreeding and genetic gain.

27.1 Introduction

South Africa is one of the major goat-producing countries with over 6 million goats (DAFF 2014) that constitutes 55% of southern Africa's goat population (FAOSTAT 2013). In a dual production system (Roest and Kirsten 2005), commercial farmers are mainly in the Northern Cape, whilst KwaZulu-Natal, Eastern Cape, and Limpopo have the highest proportion of the country's smallholder farmers (NDA 2012). The commercial sector farms use the Boer, Kalahari Red, Savanna goat breeds, which are examples of breeds successfully developed in South Africa that have turned out to be internationally relevant. Non-descript veld-type goats dominate the low input smallholder production systems in the marginal communal areas of the country (Mamabolo 1999; Bester et al. 2009; Gwaze et al. 2009a). The commercial, exotic, and crossbred types have not been able to function fully under communal production systems (Norris et al. 2011). Apart from the domestic goats, South Africa has a minute population of the feral Tankwa breed that naturally inhabits the Karoo region from which it has found sanctuary in a conservation unit at Carnavon Research Station since the year 2009.

The commercial sector is characterized by controlled breeding strategies and intensive management practices such as disease control and nutrition. On the contrary, the feral Tankwa and goats reared under smallholder communal production systems thrive with limited human intervention under suboptimal conditions suggestive of adaptive abilities that are lacking in the commercialized breeds. Adaptation and tolerance to local environmental conditions are paramount to the survival of these goat populations. However, the full genetic potential of goat populations remains unclear because their characteristics and genetic potential are not fully understood. Climate change and scarcity of resources are factors making it imperative to streamline allocation of resources to maximize profits in livestock enterprises. Thus, a foundation for development of breeds that produce optimally under extensive production systems in rural South Africa and/or other countries with similar resource constraints and environmental challenges is a priority. There is scope for selecting for production and robustness in the diverse untapped Tankwa and veld goats.

Rapid advances in goat genomics led to the introduction of whole genome sequence data, high-density single nucleotide polymorphism (SNP) array and gene expression profiles in characterizing and improving breeds and populations

(Kristensen et al. 2015). A number of goat reference genomes (Dong et al. 2013, 2015) are now available including the Illumina goat SNP50K array launched in 2014 (Tosser-Klopp et al. 2014) which has found use in characterization and genetic evaluation programs (Kijas et al. 2013; Mdladla et al. 2016a). In South Africa, the efficacy of this SNP panel has been demonstrated in exotic dairy and wool (Lashmar et al. 2016) breeds as well as in the indigenous commercial meat types, non-descript village goats and the Tankwa feral goat population (Mdladla et al. 2016a). Although substantial reports have appeared on the characterization of goat breeds and populations and enhancing the genetic merit of populations for economically important traits such as growth, reports on meat quality, and health-associated traits have been sparse. However, the potential of such utility has been documented in other countries (Kijas et al. 2013).

This chapter presents an overview of the goat genetic resources of South Africa, the production systems and challenges they face. Evidence of geographically sub-structured populations that enables them to survive and produce optimally under adverse production conditions will be presented. The use of genomics in characterizing indigenous goat populations of South Africa will be highlighted. Finally, we have outlined some thoughts on how the current and ongoing developments in genomics could enhance the production and adaptive potential of local goat breeds.

27.2 Goat Populations and Production Systems

There are three different lines of products from South African goats, which are meat (chevon), milk, and fiber produced from different breeds. Milk and fiber commercial sectors predominantly utilize exotic breeds (NDA 2012) compared to the meat production, where indigenous commercial breeds predominate. Another important sector is the smallholder communal production system, which is integral to the livelihood in village communities. The smallholder village systems make use of non-descript village goat populations that are often referred to as ecotypes differentiating them from well-established breeds. For the scope of this book, this chapter is going to focus on meat and the smallholder farming systems where indigenous goat genetic resources are reared and where genetic adaptation would find immediate application.

27.2.1 Commercial Meat-Type Goat Genetic Resources

The Boer, Savanna, and Kalahari Red goats are industrial indigenous breeds kept mainly for chevon production on commercial farms. About one-third of the goats are slaughtered by the meat industry annually with nearly 90% of goat meat produced from breeds indigenous to South Africa (FAOSTAT 2013). Between the years 2001 and 2011, goat production in South African contributed R3.6 billion to the economy through chevon production (DAFF 2012). The Boer Goat is a South African Landrace goat that was established in the 1900s (NDA 2012) and primarily developed for meat production (Fig. 27.1). It is now commercially farmed for meat production across the world. This breed was developed out of the Xhosa Lop Ear goat and some European and Indian breeds (Miles 2007). According to the Boer Goat Breed Association, the foundation breeding stock of the South African Boer was from crossbreeding shorthaired female goats that had white bodies and light colored heads to a large dapple-colored male goat (www.boergoats.co.za). Out of selection and improvement over a number of generations emerged the "Improved/ Ennobled Boer Goat" breed which has a distinct pattern of white body and a red head unlike the original type of goats of the unimproved type.

The white Savanna (Fig. 27.1) is also a product of selection from indigenous goats. Messers Cilliers and Sons are regarded as the developers of the breed, which was first recognized as a distinct breed after the formation of the Savanna Goat Breeders Society in 1993 (Campbell 2003). Numerous breeders in South Africa with varying breeding objectives developed the Kalahari Red (Fig. 27.1). Although its developmental history is convoluted, the Kalahari Reds sprang from two lines of brown lop-eared "unimproved" indigenous goats in South Africa and Namibia and the Boer goats (Campbell 2003). Literature from the 1970s, records Mr. Voster collecting red and red-dappled goats from around South Africa and Namibia. In the 1990s, Albie Horn also started selecting indigenous brown and brown and white goats from the former homelands of the Eastern Cape, the Karoo, and Namibia (http://studbook.co.za). The criteria for selection of the goats considered the traits of hardiness, adaptability, and conformation. Ewes were selected for good mothering ability, fertility, and milk production for the kids (Personal communication with Albie Horn, a farmer in Northern Cape).

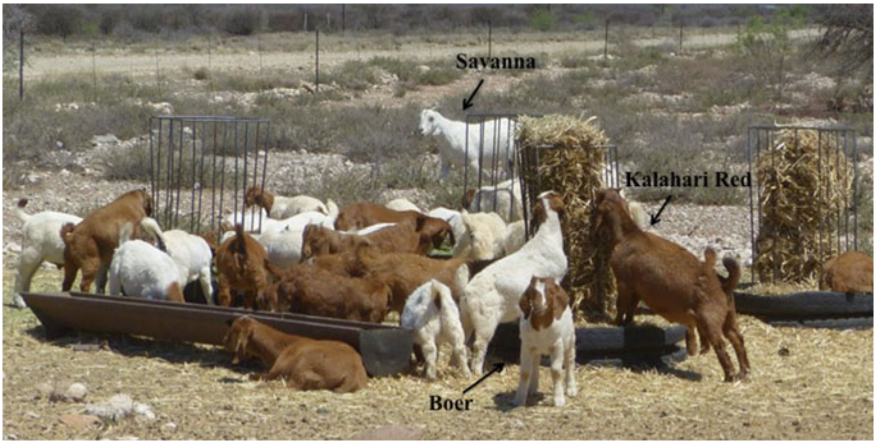

Fig. 27.1 Boer, Kalahari Red, and Savanna goats from Northern Cape (provided by K. Mdladla)

27.2.2 The Smallholder Communal Goat Genetic Resources

The smallholder sector consists of goat farmers, found mostly in the marginalized communal areas of the country that produce for family consumption. The non-descript indigenous veld goats are native to Southern Africa (Mamabolo 1999; Morrison 2007) and are largely an unimproved population. Herd sizes are usually small with goats often left to fend for themselves but are occasionally supplemented with household leftovers (Mdladla 2017). South African smallholder farmers predominantly keep multipurpose and uncharacterized veld-type indigenous goat ecotypes that have not been subjected to any structured improvement in the past. They are mainly found in the communal regions of the Eastern Cape, Limpopo, Northwest, and KwaZulu-Natal provinces.

These types of goats are generally named according to the ethnic group of the farming communities that keep them and morphological characteristics. Examples include the Nguni (iMbuzi), Pedi and the Xhosa Lop ear ecotypes (Morrison 2007; DAFF 2012). The indigenous veld goats are hardy, tolerant to local diseases such as heartwater (Miles 2007) and characterized by a diversity of coat patterns (Fig. 27.2). They are considered well adapted to extremely hot environments presumably due to their hooves and skin pigmentation (Gwaze et al. 2009b).

Fig. 27.2 Coat color patterns of non-descript indigenous goats from Mathengwenya village in KwaZulu-Natal (provided by K. Mdladla)

27.2.3 Feral Goat Population

Feral populations may be sources of genetic variation including primitive traits missing in modern industrial-type breeds, and could harbor novel or rare genes for adaptations (van Vuren and Hedrick 1989). Distribution and density of feral goats in South Africa is limited to the Tankwa goat from the Northern Cape Province (http://www.nzg.ac.za). According to the Department of Agriculture, Land Reform, and Rural Development, Northern Cape (AGRINC 2013), the Tankwa goat (Fig. 27.3) refers to feral population of goats found in the Tankwa Karoo National Park in the Northern Cape Province, where they have lived for more than 80 years. In 2010, their population size ranged between 130 and 200 mature goats. However, very little information exists regarding the history of this goat. From 2009, the goats were moved from the park to Carnavon Research Station because of perceived threats to their diversity and as a means of conserving their presumed unique genetic structure assumed absent in the goat population of South Africa (AGRINC 2013). It has been postulated that the ability of the Tankwa breed to survive harsh environmental conditions of the Karoo region is likely due to their genetic make-up (Kotze et al. 2014; Mdladla et al. 2016a).

Fig. 27.3 Tankwa goats in Carnavon Research Station, Northern Cape (provided by K. Mdladla)

27.3 Production Challenges and Selection Pressures Under Local Goat-Producing Environment

Goat farming is suited for most marginal farming regions where crop-farming activities are undesirable. The Northern Cape, KwaZulu-Natal, Limpopo, and parts of the Eastern Cape are the major goat-producing regions that are generally characterized by variations of rainfall and temperature patterns, which in turn affects the seasonal quantity and quality of feed and prevalence of endo- and ecto-parasites and other pathogenic microorganisms (Mohlatlole et al. 2015).

The different production systems focus on different production objectives and are exposed to different natural and artificial selection pressures creating subpopulations with different set of alleles and genotypes. Management systems and production in commercial systems differ significantly with those of communal farming systems. The intensive commercial goat production system has high labor requirements, moderate to high management levels, and rear specialized breeds. Selection for specific production traits and management interventions have resulted in improvements in their production performance (Almeida et al. 2006) but at the cost of reduced genetic diversity due to high inbreeding levels (Kristensen et al. 2015; Mdladla et al. 2016a). Goats raised under commercial farming are vaccinated against different common pathogens and covered by tailor-made biosecurity measures thereby providing protection from the different diseases and pathogen challenges. Consequently, they do not take advantage of natural immunity, which threatens their intrinsic ability for adaption and coping with extreme environmental conditions.

Smallholder production systems are based on the extensively raised indigenous local populations (Lebbie 2004; Webb and Mamabolo 2004) that play an integral part in meeting multiple social, economic, and cultural needs of rural households (Ilatsia et al. 2012). Thus, smallholder farmers usually have broad breeding objectives often determined by the multiple uses of goats at household level. However, the production potential of goats in the marginal areas is often compromised by poor management and production constraints such as exposure to diseases and parasites, scarce and poor quality feed, compromised adaptation due to crossbreeding and to a lesser extent, losses due to stock theft and predation. Diseases, especially heartwater have been flagged as a menace in all goat production systems (DAFF 2012) and seroprevalence studies have suggested that majority of goat populations are constantly exposed to the disease (Mdladla et al. 2016b). Other diseases caused by internal and external parasites, bacteria, viruses, have been reported mostly during summer (LHPG 2013, 2014a, b).

27.4 Genetic Structuring of South African Goat Populations Along Production and Geographic Landscapes

Knowledge of the genetic diversity and maternal lineages sheds light on important historic events such as domestication processes thereby assisting in breed characterization and differentiation (Piras et al. 2012; Doro et al. 2014). Since the mtDNA is maternally inherited as a single haplotype with no recombination, it lingers in populations even after breed divergence as signatures of maternal origins (Garrine 2007) and could be used in guiding conservation strategies.

Ncube (2016) sequenced complete mitochondrial DNA and investigated genetic diversity and maternal lineages using 50 South African goats of the commercially developed Boer ($n = 9$), the captive feral Tankwa ($n = 9$), and non-descript village ($n = 32$) goat populations. In addition, twenty-eight GenBank sequences were retrieved for comparison representing diverse global population some of which were obtained from presumed centers of goat domestication. The complete mtDNA was highly polymorphic with 184 SNPs and 41 haplotypes reported (Ncube 2016). High within-population variation was observed in all population groups. South African D-loop haplotypes clustered with Chinese lineages A and B indicative of similar maternal lineages and origins. The *COX1* gene results confirmed the Bezoar (*Capra aegagrus*) as the main contributor to the South African gene pool. The complete mtDNA analyses also demonstrated unique SA haplotypes as well as haplotype sharing of South African goats with the haplogroup A. The presence of lineage A, B, and G from various regions (China, Middle East, and North Africa) in South African goat populations shows that South African populations have multiple maternal lineages shared with other global populations. The median network joining of the *COX1* (Fig. 27.4) demonstrated close relations of South African goats with the wild Bezoar, considered one of the ancestors of domestic goats. Overall, the study highlighted high mtDNA diversity with multiple maternal lineages that are shared amongst the breeds and populations with the absence of population sub-structuring.

In another study, Mdladla et al. (2016a) investigated genetic diversity and population sub-structuring of South African goats using the Illumina goat SNP50K panel. The authors evaluated a total of 239 goats belonging to three locally developed meat-type breeds (Boer, Kalahari Red, and Savanna), a feral breed of Tankwa, and unimproved non-descript village ecotypes from four goat-producing provinces of the Eastern Cape (Xhosa), Kwazulu-Natal (Zulu), Limpopo (Venda), and Northwest (Tswana). The genetic diversity was higher in the non-descript village ecotype populations whilst, lower in the Tankwa goats due to differences in their population dynamics. The village ecotype populations are kept under low management systems with no controlled breeding, leading to high genetic diversity and gene flow from other areas all contributing to an admixed and highly diverse goat population. On the other hand, the Tankwa exists as a highly differentiated and inbred population (Fig. 27.5). The results hint on the Tankwa having experienced

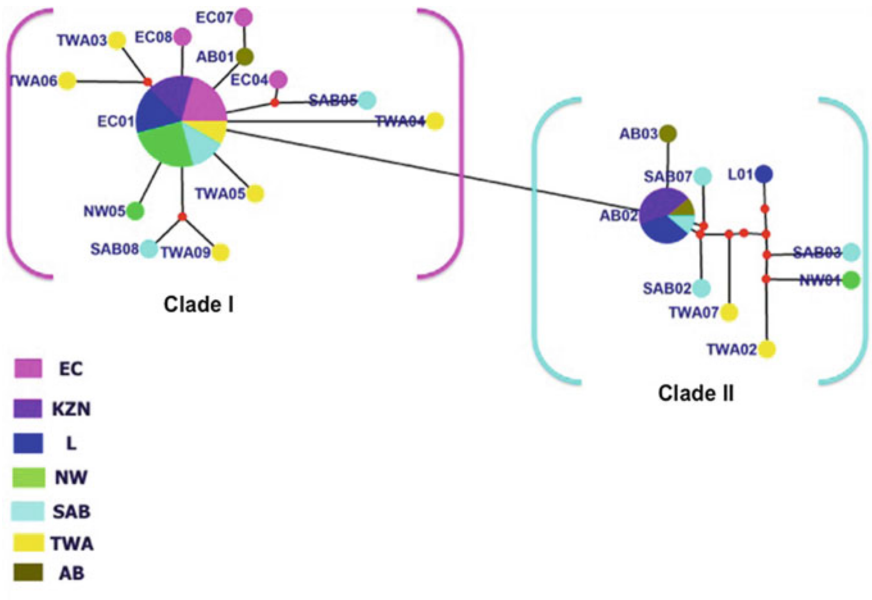

Fig. 27.4 Median network joining of the cytochrome oxidase subunit 1 (*COX1*) region of the mtDNA for South African and Genbank sequences [the sequences represented goat population from the South African provinces of Eastern Cape (EC), KwaZulu-Natal (KZN), Limpopo (L); Northwest (NW) and commercial breed of the Boer (SAB), feral goat population of Tankwa (TWA) and gene bank sequences from the Bangladesh Black Bengal goats (AB01) while is from the Wild Bezoar (AB02) and a domestic goat of Mongolian native (AB03)] from the GenBank (Ncube 2016)

founder effects and/or genetic drift when fewer than 100 individuals were used to establish the conservation unit (Mdladla et al. 2016a). These factors have major implications on the conservation and management of the Tankwa. This study underscored the effect of production systems in the genetic diversity and population structuring confirming the role of geographic isolation and production driven breeding goals in shaping genetic diversity. Such population-clustering supports the notion that local breeds have been naturally selected and accumulated genetic variation that enables their survival in arduous production environments. Such unique genetic variants should be the targets for artificial selection in breed improvement programs.

Besides, the response of South African and other indigenous goat populations to natural selection is now getting research attention especially in terms of the effects of the heterogeneous production systems. Mdladla et al. (2016b) interlaid Illumina SNP50K genotype data on geographic and climatic variables to describe the genetic structure and adaptation of South African indigenous goat populations. Population structure analysis showed that the remote population of the Tankwa breed formed a separate group with a homogeneous gene pool restricted to the Northern Cape

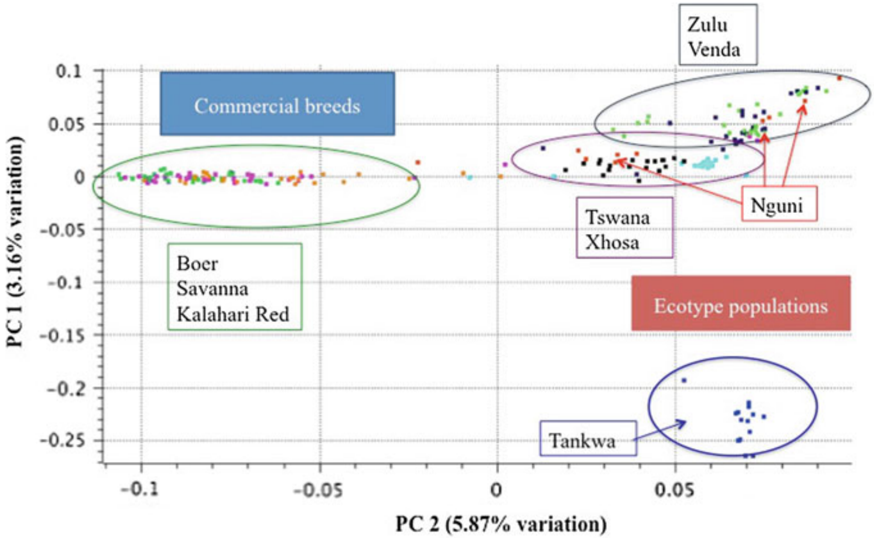

Fig. 27.5 Principal components (PC) analyses plot for South African indigenous goats. PC1 and PC2 explained 5.87 and 3.16% of the total variance, respectively (Mdladla et al. 2016a). Reprinted with permission of Wiley Online Library

province of South Africa. Village goat populations, although admixed, showed two genetic subpopulations; one composed of goats from Limpopo and KwaZulu-Natal and the other composed of goat populations of the Eastern Cape and Northwest (Fig. 27.6).

Commercial breeds represented genetic components spread across multiple sampling and geographic locations and harboring different fractions of ancestries typical in common origins of populations or a long period of genetic isolation, especially for Kalahari Red and Savanna. The study further assessed and quantified the relative importance of environmental factors (geographic location, altitude, annual and seasonal trend of temperature, and rainfall) on genetic variation of goat populations using Multivariate Redundancy Analysis. Significantly, more genetic variation was explained by climatic variables than geographic regions and the combined effects of climatic and geographic variables explained about 14.4% (R^2 *adj* = 0.09) of the total genetic variation. In addition, correlation-based landscape genomic approaches, Spatial Analysis Method (SAM) and Latent Factor Mixed Models (LFMM) identified loci associated with environmental factors implying that they influence selection pressure. Significant loci were found within genes involved in diverse biological functions potentially important for environmental adaptation. Overall, the study underlined the strong role of environmental factors in shaping the genetic diversity of South African indigenous goat populations.

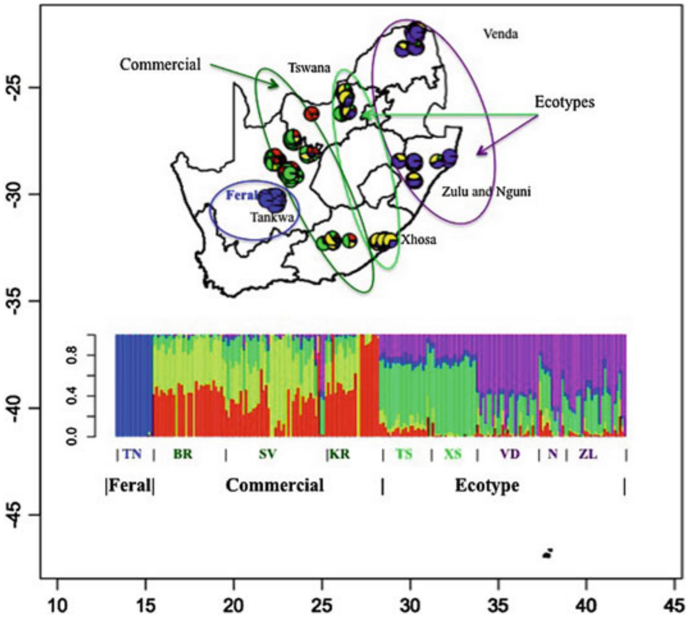

Fig. 27.6 Map of South Africa. The ADMIXTURE plot represents average coefficients of membership resulting from the genetic structure analysis (best fit model, $K = 5$). Each color represents a different genetic cluster. The included barplot represents each accession as a single vertical bar broken into K color segments, with lengths proportional to the estimated probability of membership in each inferred cluster (Mdladla 2017). The populations represented on the Admixture plots are the feral Tankwa (TN); the commercial Boer (BR), Savanna (SV) and Kalahari Red (KR), and village ecotypes of Tswana (TS); Xhosa (XS); Venda (VN); Nguni (N) and Zulu (ZL)

27.5 Genomics as a Tool for Improving Productivity and Adaptation of Indigenous Goat Populations

South African indigenous goat populations are renowned for their adaptability to local agroecological conditions and suitability for low input production systems. This is particularly important in a country where a majority of the goats are kept under marginalized communal production systems. Adaptation of animal genotypes to the environment is central to coping of local livestock populations to changing climatic and production objectives and is a key parameter to use in conservation and improvement programs.

South Africa has successfully developed world-renowned commercial meat breeds. In addition, South Africa has a feral goat population in the Northern Cape Province. However, despite its success stories and unique goat populations, majority of the South African goats are non-descript indigenous veld goats whose genetic diversity is yet to be fully characterized and harnessed. Advances in genomics and population genetics have led to substantial progress in identifying local genetic adaptation of livestock species and holds potential in improving productivity and robustness of local breeds to local production environments.

27.5.1 Whole Genome Sequencing and SNP Genotyping

The first reference genome was produced through optical imaging technologies and made available in 2014 based on a Chinese goat breed (Dong et al. 2013). A wild goat was subsequently sequenced and its reference genome published in 2015 (Dong et al. 2015). The Illumina goat SNP50K panel was produced in 2014 and consists of over 54,000 SNP evenly distributed across the goat genome. It has become a standard tool for breed/population characterization, genome-wide association studies, and genomic selection (Kijas et al. 2013; Tosser-Kloop et al. 2014; Visser et al. 2016; Mdladla et al. 2016a). The continuous decrease in sequencing costs coupled with the headway in genome assembly and bioinformatics pipelines is seeing an increase in the number of whole genome sequences generated and their use in characterization and improvement of goat and other livestock species.

Efforts are underway to sequence and analyze complete genomes of the Tankwa and other South African goat breeds (Mohlatlole et al. 2017). This work will facilitate SNP discovery for variants that are unique to the South African environment, further improving genomic efforts of developing local goat populations. Whole genome sequencing has ushered in technologies for screening for a wide variety of genomic variants beyond the frequently used single nucleotide polymorphisms. Copy number variants (CNVs) have been observed to be prevalent in a number of livestock genomes (Bickhart et al. 2012) and to have important roles they play in disease resistance and other adaptive traits (Bickhart et al. 2012). In South Africa, CNVs were investigated and reported in Nguni cattle, a local breed of cattle with similar geographic distribution and facing with similar production challenges and selection patterns to local goats (Wang et al. 2015).

27.5.2 RNA Sequencing and Gene Expression Profiling for Traits of Economic Importance

Although no reports of this technique are available for goats as in other livestock species, RNA sequencing and gene expression profiling wield much potential particularly in deciphering the heterogeneous production systems for South African goat populations. Genes that confer adaptation to specific environments will be differentially expressed relative to those with no role to survival and optimal production under specific conditions. It is those specific genes that are regulated under certain environments that would be targeted for selection.

RNA-Seq technology is a high-throughput sequencing platform allowing detection of rare transcripts, identification of novel transcript units, and revealing their differential expression between different samples (Geng et al. 2013). The technique includes identifying genes expressed in a stage-specific manner, defining clusters of genes showing similar patterns of temporal expression, and identifying candidate genes for functional analysis. The genes of the different expression clusters associated with different functions clearly indicate the molecular and cellular events involved in specific physiological states of the animals.

The functional annotation of animal genomes has benefited immensely from gene expression data and provides information on gene functions and regulations that will aid in gene editing and other genomics-driven improvement programs. Despite its potential, there is a dearth of information regarding gene expression analysis in goats and this area of study is still in its infancy in South Africa.

27.5.3 Signatures of Selection Analysis and Landscape Genomics

Landscape genomics merges the competing effects of production system, geographical, and environment landscapes with adaptive variation to explain variation. It combines genome-wide data with geo-environmental resources analysis to identify genomic regions conferring an advantage in traits of economic importance.

Regarding livestock species, the aim of landscape genomics is to learn from their coevolution and production systems and use the knowledge gained to better match different genotypes with production circumstances. Regions where goat genomes face selection pressure from environmental conditions such as high temperatures and lack of water in drought or others are expected to show higher genomic divergence across habitats compared to the neutral genome background.

By performing genome-wide scans on the goat genome from populations living in different habitats or across agroecological landscapes varying, from dry to wet areas, for example, landscape genomics offers the opportunity of analyzing the adaptive response of goats across a naturally occurring environmental gradients (Joost et al. 2007). Mdladla (2017) used landscape genomic analysis and observed genomic loci and associated genes and gene pathways for different environmental and geographic variables in South African goats. In addition, the AdaptMap is a project that is using genomic data from diverse goat populations distributed across different geographic landscapes to infer on signatures of selection and genomic loci conferring adaptation to diverse selection pressures.

27.6 Community-Based Breeding Programs

Community-based breeding programs refer to approaches of improving livestock genetics through the incorporation of farmer participation in selection and breeding activities, from inception through to implementation. Strategies such as community-based breeding programs also allow buck exchange and rotation among the village communities resulting in reduced levels of inbreeding, and facilitate conservation and diversity in the gene pool in the populations. Under circumstances where livestock keepers already rear mixed flocks of livestock together such as in communal grazing systems, the implementation of community-based breeding programs is regarded as appropriate. This would be a vehicle through which shared production capital (animal genotypes, grazing land, etc.) and pooled resources and services (veterinary, feeding, and marketing) can enable joint processes of decision-making. Community-based breeding strategies place utmost value in farmers' views, needs and decisions, and encourage their active participation throughout the life-cycle of the program. Genomics and community-based breeding can be integrated to offer solutions of improving goat productivity in South Africa.

27.7 Concluding Remarks

South Africa is one of the few countries that have successfully developed goat breeds that are now globally distributed and farmed internationally. Majority of the country's goat genetic resources are, however, non-descript and kept under low input production systems on communal farms where they are exposed to diverse and extreme natural selection pressures.

Genomics, through genome-wide SNP data and targeted gene sequence analyses, has enabled characterization of local goat genetic resources. With integration of whole genome sequence data and other genomic variants such as CNVs and gene expression profiles, better insight into adaptive genetic diversity of South African goat populations is envisaged.

Community-based breeding programs have been successful in a number of livestock species in Africa including goats and together with genomics, should be explored for local goat improvement programs.

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Chapter 28
Nuclear and Mitochondrial Marker-Based Diversity and Population Structuring of Indian Goats

Sonika Ahlawat and Rekha Sharma

Abstract Indian subcontinent is endowed with diverse caprine germplasm that has evolved through natural selection for adaptation to various agro-climatic conditions. Goat genetic resources of India are represented by 26 defined breeds that represent only 30% of the total goat population and several unrecognized populations being referred to as non-descript. The awareness of the importance of this diversity at the phenotypic level calls for assessment of diversity at the genetic level. An understanding of the genetic structure and diversity of the breeds also unravels the relationship between their genetic makeup and performance as well as adaptability and disease resistance. Both microsatellite and mitochondrial markers have been instrumental in determination of overall magnitude of genetic diversity among and within breeds of different livestock species including goats. This chapter puts forth the current status of genetic characterization of Indian goats by these markers. Microsatellite-based analysis reveals high level of sharing of the gene pool among breeds of northwestern, southern peninsular, and eastern regions and their clear distinction from the breeds of temperate Himalayan region. Investigation of origin and divergence of Indian goats by mitochondrial DNA sequence-based analysis and comparison with wild goat sequences established the presence of five out of seven lineages known so far in goats from different parts of the globe. It is an established fact that an understanding of the genetic richness among populations is imperative for deciding their uniqueness and therefore prioritizing their conservation. Since only a handful of reports are available concerning the genetic relationships or distinctness of different Indian goat breeds, the time has come to carry out more comprehensive meta-analyses covering maximum available germplasm to reach a logical conclusion.

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28.1 Introduction

India is endowed with a large biodiversity, which includes goats that are distributed in different agro-ecosystems throughout the country. Most of the goat breeds in India have evolved through natural selection for adaptation to various agro-climatic conditions. Consequently, they are well adapted to certain local conditions such as climatic extremes, long migration, poor nutrition, diseases and non-availability and poor quantity of drinking water.

The diverse goat genetic resources are represented by 26 defined breeds and several unrecognized populations, which form the backbone of rural livelihood and financial security systems in India (http://www.nbagr.res.in/).

Traditionally, goats are reared mainly by the poorest people contributing as the main or supplementary source of income for these people. For years, indigenous goats have been referred to as “Poor man’s cow” in India but now they are also being acknowledged as the “Future Animal” for ensuring not only rural but also urban prosperity. Goat rearing is less capital intensive as they are predominantly reared under extensive management on community rangeland employing family labor. Hence, they are usually a low-investment sustainable enterprise yielding reasonably high rates of return in terms of wool, meat, skin, milk, and manure. India ranks second in the world with about 13.9% of the world goat population and more than 135 million heads spread across different states and union territories (19th Livestock census 2012). Although goats constitute an important part of rural economy, a decline of 3.8% has been recorded over the previous census in 2007.

This chapter aims to present a comprehensive genetic analysis of goat populations of India using microsatellite and mitochondrial markers.

28.2 Diversity of Goat Genetic Resources of India

Indian goat breeds have been classified according to their body size and habitat. Most of the breeds are medium in size but there are some large-sized breeds such as Beetal, Jamnapari, Jakhrana, and Kodi Adu, in addition to small-sized animals such as Black Bengal, Barbari, Changthangi, and Chegu breeds (Fig. 28.1). Based on geographical location, the indigenous goat breeds are divided into four eco-zones, viz., temperate Himalayan, northwestern, eastern, and southern peninsular region. Details on names of registered breeds, size, utility, and ecological distributions are given in Table 28.1.

Fig. 28.1 Indian goat breeds. Beetal (**a**), Berari (**b**), Kalahandi (**c**), Ganjam (**d**), Gaddi (**e**), Changthangi (**f**), Nagaland long hair goat (**g**), Sangamneri (**h**), and Sirohi (**i**) (provided by authors)

Indian goats possess some unique attributes which have made them very popular among the local communities that rear them. For instance, there are breeds like Jamnapari and Jakhrana, with high milk production; Chegu and Changthangi, renowned world over for their fine fiber (Pashmina) production; and breeds like Black Bengal and Malabari, which are accredited for being highly prolific animals. Resilience to climatic extremes is another important characteristic of Indian goats. Beetal and Jamnapari are adapted to hot dry belt of northwestern India, whereas Chegu and Changthangi thrive well at high altitude with hypoxic conditions. Another interesting germplasm is the feral goats of Andaman Island, which depend on sea water for their survival. Their ability to withstand the prevalent inhospitable conditions is a proof of their remarkable adaptive ability and the instinct for survival. The 26 defined breeds of India represent only 30% of the total goat

Fig. 28.1 (continued)

population in the country with 70% of indigenous goats still being referred to as non-descript (Verma et al. 2010). Some of the states with noteworthy unrecognized goat populations are mentioned in Table 28.2. There is large intermixing among the breeds in the regions where two or more breeds exist. This has resulted in decline in purebred population and subsequent dilution of genetic merit.

28.3 Need for Genetic Characterization of Goats

It is universally accepted that rapid evolution of civilization has steered the loss in the genetic diversity of all animal genetic resources. Augmented demand of highly productive breeds has led to concomitant neglect of the local breeds. Understanding the genetic structure and diversity of the breeds, production characteristics, relationship among their genetic makeup and performance as well as adaptability and resistance to diseases plays an important role in the conservation of local breeds (Wilkinson et al. 2011). Principally, the maintenance of genetic variability is necessary to meet current production needs in various environments, to allow sustained genetic improvement, for understanding phenotypic variability in the future and to facilitate rapid adaptation to changing breeding objectives (Notter

Table 28.1 Production aptitude and natural habitat of Indian Goat breeds

Breed	Body size	Aptitude	Habitat	Region
Attapaddy black	Medium	Meat	Attapaddy region of Kerala	Southern peninsular
Barbari	Small	Milk, meat	Etawah, Agra, Aligarh districts of Uttar Pradesh	Northwestern
Beetal	Large	Milk, meat	Gurdaspur and Amritsar districts of Punjab	Northwestern
Berari	Medium	Meat	Vidarbha region of Maharashtra	Southern peninsular
Black Bengal	Small	Meat, skin	West Bengal, Part of Bihar and Odisha, Northeastern states	Eastern
Changthangi	Small	Fiber (Pashmina)	Changthang region of Ladakh and hilly tract of Leh	temperate Himalayan
Chegu	Small	Fiber (Pashmina)	Spiti, Yaksar, and Kashmir Valley	temperate Himalayan
Gaddi	Medium	Long hair, pack	Kangra, Kullu Valley, Chamba, Simla districts of Himachal Pradesh	temperate Himalayan
Ganjam	Medium	Meat	Ganjam and Koraput districts of Odisha	Eastern
Gohilwadi	Large	Milk, meat	Bhavnagar, Amreli and Junagarh districts of Gujarat	Northwestern
Jakhrana	Large	Milk, meat	Jakhrana, Nayasarana, and nearby villages of Alwar district (Rajasthan)	Northwestern
Jamnapari	Large	Milk, meat	Etawah, Agra, Aligarh districts of Uttar Pradesh	Northwestern
Kannaiadu	Medium	Meat	Virudnagar, Tuticorin, and Tirunelveli districts of Tamil Nadu	Southern peninsular
Kodi adu	Large	Meat	Ramananthapuram and Thoothukudi districts of Tamil Nadu	Southern peninsular
Konkan Kanyal	Medium	Meat	Sindhudurg district of Maharashtra	Southern peninsular
Kutchi	Medium	Milk, meat	Kutch region and Ahmedabad district of Gujarat	Northwestern
Malabari	Medium	Milk, meat	Calicut, Cannanore, and Malappuram districts of Kerala	Southern peninsular
Marwari	Medium	Meat, hair	Jodhpur, Pali, Jalore, Barmer, Jaisalmer, and Nagaur districts of Rajasthan	Northwestern
Mehsana	Medium	Milk, meat	Patan, Banaskantha, Mehsana, Gandhinagar, and Ahmedabad districts of Gujarat	Northwestern
Osmanabadi	Medium	Milk, meat	Osmanabad, Ahmednagar, and Solapur districts of Maharashtra	Southern peninsular

(continued)

Table 28.1 (continued)

Breed	Body size	Aptitude	Habitat	Region
Pantja	Medium	Milk, meat	US Nagar and Nainital districts of Uttarakhand	temperate Himalayan
Sangamneri	Medium	Meat, hair	Pune and Ahmednagar districts of Maharashtra	Southern peninsular
Sirohi	Medium	Milk, meat	Sirohi district of Rajasthan	Northwestern
Surti	Medium	Milk, meat	Surat and Baroda districts of Gujarat	Northwestern
Teressa	Large	Meat	Andaman and Nicobar islands	Southern peninsular
Zalawadi	Medium	Meat, hair	Surendranagar and Rajkot districts of Gujarat	Northwestern

Table 28.2 Lesser known goat populations from India

Goat breed	State
Andaman goat	Andaman and Nicobar Islands
Shigari	Jammu and Kashmir
Non-pashmina goats	Jammu and Kashmir (Ladakh)
Bidri, Chitradurga	Karnataka
Nagaland long hair goat	Nagaland
Ghumusari, Kalahandi, Bengal type, Malkangiri, Raigari, Narayanpatna	Odisha
Singharey, Black Sikkim	Sikkim
Salem black	Tamil Nadu
Mahabubnagar	Telangana
Udaipuri, Tarai, Chaugarakha	Uttarakhand
Bundelkhandi, Jaunpuri	Uttar Pradesh

1999). A major stumbling block in formulation and implementation of conservation, breeding, and management policies for different livestock breeds is the lack of information regarding their current genetic status. The amount of genetic divergence among populations is regarded as a major criterion for deciding their uniqueness and therefore prioritizing their conservation (Eding et al. 2002). In order to prioritize breeds for conservation, information about their genetic architecture is a pre-requisite.

28.3.1 Molecular Markers for Genetic Characterization

Rapid advancement in the tools for DNA analysis that has taken place in the last few decades has tremendously increased our capacity to characterize variation within and among breeds. Since 1990s, microsatellite markers are being globally exploited to establish genetic profiles of animal genetic resources (Acosta et al. 2013). In fact, they have been recommended by FAO as first priority molecular tools for the measurement of domestic animal diversity (MoDAD). For each species of interest, International Society for Animal Genetics (ISAG), in collaboration with FAO, has recommended a set of microsatellite markers to be used as the standard set for the calculation of genetic diversity. Adherence to such recommendations allows for reasonable comparison of parallel or overlapping studies and helps combine results in meta-analyses. The primer sequences and map position of each of these markers can be obtained from Domestic Animal Diversity Information System (DAD-IS-MoDAD) and are also available at www.fao.org. These are the most popular and versatile genetic markers with myriads of applications in population genetics, conservation biology, and evolutionary biology due to co-dominant transmission, locus-specific nature, high information content, relative abundance with uniform genome coverage, and higher mutation rate than standard (Sharma et al. 2013). These markers have been used to measure genetic diversity, gene flow, migration, and effective population size in livestock breeds (Kantanen et al. 2000; Peter et al. 2007).

Besides genetic diversity, co-ancestry and kinship among breeds, past genetic bottlenecks, and parentage verification are some other parameters that can be determined through the use of neutral microsatellite markers (Tapio et al. 2010). Microsatellites have been successfully used over the years to estimate the genetic diversity of goat populations in many countries across the globe like South Africa (Visser et al. 2004), Brazil (Oliveira et al. 2007), Spain (Serrano et al. 2009), China (Wei et al. 2014), Thailand (Seilsuth et al. 2016), Turkey (Bulut et al. 2016), etc. In a recent study, Lenstra et al. (2017) used microsatellite-based genotyping to characterize the phylogeography of European goats by comparing the microsatellite genotypes of Dutch and Danish Landraces with those of other Nordic and European goat breeds. A plethora of information has also been generated on the genetic characterization of Indian goats (Dixit et al. 2010, 2012) during the last decade using neutral microsatellite markers.

Mitochondrial DNA (mtDNA) is another popular marker for resolving molecular diversity, evolutionary relationship, and historical biogeography of species (Bruford et al. 2003). The remarkable properties of the mtDNA include maternal mode of inheritance, high copy number, single-copy genes, rapid rate of evolution without any recombination, and high variability among and within species, which render it suitable for phylogeographical studies (Luikart et al. 2001; Gissi et al. 2008). DNA barcoding for taxonomic identification is another application of mtDNA which is based on the principle that a short standardized sequence can distinguish individuals of a species because genetic variation among species exceeds that within species

(Herbert et al. 2003). In the standardized DNA barcoding approach, identification of a specimen as belonging to a certain animal species is based on a single universal marker, i.e., the DNA barcode sequence (cytochrome c oxidase I) (Ratnasingham and Hebert 2007). The non-coding or control region (also referred to as D loop or displacement loop), which is characterized by highly polymorphic regions known as the hypervariable region I and II (HVI and HVII), has been particularly employed to analyze the evolutionary history of vertebrates (Larizza et al. 2002). Luikart et al. (2001) analyzed polymorphisms in the control region in goats in order to establish the overall genetic structure of 88 breeds of domestic goats at the worldwide scale. Since then, several studies from different parts of the world, viz., Pakistan (Sultana et al. 2003), India (Joshi et al. 2004), China (Chen et al. 2005), Spain (Amills et al. 2004; Azor et al. 2005), Portugal (Pereira et al. 2005), South Korea (Odahara et al. 2006), and Italy (Sardina et al. 2006; Doro et al. 2014) have been conducted to estimate the genetic diversity of goat breeds.

28.4 Microsatellite Marker-Based Genetic Diversity of Indian Goats

Assessment of genetic diversity in Indian goats has been carried out using microsatellite markers during the last decade. Allele discrimination in the initial studies was based on silver staining technique, which has been employed for most the goat breeds characterized in India. But later, with the popularization and reduction in cost of fluorescent dye-based capillary methods, automated procedures were adopted. Of the 26 registered breeds of goats in India, 23 have been characterized using microsatellite markers by various researchers. In addition to the recognized breeds, eight non-descript populations have also been characterized on the basis of these neutral markers. The genetic diversity within breeds/populations is estimated in terms of observed and effective number of alleles, average allele number (allele diversity), observed heterozygosity, and expected heterozygosity (gene diversity) using softwares such as GenAlex, MICROSAT, Genepop, etc. The F-statistics is computed using the POPGENE 1.32 program (Yeh et al. 1999).

There have been quite a few comprehensive gene diversity studies in Indian goats which can be appreciated from Table 28.3. According to the classification of polymorphism information content (PIC), a marker is low polymorphic if PIC value < 0.25, moderate polymorphic if $0.25 <$ PIC value < 0.50, and high polymorphic if PIC value > 0.50 (Botstein et al. 1980). PIC values for the markers used in different breeds are >0.5 except in case of Assam Hill (0.44), suggesting that the markers are highly informative and can be used for caprine diversity studies. The observed number of alleles was minimum for Assam Hill (4.95) and maximum for Berari (11.76). The range of effective number of alleles was from 2.68 for Assam Hill to 7.71 for Mahabubnagar goats. Microsatellite marker-based analysis revealed substantial genetic diversity (expected heterozygosity values ≥ 0.6) in many

Table 28.3 Genetic diversity estimates of Indian goats based on microsatellite markers

Breed/ Population	Defined breed/ Non-descript	Sample size	Na	Ne	Ho	He	F_{IS}	PIC	References
Assam Hill	Non-descript	40	4.95 ± 2.225	2.68 ± 1.590	0.43 ± 0.285	0.48 ± 0.28	0.0850	0.44 ± 0.263	Zaman et al. (2013)
Attappady Black	Defined breed	48	7.56 ± 0.63	3.94 ± 0.36	0.57 ± 0.00	0.70 ± 0.00	0.18		Dixit et al. (2010)
Barbari	Defined breed	48	7.92 ± 0.50	3.48 ± 0.30	0.56 ± 0.00	0.67 ± 0.00	0.17		Dixit et al. (2012)
Beetal	Defined breed	48	8.28 ± 0.57	3.70 ± 0.34	0.60 ± 0.00	0.68 ± 0.00	0.12		Dixit et al. (2012)
Berari	Defined breed	50	11.76 ± 5.01	4.95 ± 2.28	0.67 ± 0.18	0.73 ± 0.19	0.15	0.82	Mishra et al. (2013a)
Black Bengal	Defined breed	48	7.84 ± 0.47	3.42 ± 0.35	0.54 ± 0.00	0.62 ± 0.01	0.14		Dixit et al. (2012)
		40	8.55 ± 0.269	5.75 ± 0.218	0.69 ± 0.013	0.81 ± 0.009		0.80 ± 0.006	Vijh et al. (2010)
Bundekhandi	Non-descript		11.08	4.96	0.69	0.73	0.73	0.82	Mishra et al. (2012a)
Changthangi	Defined breed	48	7.56 ± 0.58	3.56 ± 0.35	0.57 ± 0.00	0.66 ± 0.01	0.13		Dixit et al. (2012)
Chegu	Defined breed	43	7.36 ± 0.70	4.26 ± 0.45	0.58 ± 0.00	0.70 ± 0.01	0.18		Dixit et al. (2012)
		35	7.41 ± 0.201	4.99 ± 0.145	0.71 ± 0.008	0.80 ± 0.006		0.80 ± 0.006	Vijh et al. (2010)
Gaddi	Defined breed	48	7.68 ± 0.73	3.81 ± 0.51	0.51 ± 0.00	0.65 ± 0.01	0.22		Dixit et al. 2012)
		51	9.00 ± 0.82	6.58 ± 0.56	0.784 ± 0.02	0.8431 ± 0.01		0.810 ± 0.01	Singh et al. (2015)

(continued)

Table 28.3 (continued)

Breed/ Population	Defined breed/ Non-descript	Sample size	Na	Ne	Ho	He	F_{IS}	PIC	References
Ganjam	Defined breed	48	7.96 ± 0.69	3.68 ± 0.37	0.53 ± 0.00	0.67 ± 0.01	0.22		Dixit et al. (2010)
Ghumusari	Non-descript	48	9.80	4.28	0.73	0.71	0.002	0.78	Mishra et al. (2013b)
Gohilwadi	Defined breed	48	7.80 ± 0.82	3.73 ± 0.48	0.50 ± 0.00	0.62 ± 0.01	0.2		Dixit et al. (2012)
Jakhrana	Defined breed	48	8.08 ± 0.47	3.32 ± 0.27	0.55 ± 0.00	0.65 ± 0.00	0.17		Dixit et al. (2012)
Jamunapari	Defined breed	48	7.40 ± 0.47	3.46 ± 0.26	0.53 ± 0.00	0.67 ± 0.01	0.21		Dixit et al. (2012)
Jharkhand Black	Non-descript	48	6.88 ± 0.52	3.80 ± 0.34	0.46 ± 0.00	0.67 ± 0.01	0.32		Dixit et al. (2012)
Kalahandi	Non-descript	48	10.0	4.29	0.67	0.68	0.02	0.79	Mishra et al. (2015)
Kanniadu	Defined breed	48	8.64 ± 0.48	4.22 ± 0.35	0.53 ± 0.00	0.73 ± 0.00	0.28		Dixit et al. (2010)
Konkan Kanyal	Defined breed		10.20	4.36	0.67	0.71	0.05	0.79	Mishra et al. (2012b)
Kutchi	Defined breed	46	8.44 ± 0.74	4.31 ± 0.43	0.58 ± 0.00	0.71 ± 0.01	0.18		Dixit et al. (2012)
Mahabubnagar	Non-descript		8.8 ± 0.554	7.711 ± 0.488	0.694 ± 0.043	0.862 ± 0.010	0.196 ± 0.047	0.845	Chowdam et al. (2016)
Malabari	Defined breed	48	8.28 ± 0.96	3.79 ± 0.42	0.52 ± 0.00	0.65 ± 0.01	0.2		Dixit et al. (2010)
		48	10.36	3.22		0.6895			Verma et al. (2009)

(continued)

Table 28.3 (continued)

Breed/ Population	Defined breed/ Non-descript	Sample size	Na	Ne	Ho	He	F_{IS}	PIC	References
Marwari	Defined breed	48	8.16 ± 0.58	3.56 ± 0.35	0.54 ± 0.00	0.66 ± 0.00	0.18		Dixit et al. (2012)
		146	4.93	2.38	0.549	0.544		0.780	Yadav et al. (2015)
Mehsana	Defined breed	48	8.08 ± 0.80	4.48 ± 0.51	0.64 ± 0.00	0.69 ± 0.01	0.08		Dixit et al. (2012)
Osmanabadi	Defined breed	48	6.12 ± 0.70	3.25 ± 0.36	0.42 ± 0.00	0.61 ± 0.01	0.32		Dixit et al. (2010)
Sangamneri	Defined breed	48	6.88 ± 0.57	3.31 ± 0.27	0.53 ± 0.00	0.64 ± 0.01	0.19		Dixit et al. (2010)
Sikkim Black	Non-descript	48	5.39	2.77	0.420	0.575	0.14	0.536	Verma et al. (2015)
Sikkim Singharey	Non-descript	48	7.913 ± 0.576	3.496 ± 0.328	0.507 ± 0.042	0.649 ± 0.034	0.225 ± 0.046	0.66 ± 0.036	Shivahre et al. (2017)
Sirohi	Defined breed	48	8.24 ± 0.80	4.35 ± 0.37	0.49 ± 0.00	0.73 ± 0.00	0.33		Dixit et al. (2012)
Surti	Defined breed	48	7.96 ± 0.66	3.62 ± 0.38	0.56 ± 0.00	0.65 ± 0.01	0.13		Dixit et al. (2012)
Zalawadi	Defined breed	36	6.20 ± 0.60	3.75 ± 0.41	0.54 ± 0.00	0.67 ± 0.01	0.19		Dixit et al. (2012)

F_{IS}—Deficit of heterozygotes; He—Expected heterozygosity; Ho—Observed heterozygosity; Na—Observed number of alleles; Ne—Expected number of alleles; *PIC*—Polymorphic information content

Indian goat populations such as Black Bengal, Bundelkhandi, Chegu, Gaddi, Ghumusari, Mahabubnagar, Malabari, etc. In almost all the breeds/populations, observed heterozygosity was slightly lower than expected showing a departure from Hardy–Weinberg Equilibrium (HWE) and possibility of inbreeding.

F_{IS} value in different populations ranged from 0.002 in Ghumusari to 0.73 in Bundelkhandi. Positive F_{IS} value for most of the goat breeds/populations is indicative of heterozygote deficiency that can be attributed to various factors such as null alleles, population structure (Wahlund effect), or inbreeding. Since this value is derived from ≥ 10 microsatellite markers, therefore, segregation of non-amplifying (null) alleles is unlikely to have an effect. The main cause for high genetic homogeneity or lack of heterozygotes in the Indian goat breeds might be ascribed to inbreeding (overall positive F_{IS} value); however, the possibility of Wahlund effect (population substructure) may also not be ruled out due to pooling samples (within breed) from different breeding flocks, i.e., different villages in the same area. Further, in view of the absence of pedigreed data under field conditions, the effect of relatedness of few samples otherwise deemed unrelated during collection may not be denied.

28.4.1 Phylogenetic Analysis of Indian Goat Breeds Based on Microsatellite Markers

The genetic diversity and genetic relationships among Indian goat breeds/populations have been explored by numerous researchers (Verma et al. 2009; Dixit et al. 2010; Vijh et al. 2010; Dixit et al. 2012; Mishra et al. 2015; Verma et al. 2015). However, most comprehensive analysis of the prevailing genetic status, relationships, and structure of Indian goat breeds from different agroecological regions was estimated using 25 microsatellite markers by Dixit et al. (2012). This study included 20 defined breeds (Barbari, Beetal, Black Bengal, Changthangi, Chegu, Gaddi, Ganjam, Gohilwadi, Jakhrana, Jamnapari, Kanniadu, Kutchi, Malabari, Marwari, Mehsana, Osmanabadi, Sangamneri, Sirohi, Surti, and Zalawadi) and two non-descript populations (Attappady and Jharkhand Black). Nevertheless, now Attappady has also been recognized as a defined breed in India. The genetic diversity estimates of these populations are given in Table 28.3.

Genetic distances between each pair of the studied breeds were measured on the basis of allele frequencies and ranged from 0.092 to 0.519. The genetic distance tended to be lowest (0.092) between Jamnapari and Marwari and the widest (0.519) between Kanniadu and Zalawadi. Similar pattern of diversity was revealed by coefficients of genetic differentiation (Fst). Phylogenetic tree based on neighbor-joining algorithm was built on the basis of distance matrices among the studied breeds (Fig. 28.2). The consensus phylogenetic tree revealed two major clusters: (1) Breeds of western coastal part of northwestern region: Kutchi, Sirohi, Mehsana, and Gohilwadi; southern peninsular region: Attappady and Malabari;

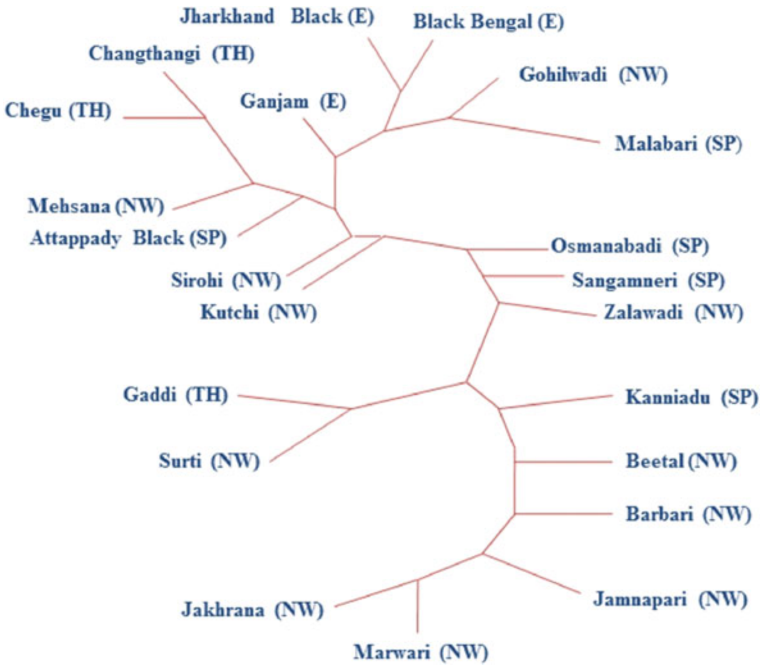

Fig. 28.2 Neighbor-joining consensus tree based on pair-wise D_A genetic distances among 22 goat populations of India. TH—Temperate Himalayan, NW—Northwestern, E—Eastern, and SP—Southern peninsular region (Adapted from Dixit et al. 2012)

eastern region: Black Bengal, Jharkhand Black and Ganjam; and those of temperate Himalayan region: Changthangi and Chegu; and (2) Breeds of western (Jakhrana, Marwari, and Surti) and northern (Jamnapari, Barbari, and Beetal) plains of northwestern region. The Gaddi from lower Himalayan region just surrounding the northern plain and Kanni Adu from the peninsular India were also part of the second cluster. Osmanabadi, Sangamneri and Zalawadi were in between these two clusters. Principal component analysis (PCA) performed using the allele frequencies of 25 markers in 22 goat breeds/populations clearly revealed three distinct clusters: Cluster 1 consisted of breeds of temperate Himalayan region (Changthangi and Chegu), Cluster 2 included breeds of western coastal part of northwestern region, southern peninsular India and those of eastern region (Osmanabadi, Sangamneri, Mehsana, Sirohi, Kutchi, Gohilwadi, Jharkhand Black and Black Bengal), and Cluster 3 consisted of breeds of northern (Gangetic plain) and western plains of northwestern region including lower Himalayan region (Barbari, Jamnapari, Jakhrana, Marwari, Beetal, Surti, Ganjam, and Gaddi). Intriguingly, Attappady and Kanniadu of southern peninsular India also joined the third cluster.

Overall picture that emerged from this analysis was that there is relatively high level of sharing of gene pool among breeds of northwestern, southern peninsular, and eastern regions and their clear distinction from the breeds of temperate

Table 28.4 Diversity of mitochondrial haplotypes among goat breeds of India

Breed	Sample size	Number of haplotypes	Diversity	Diversity (±S.E.)
Pashmina	40	17	0.926	0.022
Black Bengal	50	28	0.960	0.014
Osmanabadi	16	12	0.917	0.064
Kutchi	10	5	0.844	0.080
Marwari	30	18	0.949	0.023
Sirohi	69	36	0.964	0.010
Barbari	41	28	0.964	0.018
Jakharana	50	28	0.940	0.023
Local (Non-descript)	7	7	1.000	0.076
Jamunapari	50	34	0.984	0.007

Himalayan region. Genetic distances and principal component analysis revealed that the breeds were related as per their geographical locations with breeds from adjacent areas being relatively genetically related. Moderate level of genetic differentiation (Fst) among the breeds (16.5%) highlighted that different populations were genetically distinct. This appears to be an encouraging scenario since no breeding policy to create breeds or maintain the breed purity is currently being implemented in India.

28.5 Population Structuring of Indian Goats Through Mitochondrial DNA Markers

Mitochondrial DNA sequencing has been instrumental in elucidating the complexity and origins of many modern domestic livestock species including goats, giving a general concept of multiple maternal lineages (Luikart et al. 2001; Bruford et al. 2003). First comprehensive work on mtDNA-based population structuring in goats was by Luikart et al. (2001), who analyzed a 481 bp hypervariable sequence of the mtDNA D loop from 406 goats representing 88 breeds across 44 countries. This study included 14 samples from Indian goats as well (Barbari-3, Jamnapari-3, Sirohi-3, Osmanabadi-2, and local goats-2). Three highly divergent goat mtDNA lineages (A, B, and C) were deciphered in this study with the Indian goat breeds conforming to lineage A and B. The most common mtDNA lineage was lineage A, which was evident across all continents. However, lineage B was observed in eastern and southern Asia including Mongolia, Laos, Malaysia, Pakistan, and India, and lineage C was found at low frequencies in Mongolia, Switzerland, and Slovenia. Ancient divergence (over 200,000 years ago) and different geographical localizations of the lineages indicated the likelihood of either multiple domestication events or introgression of further lineages after the original domestication.

Subsequently, Joshi et al. 2004 investigated the origin, divergence, and past migration patterns in Indian goats by analyzing 363 goats belonging to 10 different breeds from different geographic regions and compared with published wild goat sequences. Among the ten breed populations analyzed, a total of 200 different haplotypes were observed (Table 28.4). The most common haplotypes in the data set fell within lineage A previously reported by Luikart et al. (2001). A few samples of Indian goats are clustered with lineages B and C. The absence of lineage C in the previous study could probably be due to small sample size investigated. Interestingly, few haplotypes in Barbari goat breed fell into two new lineages which were designated as lineages D and E reiterating considerable additional diversity within Indian domestic goats. Neighbor-joining (NJ) tree of the Indian goat breeds and the wild species was constructed which depicted that all domestic goats cluster together but were demarcated into three groups. Two separate clusters were found to correspond to different geographical regions with goat breeds from the north-western part of the country being distinct from breeds from the central, eastern, and southern regions. Non-descript (local goats) formed a separate cluster. This study reported population structuring of Indian goats based on their geographical regions of origin.

Liu et al. (2007) analyzed mitochondrial DNA diversity in 13 Chinese goat breeds and came out with an interesting observation. Lineages C and D, which were reported in Indian goats, were also observed in one Chinese goat breed, i.e., Tibetan goat. The authors speculated that since Tibet is close to India, there may have been high gene flow between Indian and Tibetan goat populations as transportation of goats for commercial trade or during migratory and exploratory movements of humans had been a practice in the past (Luikart et al. 2001). Another intriguing observation was reported by Sardina et al. (2006) while exploring the mitochondrial HVR1 diversity in Sicilian goat breeds, Italy. The mitochondrial lineage A was detected in all Sicilian haplotypes but three novel haplotypes were found to be different from previously described lineages and clustered with wild goat haplotypes. Their results pointed at existence of a new mtDNA lineage or a historical introgression from wild goats. The presence of a new lineage in goats from Sicily was confirmed by Naderi et al. (2007), which was designated as mtDNA lineage F. In addition, lineage G was found in goat samples from Middle East and Northern Africa, near the Fertile Crescent. All these studies establish the power of mitochondrial DNA markers for tracing multiple maternal origins for goats. The presence of multiple mtDNA lineages and their mixing within breeds possibly suggest multiple domestication events or introgression between domestic and wild species (*Capra aegagrus*). Hence, mtDNA markers can be exploited for identification of wild ancestors, localizing domestication centers and reconstructing colonization and trading routes (Bruford et al. 2003; Ajmone-Marsan et al. 2010).

28.6 New Approaches for Delineating Genetic Diversity

Substantial information about genetic diversity of goats has been generated across the globe using microsatellite and mitochondrial markers. However, now it is being increasingly realized that accurate characterization of genetic resources can be achieved by accessing variation across the whole genome. Fortunately, recent developments and decreasing costs in sequencing or SNP genotyping technologies have opened new perspectives to decipher and comprehend genomic diversity (Snyder et al. 2010). Species-specific SNP panels have been developed to permit an affordable use of genomic technologies in all livestock species including goats (Ajmone-Marsan et al. 2014). It is now possible to compare various datasets for precise characterization of the distribution of genomic diversity in various populations (Visser et al. 2016).

The sequencing of individuals' whole genomes including the mitochondrial genome has greatly expanded our understanding of existing diversity (Benjelloun et al. 2015). Alleles related to adaptability towards contrasted environmental conditions can be precisely identified by this approach. Recently, selection signatures underlying production and adaptive traits were detected in eight goat populations by whole genome sequencing (Wang et al. 2016). Such studies demonstrate the unprecedented power of sequence data to identify genomic regions associated with agriculturally significant phenotypes in goats. Although these novel approaches of characterization have not yet been adopted for Indian goats, nevertheless the future holds great promise.

28.7 Concluding Remarks

The diverse caprine genetic resources of India are represented by 26 defined breeds and several unrecognized populations which ensure livelihoods of millions of resource-poor rural households. Formulation and implementation of conservation, breeding, and management policies for Indian goats cannot be accomplished without knowledge of their current genetic status. This chapter puts forth the status of genetic characterization of goat populations of India using microsatellite and mitochondrial markers and also discusses the recent technologies that unravel the diversity at the whole genome level. Once the origins of genetic diversity are delineated and breeds with desirable attributes are identified, management of biodiversity for sustainable utilization will become a reality.

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Chapter 29
Conservation of Goat Populations from Southwestern Europe Based on Molecular Diversity Criteria

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Abstract Goat farming plays a key role in agricultural activity and in maintaining forest lands in Southwestern Europe. Remarkably, the Iberian Peninsula represents nearly 25% of the European goat census. Goat husbandry is often associated with low input production systems and uses selective breeding programs, which are less advanced than those employed in other livestock. Native goat breeds are very well adapted to produce in marginal areas under extensive conditions. Loss of their genetic diversity could have important economic, ecological and scientific implications as well as social consequences. Several methodologies have been developed to preserve the genetic diversity of single populations, but additional problems arise

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when a group of breeds, i.e., subpopulations, is considered in conservation programs. The conservation priority of a breed depends on its contribution to the overall genetic diversity of the species, in terms of the intrinsic genetic variation that it harbors and also of its relationship with other breeds. However, the estimation of the contributions of each of these two components to overall genetic diversity cannot be easily assessed. Besides, conservation goals in the short-term (avoidance of inbreeding) and long-term (adaptation to future environmental changes) should be considered when taking conservative decisions. A comprehensive analysis of Iberian goat breeds has been carried out to evaluate conservation priorities based on methodologies that account for within- or between-breed genetic diversity, or combinations of both. Based on genetic distinctiveness, breeds such as Palmera, Formentera, and Blanca Celtibérica were prioritized, whereas the maximum priority was assigned to Florida, Pirenaica, Retinta, and Moncaína breeds when focusing on within-breed diversity. Overall, combined approaches showed very little variation among breeds reflecting a history of extensive gene flow, partly due to transhumance and recent divergence. The main conclusion of our study is that these statistical analyses are useful, but conservation decisions must take into account other factors in addition to strict genetic diversity classification.

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29.1 Introduction

Domestic goats (*Capra hircus*) have traditionally played an important role in the animal husbandry sector of Portugal and Spain, producing high quality products under extensive conditions, often in marginal and forest lands. Even though goat numbers in both countries have declined sharply over the last decades, they still represent nearly 25% of the European goat census. Currently, there are 6 and 23 native breeds officially recognized in Portugal and Spain, respectively. In general, they are very well adapted to harsh local conditions, but their existence has been threatened by the progressive abandonment of agriculture in marginal areas and by uncontrolled crossbreeding with foreign transboundary breeds (Carolino et al. 2016; de Sierra et al. 2016). In Fig. 29.1 we show examples of individuals from two very distinct native goat breeds from Spain and Portugal, namely Palmera (top) from the Canary Islands and Preta de Montesinho (bottom) from the Northern region of Portugal, respectively.

Wild goats (*C. pyrenaica*) are also found in the Iberian Peninsula living in mountain areas. After decades of demographic decline due to severe population bottlenecks, the current risk status of this species is, according to the Red List criteria, the Least Concern, and the current population trend is increasing with about 50,000 individuals distributed in more than 50 subpopulations (http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T3798A10085397.en. Accessed May 10, 2017). Although hybridization between wild and domestic goats has been reported (Alasaad et al. 2012), a circumstance that represents an important issue for conservation purposes, major threats to Iberian wild goats are related to habitat fragmentation and poaching. Appropriate conservation polices could help to prevent further loss of emblematic populations, such as the extinction of the bucardo subspecies (*C. p. pyrenaica*), occurred in 2000.

Zooarchaeological and ancient DNA data suggest that the ancestor of domestic goats is the bezoar (*C. aegagrus*), which was domesticated approximately 10,000 years ago in at least two independent but contemporary Middle Eastern regions, i.e., the oriental Taurus and the Zagros mountains in Turkey and today's Iran, respectively, with substantial gene flow among European domestic goat populations since the Early Neolithic (Fernandez et al. 2006; Zeder 2008). Regarding domestic goats from the Iberian Peninsula, their origins and evolution are still under debate. It has been suggested that distinct goat populations from various geographic regions, namely from North Africa, have contributed to the Iberian gene pool (Pereira et al. 2005, 2009). In goats from the Canary Islands, an insular territory of Spain, autosomal DNA analysis supports an African influence at least for some breeds (Martínez et al. 2016). Genetic diversity and breed relationships based on microsatellite markers were reported for Portuguese native breeds by Bruno de Sousa et al. (2011), while Martínez et al. (2015) presented a comprehensive analysis of breeds from Portugal and Spain. Both studies revealed high levels of genetic diversity in Iberian goats and moderate differentiation among breeds, as expected given the historical migratory movements of small ruminants

Fig. 29.1 Individuals from two very distinct native goat breeds from Spain and Portugal, namely Palmera (top; provided by Juan Capote) from the Canary Islands and Preta de Montesinho (bottom; provided by António Sá, www.antoniosa.com) from the Northern region of Portugal, respectively

across the Iberian Peninsula associated with transhumance (Manzano and Casas 2010), a feature that promoted breed admixture.

The reduction in census and the corresponding increase in inbreeding in local goat populations have raised concerns about the best approaches to prevent genetic erosion, emphasizing the need for maintaining the genetic diversity that these breeds harbor as well as the unique adaptation features they have developed. When the goal is to maintain global genetic diversity and several breeds are candidates for conservation, priorities may have to be established based on the potential contribution of each breed to overall genetic diversity. Hence, the metapopulation is defined by the overall domestic goat population subdivided in breeds, i.e., subpopulations. Under this perspective, the contribution of a breed to both between- and within-breed genetic variation must be taken into consideration, when conservation decisions are implemented, and correctly weighted. However, to determine the relative weights of the within- and between-breed components of genetic variability is not simple at all, and several approaches have been proposed to address this issue (Toro and Caballero 2005).

Weitzman (1992) proposed a method where the marginal contribution of a breed to a metapopulation is assessed based on genetic distances among breeds, as the change in the expected diversity resulting from removing the breed from the metapopulation. In this case, only the contribution of the breed to the between-breed component of genetic diversity is considered and the conservation value will be likely assigned to geographically isolated breeds. To a certain extent, such assignment could be artifactual, being mainly due to founder effects, genetic drift or the accumulation of inbreeding. Thus, the need to further consider within-breed genetic diversity become clear, but it is not obvious which weights should be given to the between- and within-breed components of genetic diversity. Olivier and Foulley (2005) proposed an aggregate diversity procedure, where the fixation index F_{ST} and its complementary $(1-F_{ST})$ are used to weight the between- and within-breed components of genetic diversity, respectively. Other authors have suggested to assign arbitrary weights to these two components, for example attributing five times more weight to the between-breed genetic diversity (Piyasatian and Kinghorn 2003).

Alternative methods for establishing conservation priorities have been proposed, in an attempt to overcome the limitations of the procedures outlined above. These methods are known as the Core Set procedures, and they are designed to minimize global molecular coancestry in the metapopulation, by taking into account both the within- and between-breed kinship coefficients (Eding and Meuwissen 2001, 2003). Methodological variations of these procedures have also been proposed, e.g., using average molecular coancestries based on allele frequencies (Caballero and Toro 2002).

The multiple scenarios that can be envisaged when assessing the conservation value of breeds have been investigated in cattle (Cañon et al. 2011; Ginja et al. 2013) and pigs (Cortés et al. 2016), but no clear-cut conclusions were reached regarding the best combination of weights to be given to the between- and within-breed contributions to genetic diversity. Nonetheless, some of these approaches may be useful when investigating breed phylogenetic relationships and geographical patterns of genetic diversity distribution (Jordana et al. 2017). Besides genetic criteria, other aspects such as the environmental impact of a breed, as well as its social, cultural and historical role should also be taken into account when defining conservation priorities and strategies (Ruane 1999; Gandini et al. 2004).

In this chapter, we have selected a comprehensive sample of goat breeds from Portugal and Spain, including the Balearic and the Canary Islands (Spain), to evaluate different combinations of breed contributions to overall genetic diversity with the ultimate goal of establishing conservation priorities. We describe briefly the goat populations included in this analysis, and we also provide an overview of the methods available to prioritize these animal genetic resources for conservation. Finally, we discuss the results obtained with these different approaches, as well as their intrinsic limitations and outcomes.

29.2 Iberian Goat Breeds Selected for Conservation Analyses

The Iberian Peninsula is considered as a biodiversity hotspot, with local native breeds representing important reservoirs of genetic diversity. Spanish goats included in our conservation analysis were the following 19 officially recognized breeds: Azpi Gorri, Moncaína, Pirenaica, and Blanca de Rasquera from the North and North Eastern regions; two ecotypes of the same breed Blanca Celtibérica and Celtibérica, del Guadarrama, Retinta, and Verata from the Central region; Murciano-Granadina, Malagueña, Payoya, Florida, Blanca Andaluza (or Blanca Serrana), and Negra Serrana from the Southern region; Mallorquina, and Pitiüsa or Ibicenca from the Balearic Islands; and Majorera, Palmera, and two ecotypes of Tinerfeña (North and South) from the Canary Islands (Fig. 29.2). Additionally, two

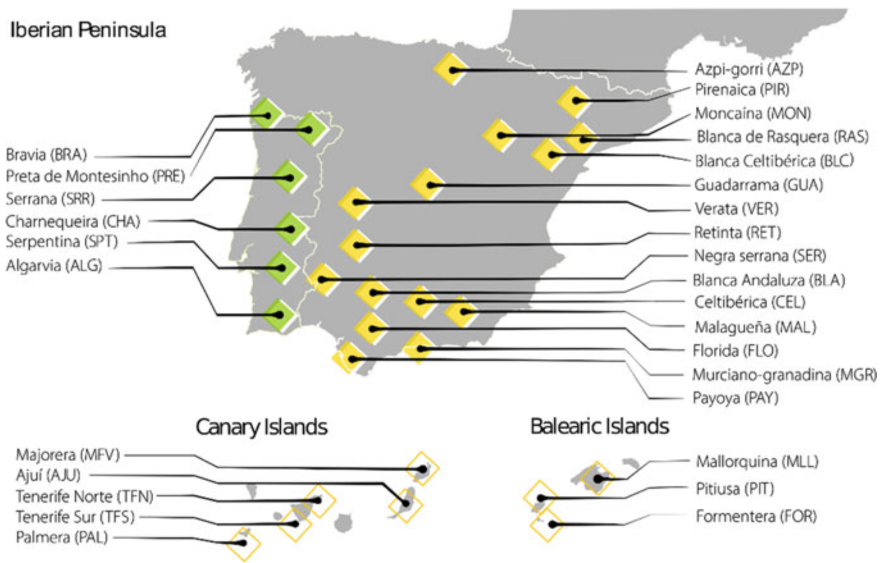

Fig. 29.2 Map showing the distribution of 29 native goat populations from Spain and Portugal

small isolated non-officially recognized goat populations were analyzed, namely Formentera and Ajuí from the Balearic and the Canary Islands, respectively. The populations Blanca Celtibérica and Celtibérica are two well-differentiated varieties of the same breed, each raised in different regions of the Iberian Peninsula (Fig. 29.2). The Northern and Southern ecotypes of the Tinerfeña breed are adapted to distinct climate conditions, i.e., while the former is raised in the humid and rainy areas of the Northern region of the Tenerife island, the latter is well adapted to the dry climate typical of the South (Martínez et al. 2006). The six Portuguese breeds analyzed here were the following: Bravia, Serrana and Preta de Montesinho from the Northern region; Charnequeira from the Central region; and Serpentina and Algarvia from the South of the country (Fig. 29.2).

Detailed information on the Iberian goat populations selected for conservation analyses is shown in Table 29.1, namely their geographic origin, breed names and acronyms, risk status as defined by the Food and Agriculture Organization of the United Nations—FAO, their census based on the number of breeding females (when available), and sample sizes. For comparison purposes, data on three transboundary commercial goat breeds, Saanen, Anglo-Nubian and Alpine, were also included in the analysis. A total of 970 goats were sampled by the BioGoat consortium (https://biogoat.jimdo.com/) according to recommended procedures for the collection of biological specimens (blood, semen or hair roots). Details on the sampling procedures and breed distributions were reported by Martínez et al. (2015). International and national regulations regarding experimental research on animals were strictly followed during collection procedures.

Considering the census of these breeds and the European Union regulation EC 445/2002, which establishes a number below 10,000 purebred breeding females as the threshold for classifying a goat breed as threatened of extinction, there are a total of 24 endangered Iberian native breeds (22 of which were included in our study; Table 29.1). Nevertheless, the majority of these goat populations are managed by well-organized breeder associations which keep and update herdbooks and carry out in situ conservation programs. Although Portugal and Spain have similar goat densities (5.8 animals per km^2), the origin of their caprine gene pools is quite different. In Spain, there are three million goats which belong almost entirely to native breeds or their crosses (de Sierra et al. 2016); while in Portugal the native goats represent only 12.5% of the national stock, and the majority of the animals has been crossed with transboundary commercial breeds (Carolino et al. 2016).

Iberian native breeds are traditionally raised in extensive agri-silvi-pastoral systems. Using poor natural pastures and marginal agroforestry lands, goats are able to optimize these resources thus contributing to the management of these ecosystems. Moreover, they play a crucial socio-economic role by contributing to the economic development of rural populations in less-favored regions. In general, Iberian native goat breeds have dual-purpose meat-milk abilities and they generate a large variety of cheese and meat products. Their certification by the European Union as quality products (http://ec.europa.eu/agriculture/quality/door/list.html. Accessed November 14, 2017) enhances the increased regional appreciation and commercial value of these breeds.

Table 29.1 Within-breed genetic diversity of 29 native goats from the Iberian Peninsula, the Balearic and Canary Islands, as well as three transboundary commercial breeds

Goat breed (acronym)	FAO risk status	Year	Census	n	H_e ± S.D.	H_o ± S.D.	MNA ± S.D.	Rt ± S.D.
Spain (continental part)								
Azpi Gorri (AZP)	Endangered	2016	1005[a]	40	0.654 ± 0.041	0.634 ± 0.017	6.79 ± 2.76	3.10 ± 0.75
Blanca Andaluza (BLA)	Endangered	2016	7334[a]	39	0.664 ± 0.042	0.628 ± 0.018	6.68 ± 2.69	3.18 ± 0.86
Blanca Celtibérica (BLC)	Endangered	2016	7288[a]	30	0.646 ± 0.046	0.577 ± 0.021	6.58 ± 2.32	3.11 ± 0.88
Blanca de Rasquera (RAS)	Endangered	2015	4617[a]	40	0.642 ± 0.051	0.588 ± 0.018	6.37 ± 2.95	3.07 ± 0.91
Celtibérica (CEL)	Endangered	2016	N.A.[a]	40	0.657 ± 0.044	0.618 ± 0.018	7.21 ± 2.72	3.16 ± 0.85
Florida (FLO)	Not at risk	2016	20,165[a]	40	0.695 ± 0.036	0.663 ± 0.017	7.47 ± 3.39	3.33 ± 0.77
Guadarrama (GUA)	Endangered	2016	7498[a]	11	0.643 ± 0.056	0.580 ± 0.038	4.68 ± 2.11	3.09 ± 1.01
Malagueña (MAL)	Not at risk	2016	39,420[a]	40	0.678 ± 0.043	0.623 ± 0.018	6.79 ± 2.95	3.24 ± 0.83
Moncaína (MON)	Endangered	2016	2809[a]	29	0.688 ± 0.049	0.626 ± 0.021	6.89 ± 3.00	3.35 ± 0.97
Murciano-Granadina (MGR)	Not at risk	2016	63,113[a]	40	0.650 ± 0.052	0.608 ± 0.018	6.53 ± 2.41	3.16 ± 0.89
Negra Serrana (SER)	Endangered	2016	4496[a]	40	0.652 ± 0.039	0.598 ± 0.018	6.37 ± 2.69	3.06 ± 0.73
Payoya (PAY)	Endangered	2016	529[a]	35	0.669 ± 0.042	0.677 ± 0.018	6.47 ± 3.20	3.19 ± 0.88
Pirenaica (PIR)	Endangered	2016	2117[a]	18	0.690 ± 0.045	0.654 ± 0.027	6.58 ± 2.57	3.34 ± 0.87
Retinta (RET)	Endangered	2016	1884[a]	15	0.688 ± 0.042	0.677 ± 0.029	5.61 ± 2.40	3.25 ± 0.84
Verata (VER)	Endangered	2016	8893[a]	28	0.652 ± 0.048	0.539 ± 0.022	6.53 ± 2.61	3.10 ± 0.86
Balearic Islands								
Formentera (FOR)	Endangered	2016	[†, a]	11	0.585 ± 0.052	0.541 ± 0.035	4.11 ± 1.59	2.77 ± 0.82
Mallorquina (MLL)	Endangered	2016	141[a]	40	0.634 ± 0.046	0.596 ± 0.018	6.68 ± 2.67	3.02 ± 0.83
Pitiüsa (PIT)	Endangered	2016	124[a]	40	0.647 ± 0.046	0.580 ± 0.018	6.63 ± 2.87	3.10 ± 0.85
Canary Islands								
Ajuí (AJU)	Endangered	–	1700[b]	40	0.648 ± 0.029	0.620 ± 0.018	6.05 ± 2.30	2.99 ± 0.66
Majorera (MFV)	Endangered	2016	9664[a]	40	0.635 ± 0.038	0.612 ± 0.018	6.53 ± 3.06	3.00 ± 0.75

(continued)

Table 29.1 (continued)

Goat breed (acronym)	FAO risk status	Year	Census	*n*	H_e ± S.D.	H_o ± S.D.	MNA ± S.D.	Rt ± S.D.
Palmera (PAL)	Endangered	2016	5949[a]	40	0.489 ± 0.040	0.493 ± 0.019	4.16 ± 1.68	2.34 ± 0.62
Tenerife North (TFN)	Not at risk	2016	11,625[a]	40	0.601 ± 0.038	0.575 ± 0.018	5.32 ± 2.36	2.80 ± 0.73
Tenerife South (TFS)				40	0.598 ± 0.038	0.583 ± 0.018	6.00 ± 2.69	2.84 ± 0.69
Portugal								
Algarvia (ALG)	Endangered	2016	4049[c]	30	0.677 ± 0.038	0.647 ± 0.020	6.37 ± 2.69	3.16 ± 0.75
Bravia (BRA)	Not at risk	2016	10,908[c]	39	0.628 ± 0.048	0.620 ± 0.018	6.05 ± 2.57	2.96 ± 0.78
Charnequeira (CHA)	Endangered	2016	4283[c]	29	0.683 ± 0.036	0.655 ± 0.020	6.37 ± 2.39	3.22 ± 0.77
Preta de Montesinho (PRE)	Endangered	2016	1107[c]	37	0.663 ± 0.045	0.563 ± 0.019	6.79 ± 2.86	3.15 ± 0.90
Serpentina (SPT)	Endangered	2016	4519[c]	30	0.666 ± 0.047	0.615 ± 0.020	6.89 ± 3.26	3.17 ± 0.91
Serrana (SRR)	Not at risk	2016	18,249[c]	29	0.669 ± 0.045	0.594 ± 0.021	6.95 ± 2.90	3.20 ± 0.84
Transboundary Breeds								
Alpine (ALP)	Not at risk	–	N.A.	35	0.703 ± 0.048	0.683 ± 0.018	6.74 ± 2.84	3.39 ± 0.87
Anglo-Nubian (ANG)	Not at risk	–	N.A.	40	0.638 ± 0.030	0.606 ± 0.018	5.79 ± 2.23	2.94 ± 0.60
Saanen (SAA)	Not at risk	–	N.A.	36	0.641 ± 0.054	0.602 ± 0.019	6.63 ± 2.48	3.11 ± 0.90

Geographic origin, breed names and acronyms, FAO risk status, census, sample sizes (*N*), observed (*Ho*) and unbiased expected (*He*) heterozygosities, and mean number of alleles (MNA) are shown; *S.D.* standard deviation; *N.A.* not applicable

Census Spanish goat breeds considering the number of registered animals (breeding females)

[a]https://aplicaciones.magrama.es/arca-webapp/flujos.html?_flowId=explotaDatosCensosRazaExcel-flow&_flowExecutionKey=e3s1 (Accessed November 14, 2017)

[b]https://doi.org/10.1186/s12711-015-0167-8 (Accessed November 14, 2017)

[c]Census Portuguese goat breeds considering the number of registered animals (breeding females)—http://dad.fao.org/ (Accessed November 14, 2017)

[†]Population registered in the same herdbook of Pitiüsa

29.3 Microsatellite Markers Suitable to Define Conservation Priorities in Goats

We used a microsatellite dataset previously generated by the BioGoat research consortium (Martínez et al. 2015; Ginja et al. 2017). A set of 19 short tandem repeat markers, recommended by the International Society for Animal Genetics (ISAG)/ Food and Agriculture Organization of the United Nations (FAO) Advisory Committee for genetic diversity studies in goats was genotyped, namely: *BM1329, BM6506, BM6526, BM8125, CRSM60, CSRD247, ETH010, ETH225, ILSTS011, INRA063, MAF065, MAF209, McM527, MM12, OarFCB048, OarFCB304, SPS115, SRCRSP08, and TGLA122*. Genotyping and allele standardization procedures have been validated and they were described in detail by Bruno de Sousa et al. (2011). Among the 19 markers, there was no evidence of null alleles segregating at high frequencies ($r > 0.2$) in any of the analyzed breeds (Bruno de Sousa et al. 2011; Martínez et al. 2015; Ginja et al. 2017). Although linkage disequilibrium was significant ($P < 0.0001$) for several short tandem repeat pairs, only the following three pairs appear to correspond to loci located in the same chromosome and thus are probably truly linked: *BM1329/SRCRSP08*, *BM8125/MAF209* and *BM8125/OarFCB048* (Ginja et al. 2017).

29.4 Brief Description of the Methods Used to Prioritize Animal Genetic Resources for Conservation Purposes

Conservation analysis depends on how the metapopulation is defined in order to investigate partial contributions of each sub-population to global genetic diversity. Furthermore, breed prioritization will vary considerably according to the relative importance of the within- and between-breed components of genetic diversity contributed by each breed, being the genetic relationships among breeds another important factor worth to mention. In this study, we included in a single metapopulation the 29 native goat populations from the Iberian Peninsula, the Balearic and the Canary Islands, as well as the three transboundary goat breeds. This allows to compare the impact on conservation estimates of prioritizing more diverse local goats *versus* highly selected commercial breeds.

For the conservation analyses, we followed the methods described by Cañon et al. (2011). Moreover, we categorized the different approaches as reported in Ginja et al. (2013), i.e., methods that aim at minimizing the overall kinship coefficient of the metapopulation (kinship-based methods); a method that reflects only the between-breed diversity component (Weitzman approach); and combined approaches that take into consideration both the within- and between-breed components of global genetic diversity.

Within-breed genetic diversity was characterized by using simple statistics obtained with GENETIX v. 4.05.2 (Belkhir et al. 1996–2004), namely observed (*Ho*) and unbiased expected (H_e) heterozygosities, and mean number of alleles (MNA) per breed. Additionally, FSTAT v. 2.9.3 (Goudet 2001) was used to estimate the *F* statistics per locus according to Weir and Cockerham (1984), and *P*-values were obtained based on 1000 randomizations. Allelic richness (R_t) over all loci for each breed was also calculated by rarefaction using this software and assuming a minimum of three animals per breed.

29.4.1 Minimizing Inbreeding of the Metapopulation: Kinship-Based Methods

We applied the Core Set methods of Eding et al. (2002) to investigate the population contributions to global diversity that account for within- and between-breed kinship coefficients by (1) minimizing the overall kinship coefficient of the metapopulation considered and (2) eliminating the genetic overlap between breeds included in the core set (Boettcher et al. 2010). Estimation of possible negative contributions by a given population is avoided through an iterative process that assigns a zero value to the lowest contribution and recalculates contributions after removal of that population.

In the absence of genealogical data, kinships were estimated from molecular data with different methods: (1) marker-estimated kinships (MEKs) obtained from individual genotypes, as described by Eding and Meuwissen (2001); (2) a variation of the MEK method based on log-linear regressions (Eding and Meuwissen 2003) obtained with the weighted log-linear model (WLM); (3) same as (2) but the log-linear regressions were obtained with the mixed model (WLMM); and (4) average molecular coancestries (*fm*) based on allele frequencies (Caballero and Toro 2002). MEKs were estimated with a macro function in Excel (Cañon et al. 2011), whereas the solutions for WLM and WLMM were obtained with matrices built with the MATLAB software (The MathWorks, Inc., USA). Average coancestry coefficients within (f_{ii}) and between (f_{ij}) each goat breed were calculated with the MOLKIN3 software (Gutierrez et al. 2005). Conservation analyses based on these similarity matrices (MEKs, WLM, WLMM and *fm*) were carried out with a FORTRAN program, as in Ginja et al. (2013). We derived pairwise kinship distances from the MEK coefficients following Eding et al. (2002) as: $d(i, j) = f_{ii} + f_{ij} - 2f_{ij}$. Kinship genetic distances were used to construct the neighbor-net phylogeny of the goat breeds with the SPLITSTREE4 4.12.6 software (Huson and Bryant 2006). Subsequently, breeds were sorted based on their genetic proximity to build contour plots of kinship coefficients (MEKs and *fm*) with the MATLAB software (The MathWorks, Inc., USA). In order to directly assess the importance of within-breed genetic diversity, partial contributions were also calculated as the proportional variation in the expected heterozygosity of the metapopulation after removal of each breed (PC_{He}).

29.4.2 Prioritizing Breed Differentiation: The Weitzman Approach

We calculated the partial contributions (PC_{Weitz}) of each goat breed to the total genetic diversity using the Weitzman method (Weitzman 1992). Here, Reynolds genetic distances (Reynolds et al. 1983) were used as a measure of between-breed diversity, while within-breed diversity was ignored. This approach estimates the reduction in length of the branches in a maximum likelihood phylogeny after removal of closely related populations, and PC_{Weitz} were calculated with the FORTRAN program developed by García et al. (2005). Pairwise Reynolds genetic distances were calculated with the POPULATIONS 1.2.32 software (Langella 1999–2002) and used to obtain a neighbor-net phylogeny of the Iberian goat breeds with the SPLITSTREE4 4.12.6 software (Huson and Bryant 2006).

29.4.3 Accounting for Within- and Between-Breed Genetic Diversity: Combined Approaches

Ideally, analyses of conservation priorities should take into account both within- and between-population genetic variability in order to make more accurate management decisions. We used three approaches to calculate contributions that combine these two levels of the global diversity of the metapopulation: (1) aggregate diversity (PC_{Fst}) (Ollivier and Foulley 2005), which uses Wright's F_{ST} to and its complementary ($1 - F_{ST}$) to weight the between- and within-population components of diversity, respectively, i.e., $PC_{Fst} = PC_{WEITZ} * F_{ST} + PC_{He} * (1 - F_{ST})$; (2) the approach of Piyasatian and Kinghorn (2003), which assigns the between-population component an arbitrary weight, i.e., five times higher than within-breed genetic diversity, such that $PC_{5:1} = PC_{WEITZ} * 0.833 + PC_{He} * (1 - 0.833)$; and (3) the method proposed by Caballero and Toro (2002) and Fabuel et al. (2004), which gives equal weights to within-population coancestries and genetic distances. In this case, Nei's minimum distances (Nei 1987) were used and calculations were carried out with the MOLKIN3 software (Gutierrez et al. 2005).

29.5 Results of the Different Conservation Approaches Applied to Iberian Goats

29.5.1 Within-Breed Diversity and Genetic Relationships of Iberian Goats

Summary statistics describing the genetic diversity of the Iberian goat breeds under analysis are shown in Table 29.1. Overall, genetic diversity was high ($H_o = 0.606 \pm 0.042$, $H_e = 0.648 \pm 0.041$, MNA = 6.29 ± 0.81, and $R_t = 3.08 \pm 0.20$), with Florida from south Spain showing the highest diversity ($H_o = 0.663 \pm 0.017$, $H_e = 0.695 \pm 0.036$, MNA = 7.47 ± 3.39, and $R_t = 3.33 \pm 0.77$). Endangered and isolated populations had the lowest diversities ($H_o < 0.550$, $H_e < 0.600$, MNA < 5.0, and $R_t < 2.8$), namely Palmera and Formentera from the Canary and Balearic Islands, respectively. Among the three commercial transboundary breeds analyzed, Saanen, Anglo-Nubian and Alpine, this latter had the highest diversity across all estimates ($H_o = 0.683 \pm 0.018$, $H_e = 0.703 \pm 0.048$, MNA = 6.74 ± 2.84, and $R_t = 3.39 \pm 0.87$). The levels of within-breed diversity can also be assessed using kinship coefficients with either the MEKs obtained from individual genotypes or average coancestries (*fm*) estimated from allele frequencies. In order to visualize both within- and between-breed kinships, contour plots were drawn by sorting populations according to their genetic proximity defined in the phylogenetic neighbor-net graph of kinship distances (Fig. 29.3, top). In the contour plots of Fig. 29.4, red areas represent highly inbred goat breeds i.e., Palmera (MEKs = 0.355 and *fm* = 0.517) and Formentera (MEKs = 0.268 and *fm* = 0.442). The Neighbor-Net of Reynolds genetic distances is shown in Fig. 29.3 (bottom). Goats from the Canary Islands grouped together in a tight net, with a possible influence from the transboundary Anglo-Nubian goats and more distant relationships with the remaining breeds. The Balearic goats were closely related to breeds from the Iberian Peninsula, but Formentera showed a more distant branch probably as a result of genetic drift. The Pirenaica and Moncaína breeds from the Pyrenees were entangled with the transboundary Saanen and Alpine goats. The remaining populations from Spain and Portugal showed weak differentiation, with a strong degree of interspersing, regardless of their geographical distribution, as previously described by Martínez et al. (2015).

29.5.2 Conservation Analyses in Iberian Goats

The results of the conservation analyses carried out for the set of breeds included in this study are shown in Tables 29.2 and 29.3. The kinship-based methods, namely MEKs, *fm* and WLM, resulted in a considerable number of goat breeds with a null contribution to overall genetic diversity, i.e., 27, 24 and 25 breeds, respectively (out of 32). In consequence, only highly prioritized breeds can be easily identified, i.e.,

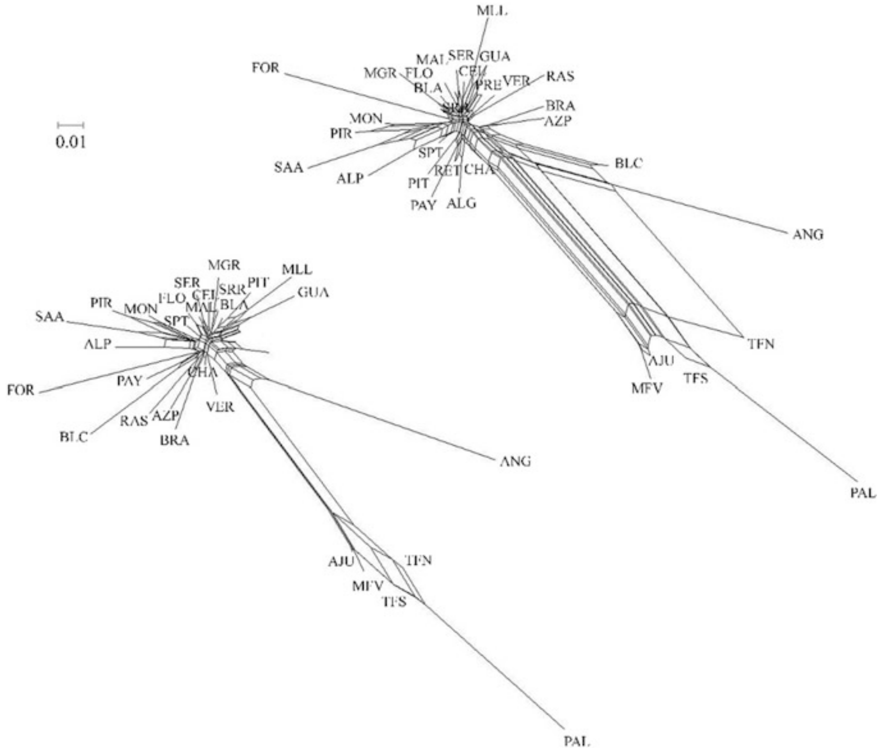

Fig. 29.3 Neighbor-net graph of kinship (top) and Reynolds (bottom) genetic distances depicting the relationships among 29 native goats from the Spain and Portugal, as well as three transboundary commercial breeds. Acronyms for breed names are defined in Table 29.1

Alpine, Ajuí, Anglo-Nubian, Pirenaica, Florida, Majorera, Moncaína, Blanca Celtibérica, and Retinta (0.085 < MEKs < 0.281, 0.014 < *fm* < 0.277 and 0.0.010 < WLM < 0.234) and the results were similar for the three methods. These results may reflect the high within-breed genetic diversity of these breeds, possibly as a result of crossbreeding. The WLMM method, which allows only one null contribution (in this case the Portuguese Bravia population), separated breeds more effectively and selected for conservation the breeds Anglo-Nubian, Alpine, Pirenaica, Majorera, Retinta, Ajuí and Moncaína goats (0.56 < WLMM < 0.104).

The proportional contribution of each breed to the average heterozygosity of the metapopulation resulted in many negative values (15 breeds). If these breeds were removed, this would lead to a 'gain' in diversity. In accordance with their inbred status (high within-breed kinship coefficients, f_{ii}), Palmera, Formentera, Tenerife South, Tenerife North, and Bravia breeds had the most negative PC_{He} values (between −0.798 and −0.103). This method ranked breeds displaying greater H_e values at a higher level, such as Alpine, Florida, Pirenaica, Retinta, Moncaína (0.191 < PC_{He} < 0.268). In contrast, Charnequeira, Malagueña, Algarvia, Payoya,

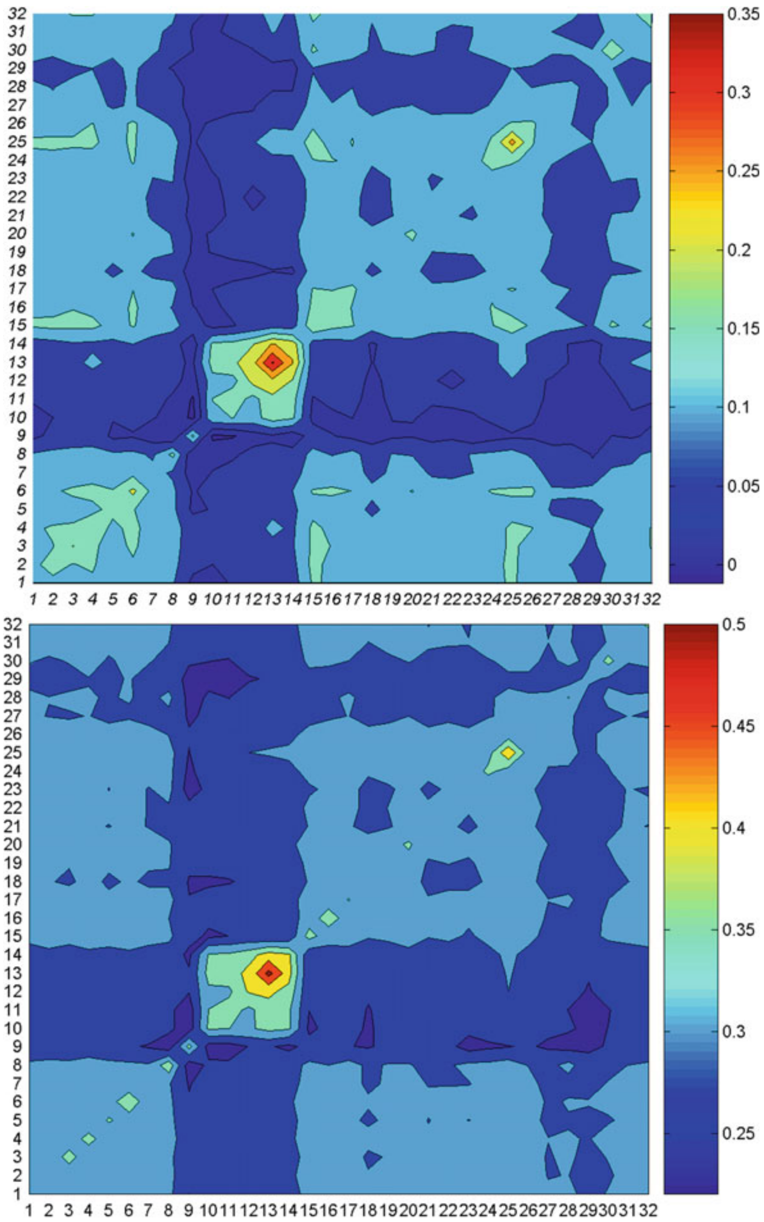

Fig. 29.4 Contour plots of marker-estimated kinships (MEKs; top) and average coancestries (*fm*; bottom) with goat breeds sorted according to their kinship phylogeny. Breed numbers correspond to the following: 1. Serrana, 2. Preta de Montesinho, 3. Blanca de Rasquera, 4. Verata, 5. Azpi Gorri, 6. Bravia, 7. Charnequeira, 8. Blanca Celtibérica, 9. Anglo-Nubian, 10. Ajuí, 11. Majorera, 12. Tenerife North, 13. Palmera, 14. Tenerife South, 15. Guadarrama, 16. Mallorquina, 17. Celtibérica, 18. Florida, 19. Malagueña, 20. Negra Serrana, 21. Algarvia, 22. Retinta, 23. Payoya, 24. Pitiüsa, 25. Formentera, 26. Serpentina, 27. Moncaína, 28. Pirenaica, 29. Alpine, 30. Saanen, 31. Blanca Andaluza, 32. Murciano-Granadina

Table 29.2 Contributions of 29 Iberian native and three commercial transboundary breeds to overall genetic diversity of goats according to: marker-estimated kinships (MEKs), average coancestries (*fm*), weighted log-linear model (WLM), weighted log-linear mixed model (WLMM), Weitzman formula (PC_{Weitz}), proportional variation of expected heterozygosity (PC_{He}), aggregate diversity (PC_{Fst}), and the Piyasatian and Kinghorn formula ($PC_{5:1}$)

Goat breed	Meks	*fm*	WLM	WLMM	PC_{He}	PC_{Weitz}	PC^{a}_{Fst}	$PC_{5:1}$
Azpi Gorri	0	0	0	0.016	0.024	2.50	0.225	2.09
Blanca Andaluza	0	0	0	0.014	0.074	1.15	0.161	0.97
Blanca Celtibérica	**0.085**	0.053	0	0.018	−0.018	**6.23**	**0.488**	**5.19**
Blanca de Rasquera	0	0	0	0.025	−0.035	3.08	0.218	2.56
Celtibérica	0	0	0	0.017	0.040	1.22	0.136	1.02
Florida	**0.099**	**0.110**	0	**0.040**	**0.227**	1.14	0.301	0.99
Guadarrama	0	0	0	0.003	−0.029	2.84	0.204	2.36
Malagueña	0	0	0	0.027	0.141	0.70	0.186	0.61
Moncaína	0	**0.058**	0.058	**0.056**	**0.191**	1.34	0.284	1.15
Murciano-Granadina	0	0	0	0.023	0.005	2.62	0.217	2.18
Negra Serrana	0	0	0	0.002	0.015	1.16	0.108	0.97
Payoya	0	0	0	0.044	0.100	2.79	0.318	2.34
Pirenaica	0	0.014	**0.187**	**0.070**	**0.202**	1.28	0.289	1.10
Retinta	0	0	**0.168**	**0.061**	**0.195**	0.76	0.240	0.67
Verata	0	0	0	0.009	0.014	2.05	0.179	1.71
Formentera	0	0	0	0.019	−0.320	**6.34**	0.220	**5.23**
Mallorquina	0	0	0	0.014	−0.074	3.03	0.178	2.51
Pitiüsa	0	0	0	0.015	−0.009	2.11	0.162	1.76
Ajuí	**0.281**	**0.202**	0.010	0.057	−0.007	0.68	0.049	0.57
Majorera	0	0.036	**0.169**	0.064	−0.072	1.20	0.031	0.99
Palmera	0	0	0	0.008	−0.798	**12.20**	0.255	**10.03**
Tenerife North	0	0	0	0.019	−0.239	2.99	0.023	2.45
Tenerife South	0	0	0	0.034	−0.254	1.65	−0.100	1.33
Algarvia	0	0	0	0.032	0.140	2.43	**0.325**	2.05
Bravia	0	0	0	0.000	−0.103	2.39	0.099	1.97
Charnequeira	0	0	0	0.015	0.166	1.17	0.248	1.00
Preta de Montesinho	0	0	0	0.024	0.070	0.95	0.142	0.80
Serpentina	0	0	0	0.018	0.082	0.90	0.148	0.76
Serrana	0	0	0	0.026	0.100	0.71	0.150	0.61
Alpine	**0.279**	**0.277**	**0.234**	**0.081**	**0.268**	3.00	**0.489**	2.54
Anglo-Nubian	**0.257**	**0.251**	**0.174**	0.104	−0.055	**11.51**	**0.882**	**9.58**
Saanen	0	0	0	0.043	−0.043	**5.07**	**0.371**	**4.22**

Values for the five breeds with the highest contributions are shown in bold

[a]Aggregate diversity was calculated as: $PC_{Fst} = PC_{WEITZ} * 0.081 + PC_{He} * 0.919$

Table 29.3 Average coancestries (f_{ii}) and Nei's genetic distances (D_{Nei}), contributions to global coancestry (f) and to average Nei's distance (D), global coancestry (GDT|i) and proportional loss or gain in genetic diversity after removing each breed, proportional contributions (PC) to a pool of maximum genetic diversity weighted and unweighted by sample sizes

Goat breed	f_{ii}	D_{NEI}	Contribution to f^a	Contribution to D^a	GDT|i	loss/gain (%)[a]	$PC^a_{weighted}$	$PC^b_{unweighted}$
Azpi Gorri	0.354	0.056	0.011	0.026	0.702	0.049	3.69	3.12
Blanca Andaluza	0.341	0.046	0.011	0.025	0.703	0.090	3.61	3.13
Blanca Celtibérica	**0.383**	0.077	0.009	0.019	0.702	−0.021	2.74	3.08
Blanca de Rasquera	0.366	0.060	0.011	0.026	0.703	0.066	3.65	3.08
Celtibérica	0.352	0.049	0.011	0.026	0.703	**0.110**	3.67	3.10
Florida	0.314	0.049	0.010	**0.027**	0.701	−0.104	**3.87**	**3.27**
Guadarrama	0.368	0.065	0.003	0.007	0.702	0.004	1.01	3.10
Malagueña	0.331	0.047	0.011	0.026	0.702	0.031	**3.76**	3.18
Moncaína	0.328	0.058	0.007	0.020	0.701	−0.085	2.78	**3.24**
Murciano-Granadina	0.358	0.055	0.011	0.026	0.703	0.084	3.66	3.10
Negra Serrana	0.358	0.051	0.011	0.026	0.703	**0.135**	3.64	3.08
Payoya	0.340	0.057	0.009	0.023	0.702	−0.033	3.30	3.18
Pirenaica	0.352	0.067	0.005	0.012	0.702	−0.041	1.69	3.18
Retinta	0.333	0.050	0.004	0.010	0.702	−0.004	1.41	3.19
Verata	0.365	0.52	0.008	0.018	0.703	**0.103**	2.53	3.05
Formentera	**0.442**	0.090	0.004	0.007	0.702	0.038	0.94	2.88
Mallorquina	0.374	0.063	0.011	0.026	0.703	0.075	3.63	3.07
Pitiüsa	0.361	0.054	0.011	0.026	0.703	**0.102**	3.65	3.08
Ajuí	0.360	0.088	0.010	**0.027**	0.700	−0.228	**3.82**	**3.23**
Majorera	0.372	**0.092**	0.010	**0.027**	0.701	−0.206	**3.78**	3.20
Palmera	**0.517**	**0.145**	**0.014**	0.023	0.702	0.025	3.30	2.79
Tenerife North	**0.405**	**0.094**	**0.012**	0.025	0.702	−0.045	3.62	3.06

(continued)

Table 29.3 (continued)

Goat breed	f_{ii}	D_{NEI}	Contribution to f^a	Contribution to D^a	GDT|i	loss/gain (%)[a]	$PC^a_{weighted}$	$PC^b_{unweighted}$
Tenerife South	**0.409**	**0.094**	**0.012**	0.025	0.702	−0.025	3.60	3.04
Algarvia	0.333	0.055	0.008	0.020	0.702	−0.044	2.85	3.21
Bravia	0.379	0.059	**0.012**	0.025	0.703	**0.148**	3.49	3.02
Charnequeira	0.328	0.046	0.008	0.019	0.702	0.012	2.74	3.19
Preta de Montesinho	0.348	0.048	0.010	0.024	0.703	0.093	3.40	3.11
Serpentina	0.345	0.047	0.008	0.019	0.703	0.070	2.77	3.12
Serrana	0.344	0.047	0.008	0.019	0.703	0.060	2.68	3.12
Alpine	0.311	0.061	0.008	0.024	0.701	−0.210	3.45	**3.33**
Anglo-Nubian	0.368	**0.115**	0.009	**0.028**	0.698	−0.514	**3.93**	**3.32**
Saanen	0.368	0.074	0.010	0.024	0.702	−0.071	3.34	3.14

Values for the five breeds with the highest contributions are shown in bold, except for contributions to f and D for which only the two highest values are in bold
[a]average coancestries weighted by sample sizes; [b]average coancestries estimated by ignoring sample sizes; mean coancestry within-breeds, $f = 0.363$; mean Nei's minimum distance in the metapopulation, $D = 0.066$; mean coancestry in the metapopulation, $f = 0.298$; global genetic diversity of the metapopulation, GDT = 0.702

and Serrana breeds were associated with intermediate contributions ($0.100 < PC_{He} < 0.166$).

The Weitzman approach prioritizes highly differentiated breeds (i.e., those with displaying large genetic distances with regard to their counterparts) based only on their contribution to between breed genetic diversity. In this case, breeds with the highest contributions ($5.07 < PC_{Weitz} < 12.20$) were Palmera, Anglo-Nubian, Formentera, Blanca Celtibérica, and Saanen followed by Blanca de Rasquera, Mallorquina, Alpine, Tenerife North, Guadarrama, Payoya, Murciano-Granadina, Azpi Gorri, Algarvia, Bravia, Pitiüsa, and Verata ($2.05 < PC_{Weitz} < 3.08$). The Preta de Montesinho, Serpentina, Retinta, Serrana, Malagueña and Ajuí breeds had the lowest contributions amongst all breeds (<1%).

The combined approach of Ollivier and Foulley (2005) (PC_{Fst}), which takes into account both within- and between-breed components of the genetic diversity, seems to provide more balanced solutions. In this case, the between-breed component (i.e., PC_{Weitz}) was weighted by the overall F_{ST} value of 0.081 obtained for the metapopulation of goat breeds. The PC_{Fst} approach prioritized breeds that also ranked high with the PC_{He} and the kinship-based methods (i.e., with high within-breed diversity), namely Alpine, Algarvia, Florida, Pirenaica and Moncaína ($0.284 < PC_{Fst} < 0.489$). Nevertheless, several breeds prioritized by PC_{Weitz} (i.e., with greater genetic distances) also had high PC_{Fst} estimates, particularly Anglo-Nubian ($PC_{Fst} = 0.882$), Blanca Celtibérica ($PC_{Fst} = 0.488$) and Saanen ($PC_{Fst} = 0.371$) and Payoya ($PC_{Fst} = 0.318$), while goat breeds Palmera, Charnequeira, Retinta, Azpi Gorri, Formentera, Blanca de Rasquera, Murciano-Granadina, and Guadarrama had intermediate conservation values ($0.200 < PC_{Fst} < 0.260$). Overall, the $PC_{5:1}$ method gave similar results, in terms of breed ranking for conservation, with regard to those obtained with the Weitzman approach, implying that higher between-breed genetic diversity was favored.

The results of the combined approach of Caballero and Toro (2002) and Fabuel et al. (2004) are shown in Table 29.3. The isolated Palmera breed from the Canary Islands made the greatest contribution to global coancestry (f, 0.014) because its within-breed coancestry was quite high ($f_{ii} = 0.517$). The Tenerife South, Bravia, and Tenerife North breeds made high contributions to f (0.012) as a consequence of their high f_{ii} values ($\sim$0.400) and also to their relatively low within-breed genetic diversity ($H_e \approx 0.600$). Although the Formentera, Blanca Celtibérica, Guadarrama, and Anglo-Nubian breeds had high f_{ii} values (between 0.368 and 0.442), their mean genetic distances were also large (between 0.065 and 0.115). Thus their contributions to f, obtained from the difference between f_{ii} and D_{Nei}, were less significant (between 0.003 and 0.009). Proportional contributions to genetic diversity were identical across goat populations ($PC_{weighted} \approx 3$), with only Formentera, Guadarrama, Retinta and Pirenaica ranking low ($PC_{weighted} < 2$). Nevertheless, lower estimates can be biased as a consequence of the rather small sample size of these populations (N < 18). Indeed, when the proportional contributions to genetic diversity are estimated by ignoring sample sizes ($PC_{unweighted}$), only the Formentera breed maintains its low ranking. The proportional contribution of each breed to a pool of maximum genetic diversity showed very little variation among goat breeds

($\sim$0.700), but removal of the Anglo-Nubian, Ajuí, Alpine, and Majorera breeds from the metapopulation of goats caused the greatest loss in total genetic diversity (between −0.5 and −0.2%).

29.6 Limitations and Outcomes of Different Conservation Approaches When Prioritizing Iberian Goats

Organized programs for the conservation of Iberian goat breeds exist in Portugal and Spain, nonetheless goat populations have declined in both countries and most breeds are currently classified as endangered in the Domestic Animal Diversity Information System hosted by the FAO (http://dad.fao.org/ Accessed November 14, 2017) Ideally, a conservation program should target several breeds even though financial resources are limited. For this reason, conservation priorities need to be established. Factors that should be considered when defining such priorities include the importance of a breed in terms of genetic uniqueness but also its own genetic diversity, and other aspects such as adaptation to specific environments, display of unique phenotypes, cultural and historical value, contribution to environmental sustainability, etc. (Ruane 2000). Once priorities have been established, different conservation strategies can be applied, namely in situ or ex situ in vivo preservation, and cryoconservation, which differ in their ability to capture and maintain genetic diversity as well as to address the different aspects considered in the rationale for conservation (FAO 2012a). Knowledge of the population structure of a livestock species in terms of distribution of genetic variability within and between breeds is a key factor for establishing conservation priorities and strategies (Caballero and Toro 2002) aiming to maintain genetic diversity for the benefit of the future generations (Notter 1999).

Previous studies confirmed that Iberian goat breeds have retained high levels of genetic diversity and, with the exception Canarian goats, they are weakly differentiated as a consequence of extensive gene flow due to transhumance and common ancestry (Cañon et al. 2006; Bruno de Sousa et al. 2011; Martínez et al. 2015). It has also been claimed that long-distance cyclic migrations, the great mobility of goats, and recent divergence are the main causal factors that explain the poor phylogeographic structure detected with mitochondrial markers in the Iberian Peninsula (Azor et al. 2005; Pereira et al. 2005) and at a worldwide scale (Luikart et al. 2001; Fernandez et al. 2006). In order to preserve breed identities, reduce inbreeding, and maintain overall biodiversity when prioritizing breeds for conservation it is important to characterize both within- and between-breed genetic variability. For example, genetic substructure has been identified in several goat breeds from the Iberian Peninsula, such as the Spanish dairy goat Murciano-Granadina breed and the Portuguese Serrana breed (Martínez et al. 2015). While in the first case substructure results from breeding decisions to keep separate herds, the latter is associated with ecotypes raised in distinct geographic regions. Because several of these ecotypes may harbor specific adaptive traits, it is relevant that management strategies for breed conservation take into account the existence of weak population structure as well as the specificities of breed demographic histories (Cañon et al. 2011). As expected, conservation priorities of the goat populations analyzed here depended on whether the method used to set them placed more emphasis on the contribution of each breed to the within- or the between-breed components of genetic diversity. Thus, if the focus was on breed distinctiveness, priority was given to breeds such as Palmera, Anglo-Nubian, Formentera, Blanca Celtibérica, and Saanen, whereas if the focus was on within-breed diversity, priority was given to Alpine, Florida, Pirenaica, Retinta, and Moncaína breeds. Finally, the contribution to genetic diversity based on average coancestries combined with genetic distances showed very little variation among goat breeds (Table 29.3). This feature probably reflects the extensive levels of admixture observed across these breeds, in a way that all breeds made similar contributions to the overall genetic diversity of the metapopulation.

The difficulties and challenges associated with the choice of the best method to prioritize breeds for conservation decisions have been broadly discussed (Toro et al. 2009; Meuwissen 2009; Caballero et al. 2010; Cañon et al. 2011; Bruford et al. 2015). For instance, previous studies focused on cattle indicated that breeds with a small census, which are often inbred, will be selected for conservation when the emphasis is placed on the between-breed component of genetic diversity (Bennewitz et al. 2006; Consortium 2006; Ginja et al. 2013). This outcome invalidates the use of the Weitzman approach, which is based on genetic distances, as a single criterion for breed prioritization. In contrast, higher ranking will be given to large, and possibly crossbred, populations when the emphasis is placed on the within-breed component (Meuwissen 2009). This pattern of genetic variation distribution is typical of subdivided populations in which the global genetic diversity of the species is maintained at the cost of a loss in the genetic variability of the subpopulations. Overall, the choice of the most appropriate method to prioritize breeds for conservation decisions is determined by whether it is important to maintain genetic diversity in either the short- or long-terms. For example, if the focus is on short-term objectives, the emphasis should be placed on maintaining high levels of heterozygosity, while if the goal is focused on long-term goals, the main stress should be placed on allelic richness and breed differentiation (Medugorac et al. 2011). In several goat breeds, selection for adaptation to specific environments has played a major role in their genetic composition. Thus, maintaining high levels of allelic diversity is a key element for the long-term preservation of these breeds as well as for ensuring their ability to cope and adjust to future environmental changes. Maximizing heterozygosity may be a wrong approach, as highly crossbred breeds are often valued for conservation under these circumstances. Statistical analyses aimed at making conservation decisions are useful but they should be considered carefully, since there is a risk of ignoring certain breeds or breed groups in conservation programs. Thus, such decisions must take into account additional factors, including the results of other population genetics methods such as cluster and admixture analyses as well as other factors in addition to strict genetic diversity priorities.

The establishment of conservation decisions exclusively based on 'neutral' genetic markers, such as microsatellites, can fail to take into account important genetic information associated with phenotypic variation (e.g. morphology or production traits), disease resistance, and other adaptive traits. Whole-genome approaches using next-generation sequencing have been developed for livestock species, including goats, which allow for the identification of genomic regions under selection (Song et al. 2016; Dong et al. 2015; Wang et al. 2016). Because a high number of genetic markers (e.g., SNPs) in coding and non-coding genomic regions can be used in population genomics, these approaches can provide more reliable estimates of inbreeding coefficients, particularly when pedigree information is lacking, as well as more accurate measures of the genetic diversity and of the conservation value of the breeds under study (Hall et al. 2012). Nonetheless, it is necessary to carefully evaluate the usefulness of the analyses described here to define conservation priorities on the basis of whole-genome SNP data. This is even more important when prioritizing genetically distinct native breeds, because commercial SNPs may not be informative as these breeds were not considered when the marker arrays were developed (FAO 2012b). Additionally, genome sequencing will be extremely useful to identify genomic regions under selection in Iberian goats as well as in other breeds.

29.7 Concluding Remarks

Prior to the large scale application of the conservation principles discussed here, it is essential to reach a consensus on the specific criteria to be used in the definition of such priorities. Besides factors directly associated with genetic diversity, which have been the main subject of our discussion, other aspects such as the contribution of a breed to food security and economic return, demography and risk status, the existence of unique traits or specific adaptation features, historical and cultural values, the contribution to sustainable development and environmental balance, etc., should be also taken into account when defining conservation priorities (Ruane 2000). The final outcome may be an index combining the different ranking criteria weighted appropriately in order to establish conservation priorities, as outlined by the FAO (2012a, b). Moreover, high-throughput genetic markers, such as SNPs, may detect additional genetic factors related to breed differentiation, especially those underlying adaptation and production traits, and they should be further investigated for their potential applications in conservation genetics.

Recently and as a result of the last conference of the European Science Foundation Genomic Resources program (https://livestockgenomics.wordpress.com/2014/04/15/home/), several problems and challenges for the effective conservation of livestock genomic resources until 2020 were summarized in a publication (Bruford et al. 2015). One of the major conclusions was the following: "Despite the fact that the livestock sector has been relatively well-organized in the application of genetic methodologies to date, there is still a large gap between the current state-of-the-art in the use of tools to characterize genomic resources and its application to many non-commercial and local breeds, hampering the consistent utilization of genetic and genomic data as indicators of genetic erosion and diversity" (Bruford et al. 2015).

In any case, the consensus is that the best way to ensure the survival of a breed is to make it profitable and appealing to producers. The development of sustainable utilization and organized mating programs of goat breeds, and the added value resulting from their products, could make a major contribution towards their survival in the future.

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