A review on goats in southern Africa: an untapped genetic resource

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Highlights

• Number of southern African goats increased over the last two decades.

• Many non-descript, indigenous goat populations with moderate genetic diversity.

• Genetic improvement in harsh environments mainly due to natural selection.

• Lack of animal recording is a major limiting factor in breeding programs.

• Genomic technology could benefit genetic improvement within a formal strategy.

Abstract

Goats migrated to southern Africa approximately 500 to 600 years ago, and have since fulfilled a crucial role in both ceremonial and food security aspects of African cultures. The increasing numbers of goats in this region indicate that their relative importance has not diminished over time, and that they still contribute significantly to the world population. Southern Africa hosts a large number of poorly described indigenous meat goat populations, which largely lack both phenotypic and genetic characterization, as well as three well-described locally developed commercial breeds namely the Boer goat, Kalahari Red and Savanna breeds. Characterization studies on these populations indicated sufficient levels of genetic diversity to sustain genetic improvement. Within the challenging environment and production system where these goats survive, most genetic improvement has however occurred on an adaptive level through natural selection. A lack of well-formulated breeding objectives, animal recording and infrastructure further limited genetic improvement reported in this species. The role that genomic tools can play to attain future genetic progress will depend on national and regional selection strategies, as well as training and capacity building in the field of animal breeding and genetics.

Keywords: characterization, indigenous, production, recording, selection, smallholder

1. Introduction

The bezoar (*Capra aegagrus*) has been widely accepted as the common ancestor of the domestic goat (*Capra hircus*) (Amills et al., 2017). This species was one of the first wild herbivores to be domesticated (Pereira et al., 2009) approximately 10 000 years ago in the Fertile Crescent (Naderi et al., 2008). The domestication of goats was probably a gradual process, with the animals first being hunted and later kept and managed by humans as a constant food source. Three main matrilineal lines (Fernandez et al., 2002; Gentry et al., 2004) and six divergent haplogroups (Amills et al., 2017) have been identified based on genetic analyses. Lineage A (from the Fertile Crescent region) is estimated to have started expanding 10 000 years ago, predominates across the globe and is thought to be the origin of most modern goats, as it is represented in more than 90% of goats worldwide. Lineage B seems limited to breeds from southern Asia and Lineage C has not been convincingly confirmed.

After domestication, the portable-sized goats spread rapidly into Europe owing to trade, warfare, thievery and human migration (Pereira et al., 2009). By 6 500 before present (BP), farming communities have been established in Greece and Bulgaria, followed by settlements in Britain and

Scandinavia by 4 000 BP. Goat herders spread into North Africa by two main routes, either by crossing the Sinai Peninsula or by navigating the Mediterranean sea (Amills et al., 2017). Evidence of goats have been found at pastoral Neolithic sites in Northern Kenya, dating back to approximately 4 000 years BP (Robbins et al., 2005). The subsequent spread of livestock into southern Africa has posed a question to many researchers.

It is widely consented that Botswana might have served as a major point of access for the dissemination of livestock into southern Africa. Accelerator mass spectrometry (AMS) results suggest the arrival of livestock at Toteng (Botswana) approximately 500 to 600 years BP (Robbins et al., 2005). The livestock were most likely kept by the ancestors of the modern Khoisan-speakers, and were herded in addition to the more common practices of hunting, gathering and fishing. The lag in the timeframes between goats appearing in the North and East vs. the South of Africa can possibly be explained by the presence of a disease-prone belt North of Botswana. Bovine malignant catarrhal fever, East Coast fever and trypanosomiasis inhibited the spread of the animals southward, as this would have created an effective block of especially cattle movement (Robbins et al., 2005). Relatively small changes in the climate could have affected the efficiency of i.e. the tsetse fly, allowing the initial spread of animals southward and thereafter their rapid proliferation.

Goats have played a continuous role in modern agriculture, although they have differing functions in various cultures. On the one hand they are a reliable source of meat, milk, skins and fibre, but they are also kept for their role in traditional and cultural ceremonies (e.g. burials and weddings) (Mdlala et al., 2017; Mhlanga et al., 2018) and are still regarded as almost sacred in many cultures. In the African context, goats do not confer the same status to farmers as cattle that represent wealth and symbolizes power (Sikhondze, 2008). However, they play a significant role in terms of food security, liquid capital and as sacrifices in cultural ceremonies. The dual system of southern African agriculture, characterized by high input commercial systems on the one hand vs. smallholder and communal farmers on the other, are particularly evident in goat farming. Some locally developed meat goat breeds (e.g. the Boer goat, Kalahari red and Savanna) are farmed with on a commercial level, but indigenous goats represent over 95% of small stock in Africa, and of these, approximately 90% are kept in rural households (Monau et al., 2018). As such, this review will focus on indigenous meat goats, their contribution to African agriculture and the genetic improvement (or lack thereof) that these populations has attained during the past few decades.

2. Goat resources of Southern Africa

The goat population has increased dramatically worldwide by 75%, from approximately 589 million animals in 1990 to 1 034 million in 2017 (FAOSTAT, 2019). The number of goats in Africa has increased by approximately 150% during the same period (Table 1), and this continent currently holds approximately 41% of the world's goat population. This rise in African goat numbers supports Dubeuf & Boyazoglu's (2009) theory that an increase in goat numbers is most likely due to a growing need for subsistence farming, rather than due to the development of the species.

Table 1 Numbers of goats in southern Africa, relative to Africa and the world from 1990 to 2017 (FAOSTAT, 2019)

	Number of goats (millions)						
Region	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2017**
Southern Africa	18.4	20.8	24.8	26.5	29.8	30.7	33.4
Africa	176	200	236	280	332	401	422
Worldwide	589	673	751	839	910	1 000	1 034

Even though the number of goats kept in southern African countries are small relative to the numbers found worldwide, they still play an integral part in reducing poverty and increasing food security, especially in subsistence farming. Numbers of goats in the region has increased steadily over the past three decades (Figure 1), with especially Angola (1.5 to 4.5 million), Malawi (0.9 to 7.7 million), Mozambique (2.0 to 3.9 million), Zambia (0.5 to 2.7 million) and Zimbabwe (2.5 to 4.8 million) showing significant rises (FAOSTAT, 2019). Eswatini (formerly Swaziland), Lesotho and Namibia's goat populations remained relatively constant, with decreases observed only in Botswana and South Africa. Malawi currently contributes approximately 23.1% to the southern African goat population, followed by South Africa with 16.2%, and Angola and Botswana with approximately 14% each.

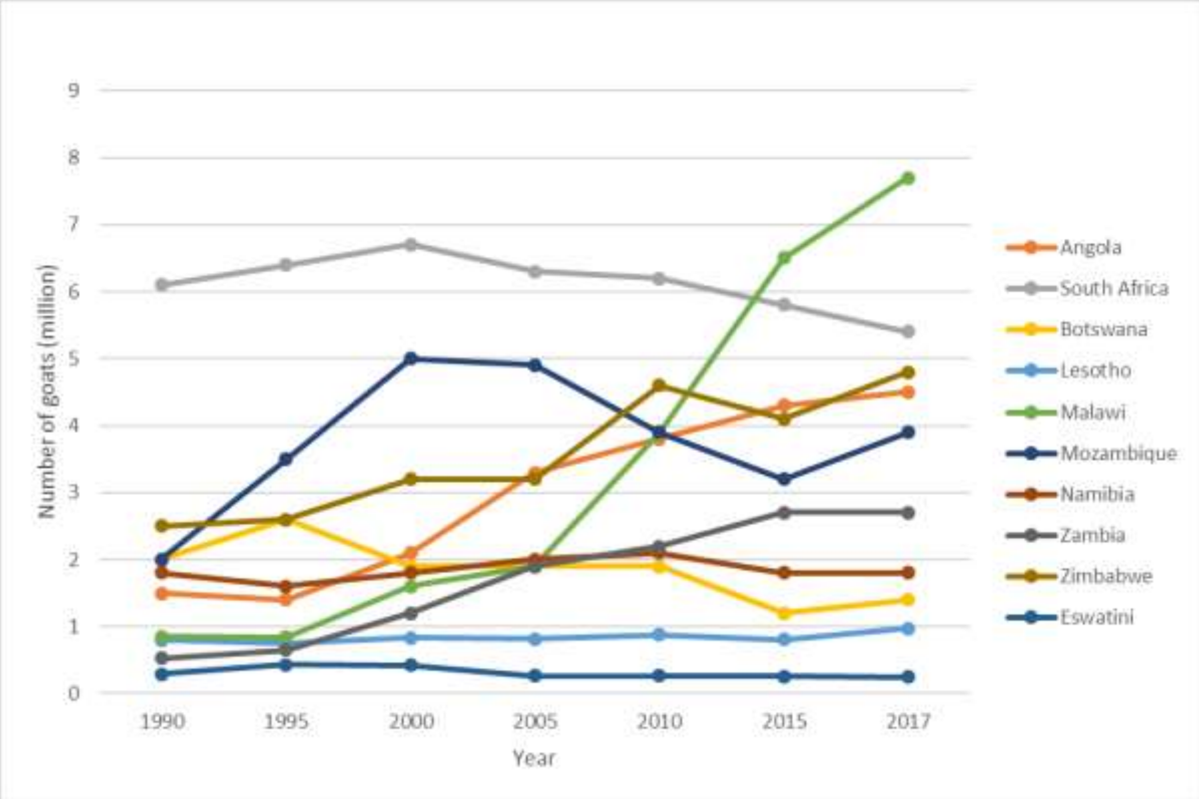

Figure 1 Trends in numbers of goats from 1990 to 2017 in southern Africa (FAOSTAT, 2019)

Numerous breeds and unspecified ecotypes contribute to the more than 33 million goats found in southern Africa. Indigenous goats are mostly characterized based on coat colours and patterns, as well as other morphological characteristics (e.g. ear shape, horn types, horn lengths etc.). Populations are commonly identified according to their geographical region or tribe (Visser & van Marle-Köster, 2018). Although goats are multi-purpose, they are mostly kept for meat production in subsistence farming systems. Table 2 provides a summary of the major meat goat breeds and populations found in southern African countries. Most of the populations are only described in terms of frame size, coat colour and ear type, without any unique characteristics or production levels being defined. A large number of the populations share phenotypic descriptions, and could probably be classified as similar, except for their geographic locations. These indigenous populations are mainly non-descript and largely lack comprehensive phenotypic and genetic characterization.

Table 2 The major indigenous meat goat breeds found in southern Africa (DAGRIS, 2019)

Breed	Description	Country
Angola dwarf	Similar to the small East African meat goat.	Angola
Tswana	Relatively large size, flat forehead; multi-coloured medium sized with long lopping ears, short coarse hair.	Botswana, Zambia, Zimbabwe
Small East African	Heavyset formation, short-coated goat; black-and-white colour pattern, less frequently brown or black coat.	Lesotho
Malawi	Relatively small; coat colour is variable, with black, black-brown, brown-red and white being very common.	Malawi
Damara	Long, wide and pendulous ears; coat hair is commonly short, and usually white, red-and-white or brown-and-white.	Malawi
Pafuri	Large body size; lopped or semi-lopped ears; males and females are bearded; variable coat colour; short coat hair.	Mozambique
Landim	Relatively large; variable coat colour, but commonly dark brown, black, pied, white, yellow and mixed; coat hair usually short and fine.	Mozambique
Nguni type (Mbuzi)	Relatively large; flabby ears; short coat hair (males can have long hair on upper part of the extremities); variable coat colour.	Namibia
Hottentot	Display characteristics of the Damara	Namibia
Damara	Long, wide and pendulous ears; short coat hair, and usually white, red-and-white or brown-and-white in colour.	Namibia
Small East African	Heavyset, short coated goat. black-and-white colour pattern, less frequently by a brown or black coat.	Namibia
Northern Cape speckled	Speckled goats with lob ears	Namibia, SA
Eastern Cape lob-eared	Multi-coloured with lob ears	Namibia, SA
Kunene-type / Kaokoland	Multi-coloured with lob ears	Namibia, SA
Tankwa (feral)	High degree of variation in colour and appearance; longer haired; coat colours include black, red, white and grey, mixed with spotted, dappled and tricolour.	SA
Nguni	Fairly large in body size; flabby ears; short coat (males can have long hair on upper part of the extremities); black, white, yellow, grey in plain or mixed pattern coats	SA, Swaziland
Swazi	Relatively large in size; medium-long, broad and lopped ears are; variable coat colour but whole colours of grey, black and white predominate.	SA, Swaziland
Zulu	Relatively large in size, medium long, broad and lopped ears; coat colour is variable, variable coat colour but whole colours of grey, black and white predominate.	SA
Small East African	Heavyset formation, short-coated goat. Black-and-white colour pattern, less frequently by a brown or black coat.	Zambia
Berber	Variations in coat colour, form and length of the ears, form and shape of the horns and hair length.	Zambia
Matebele	Large body size; similar toTswana goats.	Zambia, Zimbabwe
Mashona	Small framed type goat	Zimbabwe

Three commercial goat breeds which were developed from indigenous populations in South Africa has spread throughout Africa, and indeed globally. The locally developed SA Boer goat, Kalahari Red and Savanna are large-framed breeds that have undergone strict selection for superior growth and larger carcasses (Mohlatlole et al., 2015), and are thus preferred in terms of production potential and are often used in cross-breeding programs. However, they do not always meet the needs of smallholder and subsistence farmers due to higher maintenance requirements and less adaptive traits (Casey and Webb, 2010).

3. Phenotypic and genetic characterization

Conservation as well as sustainable utilization of indigenous genetic resources are dependent on accurate characterization. Phenotypic characterization of goats is one of the first, relatively easy steps of improving productivity (Selolo et al., 2015). This will however still not reflect the genetic similarities or differentiation found between the numerous indigenous populations, and therefore genetic characterization would be the logical next step.

Limited phenotypic characterization of goat populations has been performed previously, and usually formed part of broader studies investigating smallholder production systems. The indigenous Tswana goat of Botswana have been investigated on a phenotypic level by several authors. Nsoso et al. (2004), Baleseng et al. (2015) and Monau et al. (2018) performed phenotypic characterization on this breed where several geographically separated populations were included and a range of morphometric measurements and phenotypes were recorded. Limited differentiation between populations was observed based on these phenotypes by both Baleseng et al. (2015) and Monau et al. (2018). Nsoso et al. (2004) reported higher levels of distinctiveness, probably due to more extensive sampling covering geographical extremes within the country. In the study by Pieters et al. (2009) which aimed to use morphometric traits to distinguish between the three commercial SA goat breeds, differences in phenotypes were also found to be largely insignificant. In agreement with this, Mdlaldla et al. (2017) reported low morphometric differentiation between indigenous populations after phenotypic characterization of the commercial SA breeds, as well as four indigenous populations (Tswana, Venda, Xhosa and Zulu) and the feral Tankwa goat. Contrary to these results, Selolo et al. (2015) reported sufficient discriminating power in a study including goats from three agro-ecological zones in Limpopo province (South Africa). It can be concluded that although the priority for phenotypic characterization remains high in an effort to describe indigenous populations, it has limited application in terms of differentiating between breeds. To be able to identify populations and breeds as being unique, genetic characterization is needed.

Such efforts to characterize southern African goat breeds on a genetic level have been limited to a small number of studies. Chenyambuga *et al.* (2004) included the Ndebele and Pafuri goats of southern Africa in their genetic characterisation study of sub-Saharan goats using microsatellites. The breeds clustered according to their geographic origin, with the two southern African breeds clearly separated from the other African breeds in both PCA and phylogenetic analyses. Results obtained by Huson et al. (2014) using SNP analyses in African goats corresponded with this, with South African goats showing clear differentiation from North Africa goat populations. Geographic isolation probably lead to this well-defined genetic differentiation between southern African goats and their other African counterparts.

The three most common commercial meat goat breeds, namely the SA Boer goat, Kalahari Red and Savanna together with three indigenous populations of different geographical origin, were investigated by Visser et al. (2004) using microsatellites. Moderate to high genetic differentiation was observed between all the sampled populations. In a follow-up study (Pieters et al., 2009) which included larger sample sizes, the three commercial breeds again clustered separately based on PCA analysis. Confirming this trend, four goat ecotypes from varying geographical locations in Namibia also clustered separately in phylogenetic analyses (Els et al., 2004). Both within and between population diversity was observed in the Landim and Pafuri goats of Mozambique (Garrine et al., 2010). The Tswana goat (Maletsanake et al., 2013; Monau et al., 2018) and the Kalahari Red (Kotze et al., 2004) was genetically characterized in breed-specific research studies.

This array of research concurred that indigenous goat populations generally showed moderate to high levels of genetic variation and relatively low inbreeding. Population differentiation was generally possible based on either microsatellite or SNP analyses, and observed differentiation might be due to local adaptation to specific climatic conditions. Populations that were physically closer to one another (eg. adjacent populations), tended to be closer related on a genetic level as well, probably due to either founder effects or interbreeding (Chenyambuga *et al.,* 2004). These studies were in agreement that the southern African indigenous goat populations have sufficient levels of genetic variation to support genetic improvement.

4. Production systems

Southern African meat goat farming mainly consists of mixed cropping-livestock systems in rural areas where goats have to provide milk, dairy products and meat (Casey & Webb, 2010), of which meat is the main product. The importance of these communal goats in terms of food security and the alleviation of poverty is emphasised in almost every research paper on smallholder goat production in southern African countries. Researchers also agree on the multitude of roles that the goats play as a source of protein, but also as a readily accessible source of income and in terms of traditional ceremonies (Boogaard et al., 2012; Mdlalda et al., 2017; Mataveia et al., 2018; Mhlanga et al., 2018; Onzima et al., 2018).

Meat goat production in southern Africa takes place in the arid and semi-arid areas, and thus under extensive production systems. The (mostly) communal production system is characterized by low levels of input on both a financial and managerial level, and thus low productivity levels (Monau et al., 2018). The production areas are prone to long dry seasons and droughts, leading to seasonal shortages in quality vegetation. Goats are dependent on natural veld and shrubs, or at best on marginal lands and crop residues (Mataveia et al., 2018), and in extreme cases are subjected to scavenging. Inadequate quantity and quality of feed is one of the first limiting factors in smallholder goat production (Mdladla et al., 2017), while sources of water are also generally unreliable and of suspect quality.

To survive and produce in this challenging environment, natural selection has produced goat populations that are uniquely adapted for resiliency and sustainability (Huson et al., 2014). They have a superior ability to withstand extreme heat and dehydration, and are able to survive on low planes of nutrition (Visser, 2018). The indigenous goats are also reported to be tolerant to certain local diseases, such as heartwater (Mohlatlole et al., 2015). As browsers, they have an ability to make use of bushes and trees, and are also efficient exploiters of high-fiber, low-quality roughage (Mirkena et al., 2010). The opportunistic and selective grazing behaviour displayed by goats lead to a wide variety of materials and especially those with high nutritive value, being selected (Alexandre and Mandonnet, 2005). Functional traits such as superior walkability, hoof and skin pigmentation further contribute to the survivability of indigenous goats in the harsh production environment.

Few goat keepers provide shelter, and goats are mostly kept overnight in makeshift kraals. During the day, they either graze freely or are sometimes herded or tethered (Boogaard et al., 2012). This lack of control over grazing locations means that smallholder goat production is characterized by an absence of mating systems and are known for random mating taking place throughout the year (Monau et al., 2018). This gives rise to inbreeding, proliferation of poor quality stock and indiscriminate crossbreeding (Dube et al., 2016; Onzima et al., 2018).

Most smallholders agree that disease, including parasites, was one of the major constraints for goat production (Mataveia et al., 2018; Onzima et al., 2018), while predation could cause goat mortalities of up to 35% (Mhlanga et al., 2018). Slayi et al (2014) argued that kid mortality could be attributed to poor veterinary services and treatment in rural areas, as well as the lack of routine vaccination programs.

Lack of information regarding the value of chain of goat meat contribute to the inaccurate statistics available for goat production. Less than 1% of meat goats goats are slaughtered at central abattoirs and form part of the commercial red meat supply chain (Simela, 2005), while most meat goats are sold and slaughtered for household consumption or in the informal market. Abattoirs generally consider the supply of goats too irregular and insufficient to justify regular slaughtering. The goats that do pass through the formal channels are usually sourced from commercial meat goat breeds.

5. Genetic improvement of southern African goats

While the challenging production system in southern African countries has been described in-depth, very few papers mention any African animal recording or genetic improvement scheme for goats. In South Africa, performance recording was initiated in 1956 (Schoeman et al., 2010) and goats are included in the National Small Stock Improvement Scheme (NSIS), which dates back to 1964. However, only commercial goat breeds participate in this scheme, and very low levels of participation (38% Boer goat to 67% Savana goat) is recorded even for them (Visser & Van Marle-Köster, 2018). The Namibian animal recording system closely resembles the South African one, but no publications describing improvement schemes in the other southern African countries could be found.

It could be argued that the challenging production environment has contributed to the lack of genetic improvement of this species. For lowly skilled, resource-poor farmers, animal identification and the recording of phenotypes will remain a challenge and in addition pedigree allocation is nearly impossible in random mating systems. Many traits that are of importance, such as disease resistance, nematode resistance and reproduction efficiency, has not been routinely recorded in goats, even in commercial resource populations.

A thorough understanding of the constraints posed by the production systems is necessary to design a sustainable genetic improvement program (Mdladla et al., 2017). Within this environmental framework, attainable breeding objectives should be set to improve the genetic potential of indigenous livestock (Lebbie, 2004; Zonabend et al., 2013).

5.1 Selection strategies and breeding programs

The small population sizes and even smaller contemporary groups in goat genetic evaluations complicate accurate estimation of genetic parameters. The South African commercial goat breeds participate in the NSIS, but from 2009 to 2018 the number of weaning weight records per year has decreased from 2541 to 831 for the Boer Goats, from 405 to 248 for Kalahari Reds and remained stable at 161 to 183 for the Savanna goat. Numbers of post-weaning and reproductive records are much less, at a few hundred each for the Boar goat and generally less than 100 per year for the other two breeds (SA Stud Book: Technical and genomic advisory services, Hatfield, Pretoria). Due to the small number of breeders participating in formal recording, genetic trends are mostly erratic and unreliable. Weaning and post-weaning weights for Boer goats do however seem to follow a positive trend.

A successful selection program is dependent on accurate genetic parameters, including heritability and genetic correlation estimates. Although it is ideal to use genetic parameters that have been estimated in the population for which they will be used, phenotypic recording is almost non-existent in smallholder systems (Rumosa Gwaze et al., 2010) and thus the few estimates that have been generated on commercial and indigenous goats in Africa will have to suffice (Table 3). Jembere et al. (2017) constructed genetic parameters from 84 independent publications and confirmed the reliability of such weighted averages. This could indicate that genetic parameters estimated within the broader southern African region could be applied across countries and populations, thus resulting in faster genetic progress for all goat populations.

Table 3 Heritability estimates generated on meat goat populations in Africa

Trait	Heritability	Breed	Country
Birth weight	0.15[1]	Blended goats	South Africa
	0.16[2]	Boer goat	Tanzania
	0.16[3]	Draa goats	Morocco
Weaning weight	0.16 - 0.26 [2,4,5]	Boer goat	South Africa
	0.16[6]	Nubian goats	Sudan
Pre-weaning ADG	0.22[6]	Nubian goats	Sudan
ADG	0.17-0.19[2,4]	Boer goat	South Africa
Kleiber ratio	0.11-0.13[2,4]	Boer goat	South Africa
Litter size at birth	0.32 - 0.35[7]	West African dwarf goat	Nigeria
Kidding interval	0.03[7]	West African Dwarf goat	Nigeria

[1]Das *et al.*, 1994; [2] van Niekerk *et al.,* 1996; [3] Boujenane & El Hazzab, 2008; [4] Schoeman *et al.*, 1997; [5] Olivier *et al.,* 2005; [6] Ballal *et al*., 2008; [7] Odubote, 1994

Although a large number of traits have formed part of previous studies, only a few is practical to include a selection program. In the NSIS, the following traits are included: weaning (direct and maternal) weight, post-weaning weight, number of kids, total weight weaned, age at first kidding and inter-kid period. It is generally accepted that at least one weight record per animal should be included. Weaning weight is a common trait, and measured in many commercial systems. However, this trait is influenced by maternal factors and has low heritability estimates. Post-weaning weights, such as 10-12 month live weight, have higher direct heritability estimates, and could be included more effectively in selection programs (Olivier et al., 2005). As weighing scales are not always available in communal areas, weights can also be construed using custom-made measuring tapes (weight bands), which associates heart girth with body weight (de Villiers et al., 2010). These tapes are generally developed by research institutes and governmental organisations, and have been made readily available to small-scale farmers in KwaZulu Natal (South Africa).

Net reproduction rate (total weight of kid weaned over the lifetime of the doe) is a sex-limited trait with low heritability. Fortunately, large variation exist within populations and a reasonable rate of genetic improvement can be expected if this trait is selected for (Olivier et al., 2005). This trait is a single measurement of both maternal ability and the lamb's direct growth potential and easily interpretable by most farmers (Schoeman et al., 2010).

Carcass and meat traits are also of importance in the commercial goat sector. Goat meat is readily consumed in many African countries. Its popularity is such that the edible proportion of the goats carcasses are as much as 78% (Simela and Merkel, 2008). Thus it is likely that much more goat meat is consumed in Africa than what the official estimates imply. Furthermore, goat meat is exported from Africa to states of the Arabian Gulf (Casey and Webb, 2010), highlighting the need for consistent quality and supply.

The first step in a genetic improvement program will be the identification of relevant breeding objectives. These should include reproduction, growth and meat traits (Rumosa Gwaze et al., 2009), as well as the unique adaptive traits such as disease and drought resistance (Lebbie, 2004). Seeing that the production system and challenges facing the goat keepers are very similar across southern African countries, it might be debated whether a broad framework for genetic improvement in southern Africa could be established, within which the various countries could have scope to tailor-make some country-specific changes. Broad characterization of populations, animal identification and the recording of phenotypes will surely form the corner stones of such a program.

Indigenous meat goats have relatively high levels of genetic diversity and represent genetically adapted ecotypes that perform in poor and marginal areas (Mrode et al., 2018), but with low production potential. On the other hand, the SA Boer, Savanna and Kalahari Red breeds are renowned for their fast growth and superior carcasses, but due to their larger frame size, they are unsuited to subsistence farms with scarce nutrition and much harsher production environments (Mohlatlole et al., 2015). This large gap between the two goat types (commercial vs. indigenous), suggests that crossbreeding might be a solution to improve the production potential of goats (Leroy et al., 2015). It offers the opportunity to develop a robust, adaptive breed that can produce optimally under harsh environmental stressors, by exploiting heterosis en breed complimentarity (Rumosa Gwaze et al., 2009). However, these crossbred animals need to be evaluated in terms of their social and monetary contribution, within the challenges presented by the environment (Shresta and Fahmy, 2007). Crossbreeding has been performed in many African countries, but usually not in a formal structure thus leading to genetic erosion of indigenous resources. Care should be taken to conserve the unique adaptive genes contained in the indigenous populations. This could be attained by making use of carefully structured terminal or rotational cross breeding systems, or even by developing composite breeds (Leroy et al., 2015). Crossbreeding is however not a one-stop solution for genetic improvement. Within-breed selection is still necessary to attain improvement over generations, and is hindered by the lack of phenotypic and pedigree recording. A holistic strategy including selection at various levels, and making use of sustainable, organized crossbreeding could provide an environment for increasing goat genetic potential and improved livelihood of goat keepers.

5.2 Alternative approaches

Due to the challenges faced with regards to phenotypic recording and quantitative selection, the use of molecular tools to attain genetic improvement has received some attention. Genomic tools have been used mainly in terms of genetic characterization of indigenous goat populations, and these have led to improved knowledge regarding population parameters such as inbreeding estimates and admixture (Zonabend et al., 2013), which contribute to the informed management of goat populations. However, these tools have not yet been applied to improve production or attain genetic improvement in southern African goats. Traits that should benefit the most from genomic selection (GS), include lowly heritable, expensive and difficult to measure traits, such as disease resistance, reproduction efficiency and carcass traits (Van Marle-Köster et al., 2015). As traits of economic importance and unique adaptive traits have largely not yet been identified formally for these populations, and routine recording is mostly non-existent, no concerted effort could be made to apply GS. Additional challenges to the application of GS include the many, small population sizes and the lack of genotyping infrastructure. The prohibitive cost of genotyping (where the cost of genotyping exceeds the value of the animal) poses a major financial hurdle (Rupp et al., 2016). While across-breed reference populations could overcome some of these limitations, a lack of phenotypic information, and thus accurate estimated breeding values, remains. A comprehensive review by Van Marle-Köster et al. (2015) describes the challenges of implementing GS in the SADC region, and provides a framework for overcoming them. Unfortunately, no headway has been made in the practical implementation of these recommendations.

Zonabend et al. (2013) lists several bottlenecks for genetic improvement in southern Africa, including a lack of infrastructure, policies and financial support. The dominance of informal markets for especially the goat sector contributes to the lack of genetic improvement, as no formal value chain has been established. As such, it is difficult to identify the main clients / consumers and to structure breeding objectives to meet their demands. The most serious constraint for the development of animal breeding programs in southern and eastern Africa could however be the lack of skilled personnel in animal breeding, as also stated by Zonabend et al. (2013).

6. Conclusion

It is notable that the majority of available literature on indigenous goat resources emphasise the goat as being crucial for smallholder farmers, yet almost no genetic improvement of this resource is evident over the past few decades. The lack of phenotypic and pedigree recording is part of deeper underlying challenges. Most researchers start their investigation of indigenous populations in developing countries with a phenotypic characterization, often using surveys. However, most goat keepers do not understand the benefit of these surveys, due to a lack of participatory approaches. Researchers are also challenged by small numbers of participants, with limited availability and literacy levels (Mataveia et al., 2018).

No national or regional strategy for the genetic improvement of goats has formally been developed in southern Africa. Research is performed as isolated and disjointed events and often do not contribute to the overall improvement of breeds or populations. Numerous publications over the past two decades have stated that genetic improvement should start with the setting of breeding objectives – yet this has still not happened. Training and capacity building of extension officers and animal breeding specialists is urgently needed, as well as effective collaboration between institutes, to ensure the sustainable use of goat genetic resources.

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