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The Impact of Genetic Selection on Livestock Production and Herd Improvement

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Genetic selection has revolutionized livestock production, driving significant improvements in productivity, efficiency, and herd quality. By leveraging advancements in genomics, artificial selection, and reproductive technologies, producers can identify and propagate desirable traits, such as increased milk yield, faster growth rates, disease resistance, and enhanced reproductive performance. These developments have optimized production systems and contributed to sustainable agricultural practices. However, genetic selection also raises concerns about reduced genetic diversity, inbreeding, and the potential neglect of traits essential for long-term adaptability.

Keywords: Genomics traits, phenotypic traits, traditional livestock breeding, genomic selection etc.

Introduction

Livestock production plays a crucial role in agriculture and food security by providing essential food sources, income, and various ecosystem services. It contributes significantly to nutritional security through high-quality protein and micronutrients, which are vital for human health, particularly in developing regions. The importance of livestock extends beyond food provision, as it supports rural livelihoods and agricultural productivity. Livestock products such as milk, meat, and eggs are nutrient-dense, offering essential proteins and micronutrients that combat malnutrition. In Ethiopia, livestock-derived foods are critical for improving nutritional outcomes, especially among vulnerable populations (Getiso, 2024). Livestock serves as a secondary income source for smallholder farmers, enhancing rural economies and food security (AUTHOR_ID *et al.*, 2024).In Ukraine, livestock production has shifted to private homesteads, indicating its adaptability and importance in local food systems despite challenges (Palapa, 2024). Livestock contributes to soil fertility through manure and provides draft power for farming, indirectly supporting crop production. However, livestock farming also faces challenges such as competition for resources and environmental impacts, necessitating sustainable practices (Ibraheem, 2023).

Genetic selection in livestock has become increasingly vital for enhancing production efficiency, health, and sustainability. By leveraging genomic technologies, breeders can identify and select animals with desirable traits, leading to improved productivity and resilience in livestock populations. This approach not only addresses economic challenges but also contributes to environmental sustainability, making it a crucial strategy in modern agriculture. Genomic selection allows for the early identification of superior individuals based on genetic potential, accelerating breeding programs. The integration of genomic data increases the accuracy of breeding values, resulting in improved traits such as milk yield, fertility, and disease resistance (Stanojevic *et al*., 2023). Molecular breeding values (MBVs) are developed for various traits, enabling balanced economic decisions in breeding (Basarab *et al*., 2023).

Genetic markers associated with health traits can be identified, promoting the selection of healthier animals. Genetic improvement programs contribute to increased longevity and productivity in dairy cattle (Gianegitz *et al*., 2024). Genomic strategies can lead to significant reductions in greenhouse gas emissions, particularly in dairy and beef production. Enhanced feed efficiency and reduced waste contribute to more sustainable livestock systems (Leishman *et al*., 2024).

Genetic selection has significantly improved livestock production and efficiency over the past decades. Conventional breeding methods have contributed to this progress, but genomic selection offers even greater potential for genetic improvement. This approach uses genetic markers across the entire genome to capture all quantitative trait loci contributing to trait variation, allowing for more accurate and early-age selection (Yadav *et al*., 2018). Genomic selection has doubled genetic progress in some livestock species over the past decade. The integration of genomics, assisted reproductive technologies, and genetic engineering further enhances breeding capabilities (Schultz *et al*., 2020 a). As global demand for animal-based food products is expected to increase significantly by 2050, continued advancements in genomic technologies and their application will be crucial for sustainable livestock improvement (Georges *et al*., 2018).

The aim of the article *"The Impact of Genetic Selection on Livestock Production and Herd Improvement"* is to explore how genetic selection has revolutionized the field of livestock management and contributed to the improvement of herds and agricultural productivity. The article seeks to educate readers about the principles and applications of genetic selection, focusing on its role in enhancing desirable traits such as growth rates, reproductive efficiency, disease resistance, and product quality. By examining advancements in breeding technologies and genetic tools, the article aims to inform breeders, farmers, and researchers about the potential of these methods to optimize herd performance and production outcomes. Additionally, it addresses the challenges, risks, and ethical considerations associated with genetic selection, encouraging sustainable and responsible practices. Ultimately, the article aspires to support informed decision-making, promoting innovation and efficiency in livestock production systems.

Understanding Genetic Selection in Livestock

Genetic selection is a powerful tool for improving desirable traits in farm animals. It has led to significant increases in productivity over the past 50-60 years. However, intensive selection for production traits has also contributed to welfare issues in some species. Future breeding goals are likely to incorporate welfare traits alongside production traits, with some species already including welfare-related traits in breeding indices (Rodenburg and Turner, 2012). Modern breeding techniques, including genomic tools, offer opportunities to accelerate genetic progress and address welfare concerns (Van Eenennaam and Young, 2019 a). Selection methods have evolved from traditional phenotypic approaches to advanced genomic techniques, aiming to combine genetic gain with conserved genetic diversity (Mishra *et al*., 2018). Molecular genetics is developing DNA markers linked to economically important traits and disease resistance, which could provide objective tests for identifying desirable genes in animals (Gogolin-Ewens *et al*., 1990).

Types of Traits in Genetic Selection

Genetic selection in livestock has evolved over time, expanding from a focus solely on production traits to also consider animal welfare, health, and environmental sustainability (Miglior *et al*., 2017). Temperament traits, which influence both animal welfare and productivity, have moderate heritability and are amenable to selection. However, they are not commonly incorporated into breeding programs (Haskell *et al*., 2014).

Social genetic effects, which reflect the influence of an individual on its group mates, are crucial for improving socially-affected traits and overall welfare in livestock (Ellen *et al*., 2014). Another important focus for genetic selection is climate change adaptation, with heat tolerance being a heritable and variable trait among livestock breeds.Traits such as skin properties, coat color, and sweating capacity—along with genomic data and molecular markers—can be used to select for heat-tolerant and feed-efficient animals (Tesema *et al*., 2019). By combining genomic and phenotypic selection methods, the breeding of productive and climate-resilient livestock can be accelerated.

Phenotypic traits in livestock are complex characteristics influenced by both genetic and environmental factors. Accurate phenotyping is essential for understanding the relationships between genes and phenotypes, which in turn improves breeding outcomes (Hocquette *et al*., 2012).

Advanced technologies, including digital phenotyping and unmanned aerial systems, offer promising solutions for the automated assessment of dynamic phenotypic traits. These innovations provide valuable data on livestock adaptation and stress tolerance (Upadhyay *et al*., 2024).While most livestock traits are complex, some are controlled by single genes, such as porcine stress syndrome and double muscling in cattle. Understanding the interactions between genotype, endophenotypes, and external phenotypes is crucial for gaining insight into the genetic basis of complex traits in livestock (te Pas *et al*., n.d.).

Genetic factors play a significant role in meat quality, disease resistance, and reproduction traits in livestock. In pigs, the halothane sensitivity gene (HALn) and RN- gene greatly influence pork quality (Sellier and Monin, 1994). For cattle, heritability of meat quality traits ranges from low to moderate, with intramuscular fat content being highly heritable (Marshall, 1999). Disease resistance in livestock is often polygenic and influenced by environmental factors, making it challenging to identify specific gene variants (Reiner, 2008). In Merino sheep, genetic parameters for various traits including bodyweight, wool characteristics, and internal parasite resistance have been estimated. Heritabilities range from low (0.09-0.10) for reproductive traits to high (0.62-0.77) for fiber diameter. Many traits show significant genetic variation, suggesting potential for genetic improvement through selective breeding (Huisman *et al*., 2008). These findings highlight the importance of genetics in livestock breeding programs for improving economically important traits.

Methods of Genetic Selection

Traditional livestock breeding practices have long been based on selective breeding, focusing on visual and performance traits. In Somalia, pastoralists select animals based on characteristics like adaptability to harsh environments, market value, and milk production (Marshall *et al*., 2016). Over time, the focus has shifted from an emphasis on purebred appearance to performance-based selection, with greater attention given to economic goals (Harris and Newman, 1994). This shift has facilitated significant genetic progress in food animals, often achieved without a comprehensive understanding of the underlying genetics (Van Eenennaam and Young, 2019 b). In Southern Ethiopia, indigenous communities utilize traditional selection criteria for different livestock species, including informal pedigree tracking, phenotypic traits such as hair whorls and coat color, and functional efficiency. These traditional practices are often linked with production and reproductive efficiency, indicating their potential value in developing region-specific livestock selection strategies (Banerjee *et al*., 2014).

Genomic selection has transformed livestock breeding by using high-throughput SNP genotyping and molecular tools to identify desirable genes (Husien *et al*., 2024). This method improves breeding decisions, particularly for traits that are sex-limited, have low heritability, or are only measurable later in life (Goddard *et al*., 2010). It enables the prediction of genomic breeding values, allowing for more precise selection of breeding animals. While genomic selection has been successfully incorporated into dairy cattle breeding programs, its application in other species and crossbreeding schemes still requires further investigation. The technology has significantly altered the structure of the genetics industry, with new players entering the field and the potential to lower costs and accelerate genetic progress by reducing generation intervals (Bagnato and Rosati, 2012). However, applying genomic information to specific breeding goals in various livestock species must be approached with caution.

Crossbreeding is a commonly used strategy to enhance genetic diversity and improve livestock production by combining desirable traits from different breeds (Yadav *et al*., 2018; Mekonnen and Selam, 2020). This approach leverages heterosis, which peaks in the F1 generation, to boost productivity and reproductive efficiency. In cattle, crossbreeding has been particularly successful in improving milk yield, growth rates, and adaptation to tropical climates. However, the sustainability of crossbreeding programs in developing countries depends on factors such as consistent access to breeding stock, effective management practices, and market integration. While crossbreeding can drive innovation and development, uncontrolled practices may jeopardize the conservation of indigenous breeds (Leroy *et al*., 2016). Therefore, to ensure long-term success in livestock improvement, it is essential to implement systematic crossbreeding programs with clear and structured breeding policies (Mekonnen *et al*., 2020).

Impact of Genetic Selection on Livestock Production

Improved Productivity and Efficiency: Genetic selection has significantly improved livestock productivity and efficiency through various approaches. Marker-assisted selection (MAS) and genomic selection have revolutionized animal breeding by enabling more precise identification and selection of superior traits (Burrow and Goddard, 2023). These techniques have accelerated genetic gains and improved quantitative traits, disease resistance, and overall genetic diversity in livestock populations (Li and Lin, 2024). Traditional breeding schemes, genomics, and biotechnologies have all contributed to the advancement of livestock agriculture (Schultz *et al*., 2020 b). However, the focus on increased production has led to unintended consequences for animal health and welfare, including reduced fertility, lameness, and genetic defects. To address these issues, it is crucial to include animal welfare concepts in breeding objectives and selection strategies. The development of more robust selection indices and accurate phenotyping of welfare traits are necessary for sustainable livestock production (van Marle-Köster and Visser, 2021).

Disease Resistance: This approach utilizes proven animal breeding methods and is gaining attention from breeders. While concerns about sustainability, feasibility, and desirability have been raised, evidence suggests that enhanced disease resistance is stable under natural selection and therefore sustainable. The feasibility of selective breeding depends on trait heritability and variation among animals, which are often favorable for disease resistance traits. Mathematical models are necessary to predict the effects of genetic and epidemiological changes on disease incidence in breeding programs (Stear *et al*., 2012). Modern genomic techniques, including DNA markers, are being developed to identify desirable genes more efficiently (Gogolin-Ewens *et al*., 1990).

Better Feed Conversion: Genetic selection has significantly impacted livestock production, particularly in improving feed efficiency. Residual feed intake (RFI) has emerged as a superior measure of feed efficiency compared to traditional feed conversion ratio, showing genetic variation and heritability in both cattle and pigs (Hoque and Suzuki, 2009). This technology has already doubled genetic gains in dairy industries globally (Hayes *et al*., 2013). While past genetic improvement strategies focused on output traits, recent attention has shifted to input-related traits like feed utilization efficiency. However, challenges remain, including the high cost of recording feed intake and the need for more information on genetic relationships between feed efficiency and other traits across different production phases (Arthur and Herd, 2005). Future breeding programs aim to exploit genetic variation in feed utilization to improve overall production system efficiency.

Meat Quality and Traits: Genetic selection has significantly impacted livestock production and meat quality. While selection for increased productivity has led to changes in muscle morphology and physiology, potentially affecting meat quality and animal welfare (Henckel, 2002), genetic improvement of meat quality traits is possible due to the considerable genetic variation that exists. The integration of DNA-based technologies into breeding programs can accelerate genetic gain for meat quality traits (Berry *et al*., 2017), potentially leading to more consistent production of high-quality meat across entire populations. Factors influencing meat quality include connective tissue, sarcomere length, proteolysis rate, intramuscular fat, and post-mortem energy metabolism (Warner *et al*., 2010). Advances in molecular genetics have enabled the identification of genes and markers associated with meat quality traits. Strategies such as candidate gene approaches and genome scans have been employed to identify loci linked to meat quality (Gao *et al*., 2007).

Herd Improvement through Genetic Selection

Genetic selection plays a crucial role in improving livestock production and herd performance. Searle (1961) estimated the genetic improvement in milk fat production over a 15-year period through culling and selective breeding, demonstrating significant gains when combining herd-testing and artificial breeding. Gianola and Hammond (1990) highlighted advancements in statistical methods for genetic improvement, which have enhanced the accuracy of selection programs. Kearney (2007) emphasized that improving genetic merit, alongside proper nutrition and management, can increase productivity and profitability in dairy herds. The author stressed the importance of selecting for production, reproduction, and health traits to produce easier-to-manage cows. Lasley (1972) provided a comprehensive overview of livestock improvement genetics, further supporting the significance of genetic selection in enhancing herd performance. These studies collectively underscore the effectiveness of genetic selection in improving livestock productivity and economic efficiency. Well-designed breeding programs can achieve sustainable genetic improvements of 1-2% annually, with significant gains observed in dairy, pig, and poultry production systems (van der Werf, 2022). Demonstrating the value of herd improvement requires a multi-faceted approach that extends beyond monetary worth, considering factors such as risk and environmental footprint (Newton *et al*., 2020).0

Genetic diversity in livestock populations is crucial for meeting production needs, facilitating adaptation, and sustaining genetic improvement. However, intensive selection practices have led to increased inbreeding rates, particularly in dairy cattle and poultry (Notter, 1999; Doormaal *et al*., 2005). The advent of genomic information has enabled more accurate estimation of shared alleles between individuals, allowing for better management of inbreeding and genetic variability. This genomic approach can help identify specific regions affected by inbreeding and potentially mitigate associated performance reductions (Howard *et al*., 2017).

Challenges and Limitations of Genetic Selection

Ethical Considerations: Genomic selection in breeding programs has significant potential to enhance genetic gain in livestock. However, its implementation across various species presents several challenges (Ibáñez-Escriche and González-Recio, 2011). A major limitation is the high cost of genotyping relative to the selection value of candidates, particularly in non-dairy cattle species (Tecnología Agraria, 2011). As gene editing and selection technologies become more accessible, ethical considerations come to the forefront, particularly regarding germline editing and its potential impact on future generations. Preimplantation genetic testing (PGT) has emerged as a technique to mitigate the risk of transmitting genetic diseases, though it also faces its own set of limitations and ethical dilemmas. These advancements in genetic selection and editing technologies require careful evaluation of their utility, implications, and responsible implementation. It is essential to balance the potential benefits with the ethical and practical challenges they present (Rothschild, 2020; Giuliano *et al*., 2023).

Technological and Financial Barriers: Genomic selection holds great promise for improving genetic gain in livestock breeding programs. However, its adoption faces several challenges, particularly in low- to middle-income countries. Key limitations include the high cost of genotyping in relation to the selection value of candidates. Additional obstacles include difficulties in accurate phenotype recording, limited reference populations, concerns about sustainability, lack of infrastructure, and insufficient human capacity (Burrow *et al*., 2021). While genomic selection has been successfully implemented in dairy cattle, particularly Holsteins, its application in other species is still largely experimental (Ibáñez-Escriche and González-Recio, 2011). To overcome these challenges, researchers are exploring the use of low-density SNP chips to reduce the costs of genomic selection and make it more economically viable. Efforts are also being made to address these challenges and extend the benefits of genomic selection to smallholder farmers in developing countries (Burrow *et al*., 2021).

Maintaining Genetic Diversity: Genomic selection offers significant potential to increase genetic gain in livestock breeding programs, but its implementation faces challenges across different species. High genotyping costs relative to candidate selection value limit its application in many livestock species, though low-density SNP chips may make it more economically feasible (Ibáñez-Escriche and González-Recio, 2011). In marine resources management, maintaining genetic diversity is crucial. While extinction and hybridization are less immediate concerns for marine populations, reduction of genetic variability within populations poses a significant threat. This can occur through inbreeding in severely overfished populations or through selective fishing, which can alter life history traits and impact population dynamics. Management strategies should focus on mitigating genetic complications associated with small population sizes and fisheries-induced selection to maintain genetic diversity in marine resources (Kenchington and Heino, 2002).

Future Trends in Genetic Selection for Livestock

Future trends in genetic selection for livestock will focus on improving efficiency, reducing environmental impact, and adapting to climate change. Genomic selection, using genome-wide SNP markers, is expected to double genetic gains in dairy industries and accelerate the discovery and elimination of genetic defects. The technology aims to address growing global demand for animal products while minimizing environmental impact, focusing on efficiency, reduced emissions, and adaptation to climate change (Hayes *et al*., 2013). While molecular genetic methods and marker-assisted selection show promise, their economic feasibility depends on reduced genotyping costs. Balancing short-term selection benefits with long-term inbreeding risks remains crucial (Eisen, 2007). Rapid developments in phenotyping and genomic technologies, coupled with advanced prediction algorithms, are driving progress in livestock genetics. Future challenges include reducing livestock's impact on climate change, addressing animal welfare concerns, and meeting diverse consumer demands. The ability to measure, predict, and act will be fundamental to achieving these objectives and ensuring the continued success of animal breeding (Calus *et al*., 2022). Advanced reproductive technologies and in vitro recombination will likely accelerate genetic selection. Transgenesis and mutagenesis may be applied to introduce desired traits. Selection will expand to include environmental and adaptive traits (Hume *et al*., 2011).

Conclusion

Traditionally, breeding programs for farm animals have prioritized the genetic improvement of traits considered economically significant for production. As a result, farm animal productivity increased dramatically in the second half of the twentieth century. This remarkable progress was largely driven by the implementation of effective selective breeding programs. Social interactions play a crucial role in the genetic improvement of livestock. Implementing a selection method that accounts for both direct and social effects is essential for achieving simultaneous improvements in animal welfare and productivity.

References

1. Arthur, P. F. and Herd, R. M. (2005). Efficiency of feed utilisation by livestock—Implications and benefits of genetic improvement. *Canadian Journal of Animal Science*, ***85***(3), 281-290.

2. Bagnato, A. and Rosati, A. (2012). From the Editors—Animal selection: The genomics revolution. *Animal Frontiers*, ***2***(1), 1-2.
3. Banerjee, S., Beyan, M. and Bekele, H. (2014). Some traditional livestock selection criteria as practiced by several indigenous communities of Southern Ethiopia. *Animal Genetic Resources/Resources génétiques animales/Recursos genéticos animales*, ***54***, 153-162.
4. Basarab, J., Valente, T., Wang, Y., Vinsky, M., Li, C. and Plastow, G. (2023). Validation of genomic tools to improve production efficiency, health resilience and the carbon footprint of beef production. In American Association of Bovine Practitioners Conference Proceedings (No. 56, pp. 22-30).
5. Berry, D. P., Conroy, S., Pabiou, T. and Cromie, A. R. (2017). Animal breeding strategies can improve meat quality attributes within entire populations. *Meat science*, *132*, 6-18.
6. Burrow, H. M., Mrode, R., Mwai, A. O., Coffey, M. P. and Hayes, B. J. (2021). Challenges and opportunities in applying genomic selection to ruminants owned by smallholder farmers. *Agriculture*, ***11***(11), 1172.
7. Burrow, H. and Goddard, M. (2023). Application of Genetics and Genomics in Livestock Production. *Agriculture*, ***13***(2), 386.
8. Calus, M. P. L., Berry, D. P. and Pryce, J. E. (2022, December). Measure, predict and act; a paradigm of genetics applied to livestock production now and into the future. In *Proceedings of 12th World Congress on Genetics Applied to Livestock Production (WCGALP) Technical and species orientated innovations in animal breeding, and contribution of genetics to solving societal challenges* (pp. 53-56). Wageningen Academic Publishers.
9. Eisen, E. J. (2007). Animal breeding: What does the future hold?. *Asian-australasian journal of animal sciences*, **20**(3), 453-460.
10. Ellen, E. D., Rodenburg, T. B., Albers, G. A., Bolhuis, J. E., Camerlink, I., Duijvesteijn, N. and Bijma, P. (2014). The prospects of selection for social genetic effects to improve welfare and productivity in livestock. *Frontiers in genetics*, *5*, 377.
11. Gao, Y. U., Zhang, R., Hu, X. and Li, N. (2007). Application of genomic technologies to the improvement of meat quality of farm animals. *Meat science*, ***77***(1), 36-45.
12. Georges, M., Charlier, C. and Hayes, B. (2019). Harnessing genomic information for livestock improvement. *Nature Reviews Genetics*, ***20***(3), 135-156.
13. Getiso, A. (2024). An Overview of Livestock Role in Ensuring Food and Nutrition Security: The Case of Ethiopia. Nutrition and Food Processing, **7**(8), 01–08.
14. Gianegitz, M. R., de Souza, R. P., de Almeida, J. S., Wasilewski, R. de S., SILVA, M., Mansolelli, G. G., Braga, T., Teixeira da Cunha, I. A., Grandi, M. C., de Oliveira, S. L., Colombo, F. G. S. and da Costa, I. B. (2024). Contributions of genetic improvement programs for dairy livestock farming. Seven Editora.
15. Gianola, D., Im, S. and Macedo, F. W. (1990). A framework for prediction of breeding value. In *Advances in statistical methods for genetic improvement of livestock* (pp. 210-238). Berlin, Heidelberg: Springer Berlin Heidelberg.
16. Giuliano, R., Maione, A., Vallefuoco, A., Sorrentino, U. and Zuccarello, D. (2023). Preimplantation genetic testing for genetic diseases: limits and review of current literature. *Genes*, ***14***(11), 2095.
17. Goddard, M. E., Hayes, B. J. and Meuwissen, T. H. (2010). Genomic selection in livestock populations. *Genetics research*, ***92***(5-6), 413-421.
18. Gogolin-Ewens, K. J., Meeusen, E. N., Scott, P. C., Adams, T. E. and Brandon, M. R. (1990). Genetic selection for disease resistance and traits of economic importance in animal production. *Revue Scientifique et Technique (International Office of Epizootics)*, ***9***(3), 865-896.
19. Harris, D. L. and Newman, S. (1994). Breeding for profit: synergism between genetic improvement and livestock production (a review). *Journal of animal science*, ***72***(8), 2178-2200.

20. Haskell, M. J., Simm, G. and Turner, S. P. (2014). Genetic selection for temperament traits in dairy and beef cattle. *Frontiers in genetics*, *5*, 368.
21. Hayes, B. J., Lewin, H. A. and Goddard, M. E. (2013). The future of livestock breeding: genomic selection for efficiency, reduced emissions intensity, and adaptation. *Trends in genetics*, ***29***(4), 206-214.
22. Henckel, P. (2002). Genetic improvement in meat quality: potentials and limitations.
23. Hocquette, J. F., Capel, C., David, V., Guemene, D., Bidanel, J., Ponsart, C. and PEYRAUD, J. L. (2012). Objectives and applications of phenotyping network set-up for livestock. *Animal Science Journal*, ***83***(7), 517-528.
24. Hoque, M. A. and Suzuki, K. (2009). Genetics of residual feed intake in cattle and pigs: A review. *Asian-Australasian Journal of Animal Sciences*, ***22***(5), 747-755.
25. Howard, J. T., Pryce, J. E., Baes, C. and Maltecca, C. (2017). Invited review: Inbreeding in the genomics era: Inbreeding, inbreeding depression, and management of genomic variability. *Journal of dairy science*, ***100***(8), 6009-6024.
26. Huisman, A. E., Brown, D. J., Ball, A. J. and Graser, H. U. (2008). Genetic parameters for bodyweight, wool, and disease resistance and reproduction traits in Merino sheep. 1. Description of traits, model comparison, variance components and their ratios. *Australian Journal of Experimental Agriculture*, ***48***(9), 1177-1185.
27. Hume, D. A., Whitelaw, C. B. A. and Archibald, A. L. (2011). The future of animal production: improving productivity and sustainability. *The Journal of Agricultural Science*, ***149***(S1), 9-16.
28. Husien, H. M., Saleh, A. A., Hassanine, N. N., Rashad, A. M., Sharaby, M. A., Mohamed, A. Z. and Wang, M. (2024). The Evolution and Role of Molecular Tools in Measuring Diversity and Genomic Selection in Livestock Populations (Traditional and Up-to-Date Insights): A Comprehensive Exploration. *Veterinary Sciences*, ***11***(12), 627.
29. Ibáñez-Escriche, N. and González Recio, O. (2011). Promises, pitfalls and challenges of genomic selection in breeding programs.
30. Ibraheem, O. T. (2023). Addressing low livestock production: Key factors, challenges, and sustainable solutions for improved agricultural output, a review. World Journal of Advanced Research and Reviews, **20**(3), 1104–1125.
31. Kearney, F. (2007). Improving dairy herd fertility through genetic selection. *Irish Veterinary Journal*, ***60***(6).
32. Kenchington, E. and Heino, M. (2002). Maintenance of genetic diversity: challenges for management of marine resources. ICES.
33. Lasley, J. F. (1963). Genetics of livestock improvement.
34. Leishman, E. M., Jahnel, R. E., Harlander, A., Willems, O. W., Wood, B., Barbut, S. and Baes, C. F. (2024). 301 Leveraging genomics to advance the breeding of Canadian livestock. *Journal of Animal Science*, ***102***(Supplement_3), 178-178.
35. Leroy, G., Baumung, R., Boettcher, P., Scherf, B. and Hoffmann, I. (2016). Sustainability of crossbreeding in developing countries; definitely not like crossing a meadow…. *Animal*, ***10***(2), 262-273.
36. Li, J. and Lin, X. (2024). Analyzing the Impact of Marker-Assisted Selection on Livestock Productivity and Genetic Diversity. *Animal Molecular Breeding*, *14*.
37. Marshall, D. M. (1999). Genetics of meat quality.
38. Marshall, K., Mtimet, N., Wanyoike, F., Ndiwa, N., Ghebremariam, H., Mugunieri, L. and Costagli, R. (2016). Traditional livestock breeding practices of men and women Somali pastoralists: trait preferences and selection of breeding animals. *Journal of Animal Breeding and Genetics*, ***133***(6), 534-547.
39. Mekonnen, T. and Selam, M. (2020). Genetic Improvement Strategy of Indigenous Cattle Breeds: Effect of Cattle Crossbreeding Program on Their Reproductive Performances. *Asian Journal of Biotechnology and Genetic Engineering*, ***3***(1), 19-30.

40. Mekonnen, T., Tadesse, Y. and Meseret, S. (2020). Genetic improvement strategy of indigenous cattle breeds: Effect of cattle crossbreeding program in production performances. *Journal of Applied Life Sciences International*, ***23***(1), 23-40.
41. Miglior, F., Fleming, A., Malchiodi, F., Brito, L. F., Martin, P. and Baes, C. F. (2017). A 100-Year Review: Identification and genetic selection of economically important traits in dairy cattle. *Journal of dairy science*, ***100***(12), 10251-10271.
42. Mishra, S. P., Mishra, C., Datta, S., Taraphder, S., Mishra, D. P. and Priyadarshini, P. (2018). Selection procedure towards genetic improvement of animals: A overview. *Journal of Entomology and Zoology Studies*, ***6***(1), 599-608.
43. Newton, J. E., Axford, M. M., Ho, P. N. and Pryce, J. E. (2020). Demonstrating the value of herd improvement in the Australian dairy industry. *Animal Production Science*, ***61***(3), 220-229.
44. Notter, D. R. (1999). The importance of genetic diversity in livestock populations of the future. *Journal of animal science*, ***77***(1), 61-69.
45. Palapa, N. (2024). Livestock development is an integral part of the sustainable development of the ukrainian countryside and the country’s food security. Balanced Nature Using.
46. Reiner, G. (2008). Genetics and disease resistance. *DTW. Deutsche Tierarztliche Wochenschrift*, ***115***(7), 252-259.
47. Rodenburg, T. B. and Turner, S. P. (2012). The role of breeding and genetics in the welfare of farm animals. *Animal frontiers*, ***2***(3), 16-21.
48. Rothschild, J. (2020). Ethical considerations of gene editing and genetic selection. *Journal of general and family medicine*, ***21***(3), 37-47.
49. Schultz, B., Serão, N. and Ross, J. W. (2020). Genetic improvement of livestock, from conventional breeding to biotechnological approaches. In *Animal Agriculture* (pp. 393-405). Academic Press.
50. Searle, S. R. (1961). Estimating herd improvement from selection programs. *Journal of Dairy Science*, ***44***(6), 1103-1112.
51. Sellier, P. and Monin, G. (1994). Genetics of pig meat quality: a review. *Journal of muscle foods*, ***5***(2), 187-219.
52. Stanojevic, D., Đedovic, R. Ć. and Gligovic, N. (2023). Genomics as a tool for improving dairy Cattle Population. *" Annals of the University of Craiova-Agriculture Montanology Cadastre Series"*, ***53***(1), 291-297.
53. Stear, M. J., Bishop, S. C., Mallard, B. A. and Raadsma, H. (2001). The sustainability, feasibility and desirability of breeding livestock for disease resistance. *Research in veterinary science*, ***71***(1), 1-7.
54. Te Pas, M. F., Madsen, O., Calus, M. P. and Smits, M. A. (2017). The importance of endophenotypes to evaluate the relationship between genotype and external phenotype. *International journal of molecular sciences*, ***18***(2), 472.
55. Tesema, Z., Taye, M. and Ayichew, D. (2019). The role of phenotypic and genetic basis of livestock selection for climate change adaptation and mitigation: A review. *J Appl Adv Res*, ***4***(2), 66-77.
56. Upadhyay, V. R., Ramesh, V., Kumar, H., Somagond, Y. M., Priyadarsini, S., Kuniyal, A. and Sahoo, A. (2024). Phenomics in livestock research: Bottlenecks and promises of digital phenotyping and other quantification techniques on a global scale. *OMICS: A Journal of Integrative Biology*, ***28***(8), 380-393.
57. Van der Werf, J. H. (2022). Sustainable animal genetic improvement. In *E3S Web of Conferences* (Vol. 335, p. 00001). EDP Sciences.
58. Van Doormaal, B. J., Miglior, F., Kistemaker, G. and Brand, P. (2005). Genetic diversification of the Holstein breed in Canada and internationally. *Interbull Bulletin*, (33), 93-93.
59. Van Eenennaam, A. L. and Young, A. E. (2019). Genetic improvement of food animals: past and future.

60. Van Marle-Köster, E. and Visser, C. (2021). Unintended consequences of selection for increased production on the health and welfare of livestock. *Archives Animal Breeding*, ***64***(1), 177-185.
61. Warner, R. D., Greenwood, P. L., Pethick, D. W. and Ferguson, D. M. (2010). Genetic and environmental effects on meat quality. *Meat science*, ***86***(1), 171-183.
62. Yadav, V., Singh, N. P., Sharma, R., Gupta, A., Baranwal, A., Ahmad, S. F. and Raina, V. (2018). Crossbreeding systems of livestock. *The Pharma Innovation Journal*, ***7***(7), 08-13.
63. Yadav, V., Singh, N. P., Sharma, S., Lakhani, N., Bhimte, A., Khare, A. and Yousuf, S. (2018). Genomic selection