Chapter

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

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Abstract

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

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

1. Introduction

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

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

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

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

2. Methodology

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

2.1 Comparison of Milk Yield in Diverse Goat Types

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

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

Table 1.
Goat breeds milk production.

3. The dairy goat type for desertify zones

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

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

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

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

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

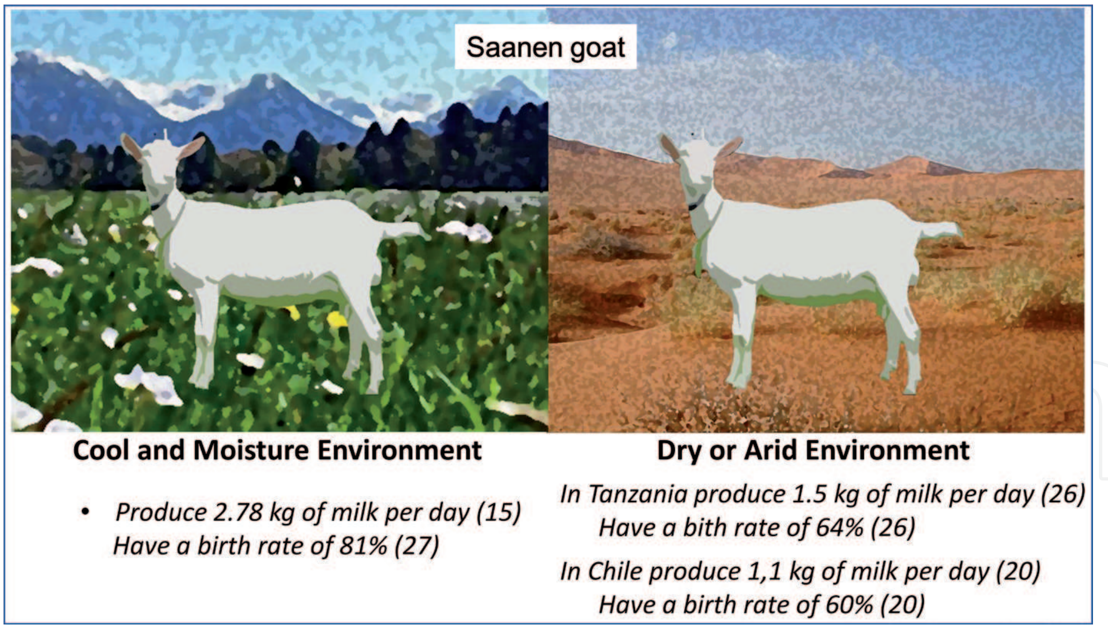

Figure 1.
*Milk production of Saanen goat in different environments. Source: The final version of **Figure 1** was developed be the authors.*

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

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

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

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

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

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

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

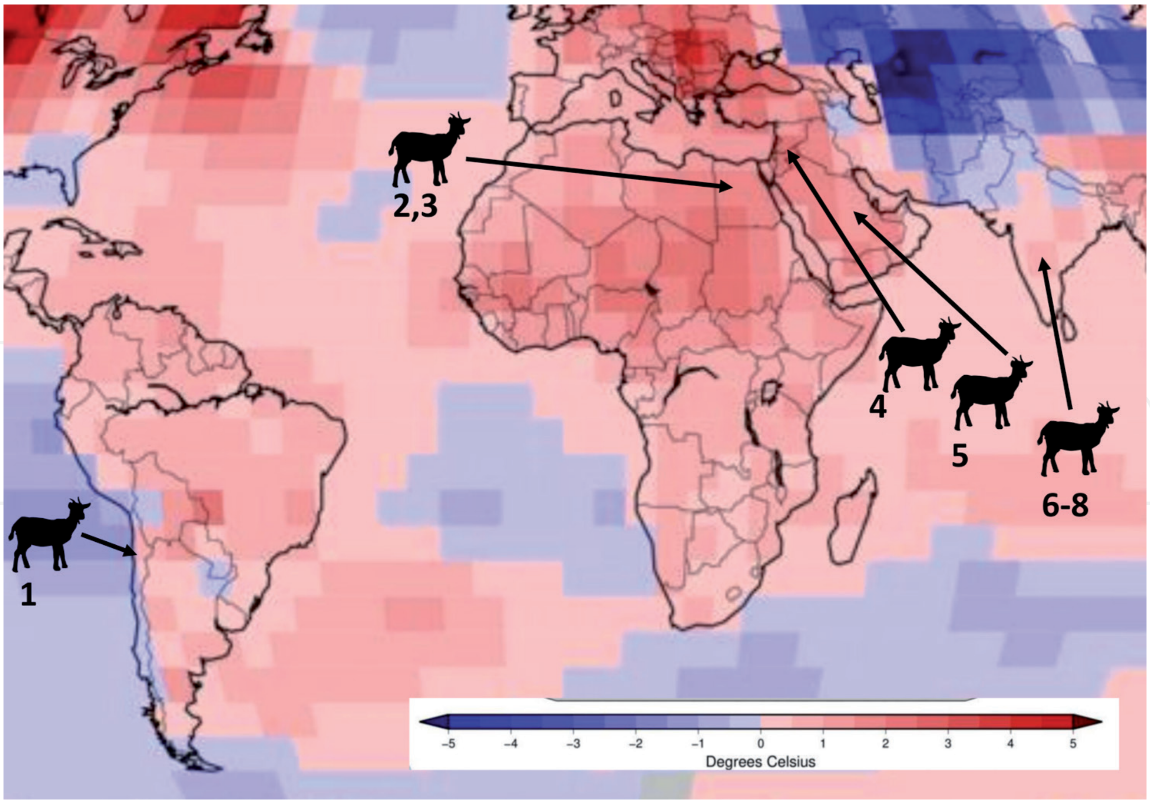

Figure 2.
Distribution of desert and creole goats with the potential to boost milk production in desertified areas. The map represents the land and ocean temperatures departures for average Dec 2020 with respect to a 1981–2010 base period (map from National Center for environmental information, GHCNM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

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

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

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

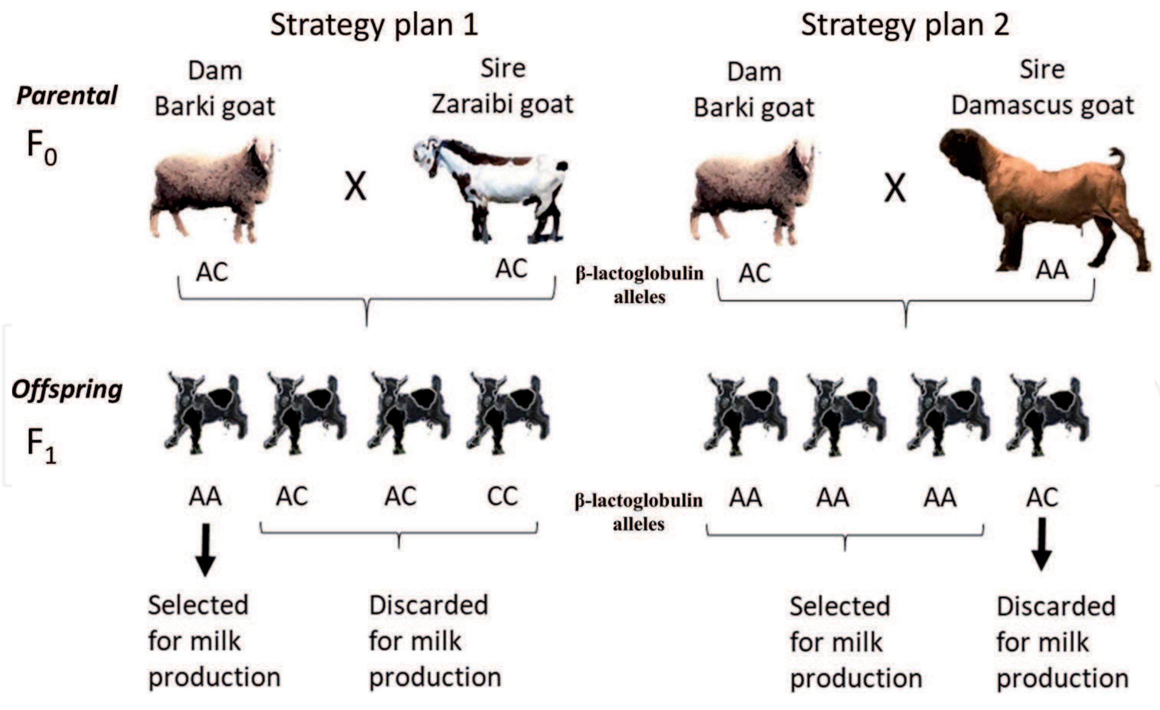

Figure 3.
Example of a crossbreeding strategy assisted by β-lactoglobulin molecular markers. Source: the figure developed by the authors.

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

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

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

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

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

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

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

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

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

4. Goat milk quality

4.1 Benefits of goat Milk

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

4.2 Goat Milk quality

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

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

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

5. Molecular markers for dairy goats

5.1 General characteristic of domestic goats

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

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

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

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

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

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

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

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

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

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

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

5.3 Single nucleotide polymorphism

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

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

6. Conclusion

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

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Conflict of interest

The authors declare no conflict of interest.

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