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Unlocking the potential of sheep and goat genetics in developing countries

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Abstract

Sheep and goats are vital components of agricultural landscapes in developed and developing countries, with Asia and Africa jointly hosting 94% and 77% of global goat and sheep populations, respectively. Despite their importance, these regions grapple with heightened food insecurity, transitioning from traditional pastoralism to cultivating cereal crops and food trees. Decreased rangelands have led to including grains in animal feed, escalating production costs. The once-prevalent mixed farming practice, involving three or more species, regulating livestock systems and farm-level production strategies, has declined. While successful selection and crossbreeding initiatives exist, many developing countries lack cohesive breeding strategies and programs to boost sheep and goat productivity. Farmer organizations often lack empowerment for efficient meat and milk production. Addressing these challenges requires exploring pathways to unlock the genetic potential of these animals. Proposed solutions advocate for an integrated approach involving "selection" and "crossbreeding" strategies, with organized consortiums comprising breeders, community-based associations, commercial enterprises, or governmental agencies. For successful implementation, international organizations must play a crucial role by providing essential support and resources. This collaborative effort holds the potential to enhance resilience, sustainability, and overall sheep and goats productivity, contributing to the global fight against food insecurity.

Keywords: Genetics; Sheep; Goats; Meat; Milk; Productivity

1. Introduction

Livestock continues to be a cornerstone of economies worldwide, playing pivotal roles in both industrialized and developing countries [1,2]. In advanced industrialized settings, livestock breeds are harnessed in market-driven enterprises. These operations boast state-of-the-art machinery, specialized infrastructure, optimized feeding systems, and substantial inputs, culminating in impressive yields. Conversely, in developing regions, livestock predominantly belongs to resource-scarce small-scale producers. These animals are managed in expansive range conditions, enduring severe environmental shifts with limited resources [1,2,3].

A comprehensive evaluation of the World's Animal Genetic Resources for Food and Agriculture [4] reported that for the quintessential "big five" species, namely cattle, sheep, goats, pigs, and chickens, a vast majority of countries confirmed the presence of at least one breeding programme. To be precise, the percentages of countries reporting such programmes were 91/116 for dairy cattle, 93/103 for beef cattle, 87/103 for multipurpose cattle, 81/123 for sheep, and 81/126 for goats [4]. However, these data warrant a nuanced perspective. While the prevalence of breeding programmes is evident, it's imperative to recognize that certain activities detailed in the country reports may not strictly align with traditional breeding programme standards [4]. The absence of coherent breeding programmes in sheep and goats and the lack of cohesive breeding infrastructures, encompassing breed owners, pose significant hurdles for many developing countries in enhancing their livestock breeds' productivity. This paper aims to elucidate the successes and

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challenges associated with breeding small ruminants while pinpointing existing opportunities that underscore their potential to unlock the genetic capabilities of sheep and goats. Special attention is given to their relevance within low-input production systems.

1.1. Livestock food production

Livestock are indispensable pillars of global economies, playing a multifaceted role that extends far beyond basic sustenance. They are vital for ensuring food security, augmenting crop yields by seamlessly integrating into agricultural frameworks, and infusing both rural and urban landscapes with crucial financial resources. Their diverse contributions, ranging from income stabilization and risk mitigation in agriculture to their role as significant assets for farming households are invaluable [1,2,3,4].

Upon examining global livestock production data, it showed that, in 2020, a total of 337 million tonnes of meat were produced. Interestingly, a dominant 88% of this production was derived from just three primary species: chickens accounted for 35%, pigs for 33%, and cattle for 20%. Meanwhile, other species, encompassing sheep and goats, made up the remaining 12%. Delving deeper into specifics, the foremost producers of chicken meat were the United States, China, and Brazil. Conversely, when it came to cattle meat, the hierarchy shifted slightly, with the United States leading, followed by Brazil and China [5].

In 2020, global milk production reached an impressive 931 million tonnes. Asia emerged as the powerhouse in milk production, commanding a substantial 42% of the global share. Europe and the Americas trailed behind with 26% and 22%, respectively, while Africa accounted for 6% and Oceania for 3%. Delving into the primary sources, dairy cattle were responsible for a dominant 80% of this production. Buffaloes contributed another 16%, leaving a 4% share for various other sources, including small ruminants [5].

1.2. Regional distribution of sheep and goats

Domestic sheep have carved a remarkable presence across diverse agroecosystems worldwide [2]. Their adaptability is evident from their presence in the frigid landscapes of places like Iceland to the rugged terrains of the Falkland Islands and Tierra del Fuego in the Southern Hemisphere. They thrive in the lush tropical environs of Southeast Asia, the lofty altitudes of the Pamir and Andean ranges, as well as the arid expanses of the deserts and steppes in Central and West Asia [1,2]. From the early stages of their domestication, animals, particularly sheep, have been instrumental in shaping and sustaining human civilizations. Their remarkable ability to transform even the most meager forage into valuable resources has been pivotal.

Mixed farming, involving three or more species (such as cattle, sheep, goats; sheep, goats, camels, etc.), used to serve as the foundation for adapting and regulating both the livestock system and production strategy at the farm level [6]. The incorporation of three or more species enables strategic adjustments to be implemented in response to various constraints. This diversity yields a plethora of advantages, encompassing the diversification of productions (particularly crucial in systems with a high emphasis on self-consumption), distinct capitalization based on the varying value of animals, optimized utilization of pastoral resources through exploiting specific differences in feeding behaviors, mitigated risk in the face of epidemic diseases, and a reduction in specific parasite pressure [6].

FAO's data underscore a notable trend: by 2020, the global population of goats and sheep surged past the billion mark [7]. Intriguingly, this growth unfolds against a backdrop where rangeland areas are shrinking across numerous countries. Currently, livestock farms, which used to be multi species and breeds, are now generally composed of a single species, or sometimes even a single breed unfolds against a backdrop where rangeland areas are shrinking across numerous countries, often giving way to cereal crops and fruit tree cultivation. Compounding this, the costs associated with animal feed have skyrocketed in recent times. Illustrative data, as depicted in Figures (1 and 2), spotlight two predominant regions as epicenters of this livestock surge. Specifically, Asia and Africa emerge as dominant custodians, collectively accounting for a staggering 94% of the global goat population. Their shares are almost evenly split at 50% each. Additionally, these regions own a commanding 77% stake in the global sheep demographic, with Asia contributing 45% and Africa close behind at 32% [7]. Regrettably, heightened food insecurity is prevalent in these substantial regions [8]. Undernourishment rates stand at approximately 29% in Eastern and Middle Africa, 15% in Western Africa, 16% in Southern Asia, and 11% in Western Asia. The global average of undernourishment is 9% [8].

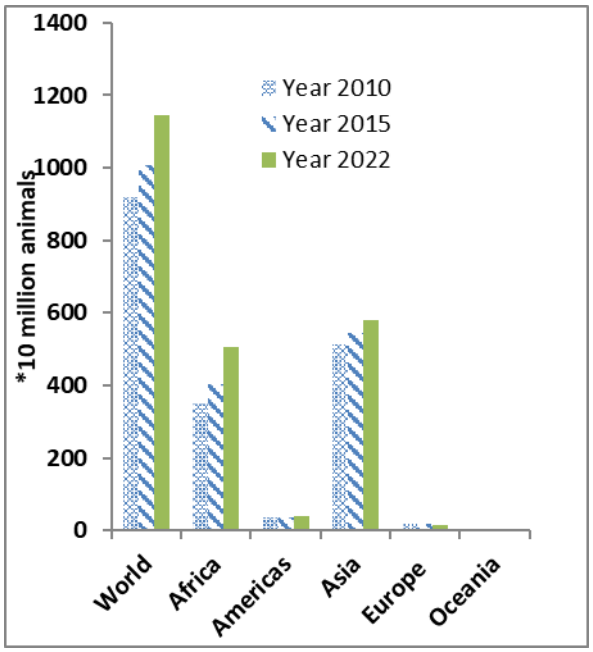

Figure 1 Trends of goat numbers by region

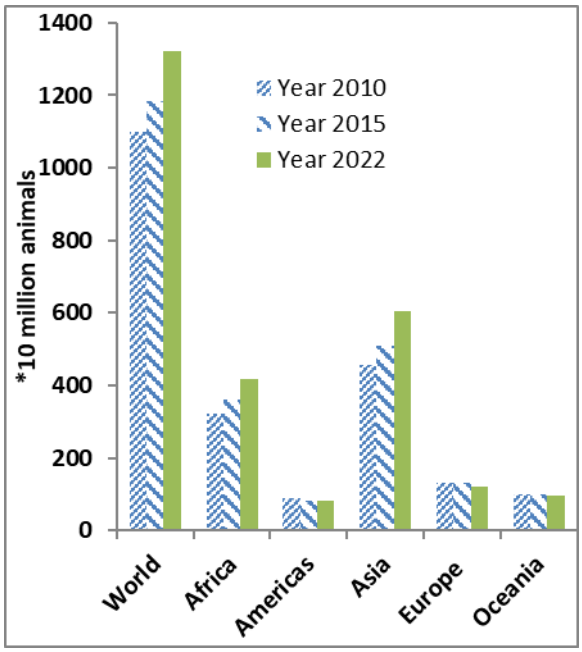

Figure 2 Trends of sheep nubmer by region

1.3. Genetic diversity of sheep and goats

The genetic landscape of sheep and goats has been meticulously examined using data from the FAO database [9]. As of 2022, the database documented a remarkable diversity, listing a total of 8859 mammalian breeds in the world reported. The number of local mammalian breeds was 4954. Small Ruminants local breeds were 1744 with 1143 for sheep and 601 for goats. Specifically, Europe is home to 34% of the global reported local goat breeds and a commanding 53% of the reported local sheep breeds (table 1). However, it's crucial to highlight a significant gap in the data. Many developing countries, despite their vast livestock diversity, have yet to conduct comprehensive species inventories. This omission impedes our understanding of the global genetic reservoir and hampers conservation efforts. It is imperative for international organizations to step forward, offering support and resources to these countries. By assisting them in conducting thorough inventories and characterizing their local breeds, we can pave the way for tailored conservation and genetic enhancement initiatives, ensuring the preservation and sustainable utilization of these invaluable genetic resources.

Table 1 Number of reported sheep and goat local breeds [9]

Species	Africa	Asia	Europe and the Caucasus	Latin America and the Caribbean	Near and Middle East	North America	Southwest Pacific	World
Goats	100	203	207	37	36	7	11	601
Sheep	102	269	602	62	49	21	38	1143

Sheep epitomize the diversity and adaptability observed across species, with their widespread presence and rich genetic diversity. The lack of sheep and goats reliable breeding strategies for their genetic improvement and promotion put them, in the majority of developing countries, subject to indiscriminate crossbreeding [3,10,11,12]. This alarming scenario accentuates the urgent need to fortify global genetic reservoirs. The ramifications are profound, influencing not just the economic destinies of livestock farmers but also the conservation of priceless genetic heritage.

1.4. Breeding Sheep and goats success stories

Certainly, there are numerous untold success stories in sheep and goat breeding. In sheep crossbreeding, a standout example is the Small Ruminant Collaborative Research Program (SR-CRSP) by the University of California-Davis in Sumatra, Indonesia as reported by [1]. Here, they blended the adaptability and high breeding rates of Sumatran sheep

with the larger size and superior growth rates of Barbados Blackbelly and Saint Croix sheep. This innovative approach has led to the creation of new sheep breeds that thrive in tropical settings and areas where breeding occurs throughout the year due to favorable environmental and feeding conditions [1].

Another notable success is the Assaf sheep breed, developed by crossing Awassi ewes with East Friesian rams. Initially exported to Spain in 1977, this breed has since gained popularity in Portugal, Chile, Peru, and the USA. The Assaf sheep breed in Spain exemplifies successful breed management. Introduced between 1977 and 1983, this breed gained official recognition by 1993 and achieved integrated status by 2019. The Assaf Spanish Breeders Association (ASSFE) plays a pivotal role, requiring members to adhere to specific guidelines for DNA testing, artificial insemination, and milking controls. In return, farmers receive Estimated Breeding Values (EBV) based on genomics, enhancing breed quality and productivity [13].

In the realm of sheep selection, Argentina and Cyprus offer compelling examples. In Argentina, efforts centered on enhancing fiber production in Merino sheep and Angora goats, supported by INTA-Bariloche. Meanwhile, Cyprus prioritized improving milk yield in Damascus goats and Chios sheep, led by the Cyprus Agricultural Research Institute [2,14]. These initiatives, initially centralized, evolved into successful programs with extensive producer involvement. Key factors contributing to their success include sustained governmental support, active producer engagement, strategic market orientation, and effective knowledge dissemination.

In North Africa, the Sicilo-Sarde sheep breed in Tunisia faced near-extinction due to declining numbers and low milk prices. Collaborative efforts involving NARS, ICARDA, and the Sicilo-Sarde Breed Association led to a remarkable recovery, marked by increased milk prices, legislative support, and innovative research programs. This revitalization has rejuvenated interest among small farmers, signaling a promising future for the breed [15,16]. In Morocco, the Association - ANOC, a professional association for sheep and goat producers, emerged from a private initiative driven by a shared passion for sheep breeding. This association has fostered collaboration among traditional breeders, experts, and various stakeholders, underpinned by a trust-based professional relationship, setting a new standard for agricultural development in developing countries [17].

1.5. Sheep and goats threats

Sheep and goats are not only genetically diverse but also globally prevalent. Despite their extensive distribution and the existence of some success stories, a total of 107 local breeds of sheep and 19 local breeds of goats were reported « Exitnct » [9]. There are only 18-19 % of the reported local breeds of small ruminants that are not at risk [9]. Besides, the genetic management of these animals remains notably limited in many developing countries. This limitation often stems from a prevailing misconception that genetic enhancement is incompatible with low-input agricultural systems or the dominance of indiscriminate crossbreeding with exotics [19]. As a consequence, many indigenous sheep and goat breeds, although resilient to harsh environments and diseases, exhibit suboptimal productivity. This entails balancing the preservation of genetic diversity with targeted breeding strategies to unlock the full potential of native sheep and goats, thereby ensuring sustainable livestock development and food security [3,11,13,18].

Preserving breeds identified as at risk is not only crucial for the biodiversity of our planet but also vital for the sustainable development of livestock sectors in developing countries. While various animal conservation methods are implemented globally, developing countries often face resource constraints and require support to effectively safeguard their native breeds. *Ex-Situ* conservation, primarily through well-established gene banks, emerges as a prominent approach in this regard. This method entails the preservation of diverse genetic materials, including semen, tissue, ova, and embryos. Additionally, maintaining live animals in reserves or zoos provides another layer of protection against potential extinction [11]. Given the limited resources and expertise in many developing countries, international organizations should play a pivotal role in facilitating these conservation efforts. Collaborative initiatives, bolstered by technical and financial support from international bodies, can significantly enhance the capacity of developing countries to preserve their unique livestock genetic resources [11]. By fostering partnerships between developed and developing countries, these collaborative efforts can promote knowledge exchange, capacity building, and sustainable practices, thereby contributing to both local livelihoods and global biodiversity conservation.

2. Viable avenues to unlock the genetic potential of sheep and goats

2.1. Genetic improvement

As our world grapples with the mounting challenges of climate change and dwindling water supplies, there's an increasingly urgent call to protect and preserve the incredible genetic diversity found in our livestock. This diverse

genetic treasure trove offers hope in creating animals that are naturally equipped to handle the changing environment, whether it's enduring longer droughts or coping with rising temperatures. This resilience, already seen in various breeds of domestic animals, opens doors to raising livestock in places we once thought unsuitable.

Developing countries endowed with a rich diversity of sheep and goat breeds must prioritize, first, the comprehensive inventorying and characterization of their local animal breeds. Subsequently, these actively managed breeds should be integrated into well-defined and cohesive genetic improvement programs. These breeding programs, as delineated in [3,11,18,21], entail a methodical and organized approach designed to systematically modify the genetic composition of a population in alignment with predetermined breeding objectives. The ultimate goal is to effectuate genetic progress through selective breeding, anchored in clearly defined performance metrics. Key components integral to the successful implementation of these programs encompass:

- Articulating precise breeding objectives.
- Rigorous animal identification protocols.
- Comprehensive performance assessment mechanisms.
- Accurate prediction of breeding values.
- Strategic implementation of selective breeding schemes.
- Thoughtfully devised mating strategies.
- Streamlining the dissemination of genetic superiority.

In the context of developing countries, particularly those rich in diverse sheep and goat breeds, determining the sustainable utilization of these breeds necessitates a nuanced approach that considers both "selection" and "crossbreeding" strategies. The "selection" pathway is particularly relevant when there is considerable within-breed variation, especially in terms of within breed genetic diversity. In such cases, collaborative efforts involving breeders, breed owners, and policymakers are essential. Together, they deliberate on prioritizing traits for selection, focusing on those with high additive genetic variation and economic relevance. To facilitate this, the establishment of an effective animal identification and performance recording program is imperative. This program enables the computation of breeding values, laying the foundation for a structured breeding scheme. With the advancements in genomics, today sheep and goat breeds are better characterized and their genetic breeding values are better predicted. By disseminating superior genes within the breed, this approach fosters the enhancement of desirable traits.

2.2. Crossbreeding

Conversely, when the objective is to harness the complementary strengths of different breeds, well-designed crossbreeding programs become indispensable. Here, a strategic approach to crossbreeding ensures that the resulting combinations accentuate the desired traits and characteristics, while also preserving a proportion of local genes when integrating exotic and native genotypes. Using F1 male crosses or sometimes F2 crosses to Exotics gave usually better results than continuous upgrading to Exotics [21 ,22]..

Typically, the stewardship of these genetic improvement initiatives falls under the purview of organized consortiums comprising livestock breeders, community-based associations, commercial breeding enterprises, or governmental agencies, ensuring a collaborative and multifaceted approach to sustainable livestock development.

2.3. Farmers organization

In both scenarios (selection or crossbreeding), the collaboration and communication among stakeholders, including breeders, owners, and policymakers, are paramount. This integrated approach, often exemplified by many developing countries, ensures that the chosen strategy aligns with the unique characteristics of the breed and advances the overarching goals of conservation and sustainable breeding practices. By adopting such a holistic approach, developing countries can effectively leverage their rich genetic resources to enhance agricultural productivity and resilience while preserving their invaluable livestock heritage.

Undoubtedly, the disparity in animal genetics utilization and conservation between developing countries and developed ones presents a significant challenge. While global strategies led by the Food and Agriculture Organization (FAO) of the United Nations aim to support countries in need, their impact often falls short at the grassroots level, particularly among local breeders and livestock owners. Addressing this disparity is not only crucial but also achievable through targeted investments in training, education, and technology transfer tailored to the specific needs of developing countries.

3. Conclusions

In developing countries, a reservoir of valuable genetic resources in sheep and goats, uniquely adapted to challenging environments and low-input production systems, exists. Despite their inherent potential, these countries grapple with challenges arising from the absence of suitable breeding schemes and the looming risk of indiscriminate crossbreeding with exotic breeds. The sustainable utilization of these breeds demands strategic selection or crossbreeding approaches. Central to this is the establishment of a robust animal identification and performance recording program, crucial for computing breeding values and laying the groundwork for a systematic breeding scheme. The success of this initiative hinges on the dissemination of superior genes within the breed, fostering the enhancement of desirable traits. The stewardship of these genetic improvement endeavors falls under the purview of organized consortiums comprising livestock breeders, community-based associations, commercial breeding enterprises, or governmental agencies. This collaborative and multifaceted approach ensures effective management, promoting sustainable sheep and goat productivity improvement. Such initiatives hold the promise of elevating small ruminants productivity, strengthening food security, and augmenting incomes, thereby significantly improving the livelihoods of millions. To translate these proposals into reality, fostering collaboration among international and regional funding agencies, as well as regional bodies dedicated to livestock development in developing countries, is imperative. This collective effort will play a pivotal role in facilitating the conservation and the implementation of sustainable practices and initiatives that have far-reaching positive impacts on sheep and goats development even under low input production systems.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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