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Application of Genomics in Livestock Production: A Review

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ABSTRACT

The speed, accuracy, and cost-effectiveness of genomic prediction have significantly altered breeding objectives, allowing for the simultaneous enhancement of multiple traits, including disease resistance. The potential of genomics in elevating the genetic profile of indigenous livestock is extensive, offering opportunities through population-specific selection, crossbreeding with improved breeds, or a combination of both approaches. By pinpointing genes and markers linked to traits like disease resistance and adaptability, genomics enables customized breeding programs that consider local conditions and preferences. The involvement of local communities in this process ensures positive socioeconomic impacts on livelihoods. Recent advances in high-throughput sequencing technologies, particularly Next-Generation Sequencing (NGS), have enriched genomic studies. NGS enables massive data generation, unveils rare variants, ensures complete genome coverage, and facilitates large-scale comparative analyses. The conclusion drawn is that genomics has emerged as a pivotal force in shaping the future of sustainable and efficient livestock production. With ongoing technological advancements, genomics is poised to play an increasingly crucial role in maintaining resilient, productive, and economically viable livestock populations that cater to the evolving needs of the global agricultural industry. The review seeks to explore the application of genomics in livestock production, aiming to enhance productivity, health, and genetic diversity of livestock species.

Keywords: Breeding, Food security, Genomics, Improvement, Livestock Production.

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1. INTRODUCTION

The livestock sector plays significant roles in the provision of livelihoods, such as food and nutrition security, in developing countries. The livestock industry is crucial for generating employment, stimulating demand for goods and services, and fostering economic transformation by contributing to human and financial capital for the development of other sectors [1]. Demand for animal source of protein is set to increase dramatically over the next few decades [2].

Despite challenges like poor breed, disease conditions, and high feed prices increasing production costs and affecting the viability of the livestock sector, nutritionists are intensifying research into the feeding value of cost-effective and readily available protein and energy sources [3].

The livestock sector also benefits other actors in the associated value chains, such as input providers, traders, processors, and retailers, through the provision of employment and income. Critically, animal-source foods, consumed in even small amounts, play a key role in the food and nutritional security of the poor, as they provide quality protein and micronutrients essential for normal development and good health [4,5].

Indigenous livestock in developing countries exhibit low productivity but possess merits such as scavenging behavior, adaptability to harsh environmental conditions, and disease tolerance [6]. Although various factors contribute to their low productivity, the fundamental issue is their low genetic potential [3,7,8]. However, there is genetic variability in productive and disease resistance traits among indigenous breeds, providing a basis for genetic improvement if fully exploited [9,10]. Genetic improvement can be achieved through selection, crossbreeding with improved breeds, or a combination of both.

Genomics, a comprehensive discipline exploring an organism's genetic makeup, stands at the forefront of scientific innovation, providing insights into the genetic framework governing crucial traits in livestock [12]. This represents a paradigm shift in livestock breeding, driven by breakthroughs in high-throughput sequencing and bioinformatics. The effects of genomics are significant, allowing for quicker and more accurate selection in various species, including cattle, pigs, and poultry, through genomic prediction.

The application of genomics, ranging from the determination of breed composition of animals in the absence of pedigree data for *in situ* comparison studies or for the application of genomic selection in breed improvement programs, is just beginning to emerge, often overcoming a constraint that would otherwise exist, such as lack of recorded pedigree.

A comprehensive exploration of the importance of livestock farming in contributing to the food supply, particularly in developing countries, is crucial. This review identifies the inadequate supply of animal protein in the diets of citizens in developing countries as a significant concern and emphasizes that the potential solution lies in robust livestock subsector production and development, justifies the need for genetic improvement in livestock, especially in developing countries, and advocates for the transformative role of genomics in revolutionizing traditional breeding methodologies for enhanced productivity and sustainability in the livestock sector. Therefore, the objectives of this review are to examine the contribution of livestock farming to food security and to assess the role of genomics in livestock genetic improvement.

2. LIVESTOCK FARMING AND FOOD SECURITY

The demand for animal source foods is rapidly increasing in developing countries; the demand in 2030 for beef, milk, poultry, and eggs is predicted to be a 124, 136, 301, and 208% increase over that in 2000, respectively, in developing countries [12]. This demand increase has been largely attributed to population growth, income growth, and urbanization [13,14]. Various challenges, such as limited access to technology and information, inadequate infrastructure, restricted market access, difficulties in controlling animal diseases, and environmental factors, play pivotal roles in hindering sustainable smallholder livestock farming [15].

2.1. Factors Affecting the Productivity of Livestock

Various factors, ranging from genetics and nutrition to management practices and environmental conditions, influence livestock productivity. Some of the factors that affect the productivity of livestock include the following:

- **Nutrition**

Nutrition plays a pivotal role in determining the productivity of livestock, influencing critical aspects such as growth rates, reproductive performance, and overall health. A well-designed and balanced diet is essential to provide the necessary nutrients that meet the specific requirements of different livestock species and various production stages [16]. The quality and quantity of the feed directly impact livestock productivity, with adequate nutrition supporting optimal growth and development, enabling animals to reach their genetic potential [17].

Reproductive performance in animals is significantly influenced by nutrition, and inadequate nutrition can lead to delayed puberty, reduced conception rates, and increased calving or lambing intervals. Specific nutrients such as energy and certain minerals are critical for supporting reproductive processes. For lactating animals, nutrition has a direct impact on milk production, and dairy cows and ewes require a well-balanced diet with sufficient energy, protein, and minerals to maintain their body condition and produce high-quality milk for their offspring [18].

Proper nutrition strengthens the immune system and enhances the livestock ability to resist diseases. Essential nutrients, particularly vitamins and minerals, play key roles in supporting immune function. Conversely, nutrient deficiencies can compromise the immune response, making animals more susceptible to infections [16].

Nutrition is a pivotal factor influencing the productivity of livestock, and a well-managed and balanced diet not only supports the physiological needs of animals but also contributes to the overall efficiency, health, and sustainability of livestock farming operations [18,16]. Careful attention to nutritional requirements is essential to maximize productivity and ensure the well-being of animals in various production systems.

- **Health and Disease Management**

The management of health and diseases is a critical factor influencing the productivity of livestock. The overall health of animals plays a direct role in affecting their growth rates, reproductive performance, and the quality of meat and milk products [19,20,16]. Implementing effective preventive measures, such as vaccination programs, biosecurity measures, and proper nutrition, can substantially decrease the occurrence of diseases, thereby enhancing the overall health of livestock and boosting productivity. A well-organized health program can effectively control and prevent infectious diseases, leading to lower mortality rates among livestock.

Diseases can have adverse effects on reproductive performance, causing issues such as infertility, abortions, and low birth weights. Healthy livestock are known to produce higher-quality products like meat and milk. Diseases can affect the composition and safety of these products, reducing their market value. Health management practices, including hygiene and disease monitoring, play a crucial role in ensuring safe and nutritious animal products [17,19].

3. ROLE OF GENOMICS IN LIVESTOCK GENETIC IMPROVEMENT

At the onset of the genomics era, the main focus for applying the technology in livestock improvement was the development of standalone genome marker tests, particularly for inherited diseases [21]. With time, the focus then shifted toward combining quantitative and genomic approaches to identify genomic variants with large effects on traits of interest for use in marker-assisted selection (MAS). However, the uptake of MAS was limited, since few QTL were reliably detected across populations, and those detected generally only accounted for a small proportion of the variation in the overall breeding objective. Over years the main focus has been on implementing and refining the methods for genomic selection [21]. Advances in the availability and cost of generating genomic information have facilitated a continual increase in the volume of genomic information that can be used for breeding value prediction and improvement.

Genomics (the study of an organism's complete set of DNA) has helped to transform the landscape of genetic enhancement in livestock. This field introduces powerful tools and methodologies that deepen our understanding of the genetic composition of animals, enabling the implementation of more accurate breeding strategies. Genomics facilitates the identification of specific genes and markers linked to desirable traits, such as high milk production, disease resistance, or efficient feed conversion [22] thereby refining the precision of genetic selection. In contrast to traditional breeding programs reliant on costly and time-consuming phenotypic observations, genomics allows for the early identification of animals with favorable genetic traits, thereby expediting and enhancing the efficiency of breeding progress [23,24,25]. Through genomic studies, researchers can pinpoint regions of the genome associated with specific traits, termed Quantitative Trait Loci (QTL).

Genomic information further facilitates more accurate prediction of animals' breeding values, enabling breeders to select superior individuals for reproduction based on their genetic potential, thereby enhancing overall herd or flock performance. The identification of genetic markers linked to disease resistance allows selective breeding to enhance immunity, thereby reducing the impact of diseases on livestock health and productivity [26,22,15].

In the realm of reproductive traits, genomic tools contribute to a better understanding, assisting in the selection of animals with improved fertility, reduced calving intervals, and other reproductive characteristics, ultimately enhancing overall reproductive efficiency [27,28,19,20,16].

Genomic technologies also play a crucial role in assessing and conserving genetic diversity within livestock populations, which is vital for maintaining resilience to environmental changes, diseases, and other challenges [29,15]. Genomics proves particularly advantageous in the genetic improvement of rare or indigenous breeds, aiding in the conservation of valuable genetic diversity within these populations and ensuring their long-term sustainability of these breeds [15]. Genomics has significantly propelled livestock genetic improvement, offering precise selection tools, accelerated breeding processes, and enhanced understanding of the genetic basis of crucial traits.

4. POTENTIALS OF GENOMICS IN ACHIEVING THE GENETIC IMPROVEMENT OF INDIGENOUS LIVESTOCK

The potential of genomics in achieving genetic improvement in indigenous livestock is vast, offering opportunities to enhance traits related to productivity, disease resistance, and adaptability. Genomic technologies can be applied through various methods, including selection within indigenous populations, crossbreeding with improved breeds, or a combination of both [30].

4.1. Genomic Selection in Indigenous Populations

Genomic tools allow the identification of specific genes and markers associated with desirable traits within indigenous livestock, such as disease resistance, heat tolerance, and efficient feed use. [31] reported that genomic information enhances the accuracy of estimating breeding values, enabling more precise selection of individuals for reproduction based on their genetic potential. Genomics helps in selecting animals within indigenous populations that possess valuable genetic diversity, thereby ensuring the preservation of unique and adaptive traits [32].

4.2. Crossbreeding with Improved Breeds

Genomics facilitates the identification of specific genes and traits in improved breeds that can positively contribute to indigenous livestock. [11] reported that crossbreeding allows the transfer of these desirable traits into the indigenous population. Crossbreeding can enhance the adaptability of indigenous livestock to changing environmental and production conditions, making them more resilient and versatile [33,34].

4.3. Combination of Selection and Crossbreeding

Genomic information enables the development of tailored breeding programs that incorporate both selection within indigenous populations and strategic crossbreeding with improved breeds. This allows for a balanced approach that addresses specific production goals and challenges [30]. Genomic tools aid in optimizing the contributions of both indigenous and improved breeds, ensuring that the resulting populations possess a desirable combination of traits for local farming systems [35]. The combination of selection and crossbreeding allows for striking a balance between maintaining adaptability to local conditions and achieving higher levels of productivity [32].

4.4. Enhanced Disease Resistance and Productivity

Genomics assists in the identification of genetic markers associated with disease resistance. By incorporating these markers into breeding programs, [36] opined that indigenous livestock can be selectively bred for improved immunity, thereby reducing the impact of prevalent diseases. Genomic selection and crossbreeding enable the improvement of key productivity traits such as growth rates, reproductive efficiency, and milk or meat yield, leading to overall enhanced livestock productivity [37].

5. COMMUNITY ENGAGEMENT AND LIVELIHOOD IMPROVEMENT

The application of genomics in indigenous livestock improvement should involve local communities, ensuring that their traditional knowledge and preferences are considered in breeding programs [38]. Improved indigenous livestock breeds developed through genomics can have a positive socio-economic impact on local communities by providing increased income opportunities, better nutrition, and enhanced livelihoods [39]. The potential of genomics in achieving genetic improvement in indigenous livestock is significant. [40] reiterated that by employing methods such as selection, crossbreeding with improved breeds, or a combination of both, genomics can contribute to the sustainable development of livestock populations that are well-adapted to local conditions while simultaneously enhancing their productivity and resilience.

6. GENOMICS AND LIVESTOCK BREEDING PROGRAMS

The impact of genomics on livestock breeding programs, particularly in cattle, pigs, and poultry, has been transformative, revolutionizing the approach to genetic improvement. [41]reported that genomic technologies have significantly enhanced the speed, accuracy, and cost-effectiveness of breeding strategies in these key livestock species.

6.1. Speed of Genetic Improvement

Genomic technologies allow for the early and accurate identification of desirable traits in young animals. It accelerates the selection process by enabling breeders to make decisions at a much earlier age, thereby reducing the generation interval [42]. With genomics, the time required to achieve genetic progress is markedly reduced. It improves accuracy in predicting breeding values and allows for quicker selection of superior animals, leading to faster overall breeding progress [43].

6.2. Accuracy of Genetic Prediction

[44] revealed that genomic prediction provides a higher level of precision than traditional methods that rely solely on pedigree or phenotypic information. Its accuracy is particularly beneficial in selecting animals for specific traits like milk production, growth rates, and disease resistance [41]. Faster and more accurate identification of genetically superior animals reduces the generation interval, leading to more efficient genetic improvement over time [43].

6.3. Cost-Effectiveness

Genomic technologies contribute to cost savings by allowing breeders to make more informed decisions without having to wait for animals to reach maturity [45]. [46] reported that genomics reduces the costs associated with maintaining and managing larger populations. The information obtained enables breeders to allocate resources more efficiently by focusing on animals with the highest genetic potential, thereby minimizing the need for extensive testing and evaluation of large populations [46].

6.4. Improved Breeding Goals

Genomic tools enable the simultaneous improvement of multiple traits, including those that are difficult to measure directly. Breeders can therefore target a broader range of traits, such as disease resilience, reproductive efficiency, and environmental adaptability. Furthermore, genomic information allows for the customization of breeding programs based on specific production goals, market demands, and environmental conditions. This flexibility enhances the overall effectiveness of breeding strategies [44].

6.5. Disease Resistance and Resilience

Genomics aids in the identification of genetic markers associated with disease resistance. This makes it possible for breeding programs to focus on selecting animals with innate resistance, thereby reducing the reliance on antibiotics and other interventions [41]. By incorporating genomic information related to adaptability and stress tolerance, breeding programs can enhance the resilience of livestock populations to environmental challenges.

6.6. Global Collaboration and Information Sharing

Genomic technologies facilitate global collaboration in livestock breeding. [43] reported that international sharing of genomic data allows for a broader genetic pool, leading to more robust breeding programs with diverse and valuable genetic resources. The global exchange of genomic information ensures that breeding programs worldwide benefit from the latest advancements, contributing to consistent improvements in livestock genetics on a global scale [41].

The speed, accuracy, and cost-effectiveness associated with genomic prediction have transformed traditional breeding practices, enabling breeders to make more informed decisions, accelerate genetic progress, and address diverse and complex breeding goals, which has led to more resilient, productive, and economically viable livestock populations that meet the evolving needs of the agricultural industry.

7. CONCLUSIONS

Conclusively, the role of genomics in livestock genetic improvement is undeniably transformative, offering a paradigm shift in the way breeding programs are approached and executed. The impact of genomics on livestock breeding programs is evident in its contributions to speed, accuracy, and cost-effectiveness. The early identification of desirable traits in young animals, coupled with high-precision genetic prediction, has reduced the generation interval and improved overall breeding progress. Therefore, genomics has assisted in revolutionizing the landscape of livestock genetic improvement, providing powerful tools for precise selection, accelerated breeding processes, and a deeper understanding of genetic traits.

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