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Deciphering and Measures of Robustness and Resilience in Farm Animal: A Review

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Authors' contributions

This work was carried out in collaboration between both authors. The article was drafted and analyzed by author LG, and it was prepared and interpreted by author HAW. Both authors read and approved the final manuscript.

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ABSTRACT

The ability of an animal to adapt to transient environmental difficulties and regain its pre-challenge state is known as resilience, and it is a dynamic and multifaceted characteristic. The ability of the herd to adapt to often shifting and uncertain environmental conditions can be strengthened by resilient animals. The capacity of contemporary technologies to capture many performance metrics of individual animals in real time is a significant advancement in assessing the resilience of farm animals. Resilience, however, cannot be measured directly; instead, quantitative resilience indicators must be derived from mathematical models with biologically meaningful characteristics. This work aimed to review and demonstrate, via examples, several modeling methodologies used with this new type of data (high-frequency recording) in order to identify and measure animal reactions to disturbances.

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1. INTRODUCTION

Animal Husbandry is an integral part of agriculture, making a significant contribution to the rural economy and socio-economic development in many developing countries. Livestock is also linked closely with the local culture and traditions, which are being followed ever since the domestication of livestock for economic benefits [1,2]. Climate change has significant implications for livestock production, affecting animals, farmers, and the entire food supply chain. Therefore, managing the impacts of climate change on livestock production is crucial for achieving economic stability and ensuring the welfare of both animals and farmers [3,4,5].

The concepts of robustness and resilience provide a framework for developing and managing animal production systems that can withstand the challenges posed by global warming. By incorporating these principles into breeding programs and management practices at animal farm, the aim is to ensure the long-term sustainability and welfare of livestock in a changing climate [6,7,8,9]. However, the capacity for animals to recover quickly from stressors is a multifaceted attribute that has far-reaching implications for both wild species and farm animals [10]. It is a crucial aspect of evolutionary fitness, welfare in farm settings, and the overall sustainability and efficiency of livestock production systems. Efforts to understand, measure, and enhance this capacity contribute to the well-being of animals, economic viability in livestock, and the long-term success of livestock farm practices [11,12]. Prior to designing strategies to enhance livestock production, it is crucial to address two key characteristics: robustness and resilience. These attributes are particularly significant in the context of climate change. This article covers the identified needs and discusses alternative solutions to address them, using livestock production as an example. The needs include anticipating environmental changes, mitigating feed scarcity, managing the advent of new diseases, and addressing increased heat stress.

2. ROBUSTNESS AND RESILIENCE

Robustness and resilience in the context of farm animals differentiate between the two terms and explain how they relate to the ability of animals to thrive in various environmental conditions. Resilience pertains to an animal's capacity to adapt to stressors and return to its normal state. In this context, 'state' encompasses not only production, but also physiological, behavioral, cognitive, and health characteristics of the animal [13]. Robustness refers to the capacity to have a significant production potential while also being resilient to stressors in various environmental conditions, without affecting reproduction, health, and wellbeing [14].

Resilience refers to an animal's capacity to bounce back from a shock, particularly one that is of relatively brief duration [15,16,17]. This suggests that animals must possess adaptability in response to a variable environment. However, Robustness is the ability of a system to withstand perturbations and continue functioning effectively over an extended period, even in unfavorable conditions.

In the context of livestock breeding or any other system, robustness implies a sustained ability to thrive despite challenges. In a stable and favorable environment, where conditions remain relatively constant and predictable, a system may require less robustness and resilience. On the other hand, in a poor or variable environment with unpredictable changes, both robustness and resilience becomes crucial [18]. A system needs to be able to cope with ongoing challenges and be capable of bouncing back from disturbances.

3. FACTORS INFLUENCING ROBUSTNESS AND RESILIENCE

3.1 Genetic Diversity

Maintaining a diverse gene pool is essential for building robust and resilient livestock populations. Genetic diversity provides the raw material for adaptation to changing environmental conditions and resistance to diseases [19].

3.2 Selective Breeding for Resilience Traits

Identify and select for traits associated with resilience. These may include disease resistance, reproductive performance, adaptability to different environments, and the ability to withstand various stressors. Integrate these traits into the breeding goals to enhance the overall resilience of the population.

3.3 Avoiding Close Inbreeding

Recent advancements in genetic selection programs have led to an increase in the annual response to selection. However, rates of inbreeding have also increased substantially as a result. For instance, animal model BLUP has improved the accuracy of EBV and has increased the likelihood of coselection of related animals. Additionally, reproductive technologies like embryo transfer (ET) and in-vitro fertilization (IVF) have led to increased selection intensity by reducing the number of parents needed to produce the next generation of breeding animals [20]. The development of multiple ovulation and embryo transfer (MOET) schemes has also reduced generation intervals, but it has led to greater emphasis on information from relatives rather than data regarding individual performance. Due to these factors, both genetic progress and inbreeding are increasing at an increasing rate in today's commercial livestock populations [21].

To address this issue, strategies for maintaining variation have been proposed, such as limiting relationships between selected animals or artificially increasing the emphasis on within-family information when estimating breeding values. Corrective mating programs are commonly used in some species, and can be adjusted to take into account the selection for economic merit while also addressing inbreeding depression [22]. One promising approach is selecting parents of AI bulls based on their optimal genetic contribution to future generations, taking into account their estimated breeding values and genetic relationships with other selected individuals. However, it is important to implement these procedures quickly to prevent further reductions in effective population size [23].

3.4 Genomic Selection or Marker Assisted Selection

Genomic selection uses genetic markers covering the entire genome to ensure that all quantitative trait loci are in linkage disequilibrium with at least one marker. By selecting animals at an early stage, it is possible to develop novel breeding strategies that can advance genetic progress while also reducing costs. It's no surprise that genomic selection is the future of livestock breeding companies, as it can improve genetic gain by reducing genetic interval and increasing reliability [24].

3.5 Cryopreservation of Germplasm

Implement cryopreservation techniques to store genetic material (such as semen, embryos, or germplasm) from a wide range of individuals. This serves as a backup and can be used to reintroduce genetic diversity if needed in the future.

3.6 Rotational Breeding and Crossbreeding

Incorporate rotational breeding or crossbreeding programs to introduce genetic diversity into the population. These strategies involve mating individuals from different lines or breeds to capitalize on the benefits of heterosis (hybrid vigor).

3.7 Monitoring Population Structure

Regularly assess the population structure to identify any decline in genetic diversity. Monitoring tools such as genetic markers or pedigree analysis can provide insights into the health of the gene pool and help guide breeding decisions.

3.8 Natural Selection and Adaptive Management

The process by which animal species that are most adapted to their surroundings endure and procreate while less adapted species become extinct is known as natural selection. Only the fit exist to pass on their genes to the following generation, because of natural selection. Exposure to environmental conditions and challenges can help identify individuals with superior adaptive traits [25]. Breeding plans are modified as part of adaptive management approaches in response to the following environmental shifts and observed results:

Genetic adaptation of farm animals to provide food for humans: Meeting expanding human requirements will require a deeper knowledge of the underlying genetic control of adaptation in native and exotic livestock. It is necessary to preserve the genetic diversity to pass it on to the following generation. Meeting expanding human requirements will require a deeper knowledge of the underlying genetic control of adaptation in native and exotic livestock [26]. It is necessary to preserve the genetic diversity to pass it on to the following generation. The developed world's livestock farmers and consumers benefited from the accessibility and affordability of animal genetic technologies. The developing world will also benefit from these tools by gaining new opportunities [27].

Genetic modification of farm animals' functional features for purposes of welfare and financial gain: Functional features lower production costs, which is a key factor in biological and economic efficiency. Due to the increasing demand from consumers for farm animal products, there must be a supply of low-cost, high-quality products that prioritize the welfare of farm animals. Functional features should be taken into account in order to create an effective and efficient breeding program [27,28].

Climate change and genetic adaptability in farm animals: Sufficient animal genetic resource conservation is required to protect adaptation prospects in uncertain times to overcome the likely climate change issue, which will be a significant force testing the elasticity of global food production systems [29]. It seems unlikely that a single method will be sufficient to achieve climate change adaptation. Thus, the efforts made to combat climate change in farm animals will be aided by the scientific commitment and genomics application. The strongest defense against climate change is to raise native breeds that are hardy in their surroundings [30]. For many years, breeds from wealthy nations have been investigated in case climate change is managed. In order to obtain the necessary information, the production system in a given location should be explained by looking at geographical features. This will require more research into the implications of adaptability, socioeconomic data, and local breed management information within the habitat. For this reason, crossbreeding might be a useful tactic to achieve higher flexibility and output. In simple terms, genetic adaptation promotes productivity, efficiency, and the preservation of genetic variety, creating more chances to match breeds to shifting environmental conditions [31,32].

4. ENVIRONMENT FACTORS

Robustness and resilience play crucial roles in ensuring the sustainability and productivity of the breeding program, in livestock breeding involve selecting for traits that enable animals to adapt to changing environmental conditions, withstand stressors, and maintain productivity. Integrating these principles into breeding programs contributes to the sustainability and success of livestock operations in diverse and dynamic environments [33,34].

4.1 Climate Adaptation

Breeding for resilience and robustness involves selecting animals that can adapt to changes in climate patterns. This may include choosing breeds or individuals with traits that enable them to thrive in varying temperature ranges, resist heat stress, or adapt to different weather conditions.

4.2 Disease Resistance

Robust breeding programs focus on building resistance to prevalent diseases, either through natural selection or targeted breeding for genetic traits associated with disease resistance. Reducing disease susceptibility contributes to the overall robustness of the livestock population [18].

4.3 Forage and Feed Efficiency

Breeding programs emphasize traits related to efficient nutrient utilization and the ability to thrive on a variety of feed sources. Livestock with robust digestive systems and efficient metabolism can better cope with fluctuations in feed quality.

5. REPRODUCTIVE PERFORMANCE

5.1 Resilience

Breeding for reproductive resilience involves selecting animals with traits that contribute to consistent reproductive performance such as fertility, adaptability to different breeding systems, and the ability to maintain reproductive performance in the face of environmental stressors [23].

5.2 Adaptability to Environmental Variability

Breeding programs emphasize adaptability to various environmental factors, aiming to produce livestock that can maintain performance and health in different ecological settings [11].

6. MEASURES OF ROBUSTNESS AND RESILIENCE

6.1 Genetic Diversity Assessment

The measurement of genetic diversity within and between populations is a standard molecular procedure that involves using various laboratory-based methods like allozyme or DNA analysis. These techniques directly measure levels of variation and are routinely used to assess genetic diversity at the molecular level. It is essential to evaluate the level of genetic variation in populations before implementing any conservation or development plans, as genetic diversity is crucial for adaptation to changing environments and artificial selection. Parameters such as effective population size and rate of inbreeding, which are independent of the number of pedigree records, are the most appropriate ways to describe genetic variation [35].

Marker data can also be used for paternity analysis and estimation of co ancestries, but accuracy requires typing thousands of markers. Genetic diversity across breeds is a crucial source of variation for rescuing problematic populations and introducing new variants. When estimating variation between populations, considering adaptive variation adds new layers of complexity [36].

6.2 Flexibility and Efficiency in High Pressure Situations

Conduct controlled studies or observations to assess the performance of animals under stressful conditions, such as heat stress or nutritional stress. Evaluate physiological and behavioral cues, such as food consumption, increase in body mass, and reproductive efficacy. Animals that are resilient experience less deterioration in their performance and demonstrate superior recuperation when faced with stressful conditions. Durable organisms regularly sustain optimal performance regardless of environmental adversities.

Assess the reproductive parameters in diverse environmental conditions, such as variations in temperature or alterations in the availability of food resources, to determine the level of reproductive success. Analyze the rates of fertility, conception, and calving intervals. Resilient breeding systems exhibit continuous reproductive performance across a wide range of environmental variables. Strong and resilient reproductive characteristics contribute to consistent and dependable breeding results [36,37].

6.3 Disease Resistance and Health Parameters

Conduct sickness challenge tests or evaluate health records to quantify the frequency and intensity of diseases. Analyze the indications of immune response and the rates of success in vaccination. Resilient breeding programs exhibit decreased vulnerability to illnesses and faster recuperation. The livestock population's overall well-being and resilience to diseases are enhanced by strong health characteristics.

Conduct an Environmental Impact assessment to assess the environmental sustainability of the breeding program, taking into account issues such as the efficiency of water and feed usage, waste management, and ecological consequences. Utilize life cycle evaluations to measure the environmental impact of the breeding program. The implementation of sustainable and eco-friendly procedures enhances the resilience of the farm animals. A decreased environmental footprint signifies a system that is more resistant and in line with objectives of long-term sustainability [24,27].

6.4 Long Term Performance Monitoring

When evaluating the effectiveness and performance of dairy farms, key performance indicators, or KPIs, are essential such as average milk production per cow, quality of milk, feed conversion efficiency, reproductive efficiency, mortality rate, heifer replacement rate, labor efficiency, energy efficiency, water usage, herd health, cost benefit ratio, financial performance, feed cost, milk cost, environmental impact, equipment cost, transportation cost and consumers satisfaction [37,38]. Sustained performance over an extended period of time indicates both durability and adaptability. Enhancing the adaptability of the breeding program involves identifying trends and proactively resolving potential issues [38,39].

Evaluate the efficacy of breeding goals and selection criteria in attaining intended outcomes. A good association suggests that the breeding program is effectively focusing on attributes linked to strength and adaptability. Modifications to the selection criteria may be necessary to further optimize the efficacy of the breeding effort [38].

Utilize scenario planning and simulation exercises to evaluate the breeding program's ability to handle hypothetical difficulties, such as disease outbreaks, climate events, or market swings. Simulate the program's ability to adjust and bounce back under different situations. The simulation results offer valuable insights into the breeding program's capacity to withstand and overcome various hurdles. Simulation outcomes can inform modifications to management tactics [36,37].

7. FUTURE DIRECTIONS AND INNOVATIONS

The future of resilience and robustness in livestock is likely to be shaped by ongoing advancements in technology, genetics, and a deeper understanding of the complex interactions between animals and their environments. Expanding the scope of genomic selection models to include a broader range of environmental stressors allows breeders to better choose animals with enhanced adaption and resilience features. Precision Livestock Farming involves the integration of sensor technology, Internet of Things (IoT), and big data analytics to enable the real-time monitoring of individual animal health, behavior, and performance [40,38].The advancements in CRISPR gene editing technology present potential options for introducing or strengthening certain features linked to enhanced disease resistance, adaptability to different climates, and general strength and resilience. Environmental DNA (eDNA) monitoring involves the utilization of eDNA to assess ecosystems and gain understanding about the influence of animals on their environment. Climate-adaptive breeding initiatives will prioritize the development of cattle populations that are better suited to withstand and thrive in changing climatic conditions [39,41]. Breeders can utilize data-driven models and scenario planning to predict and choose features that improve resilience in response to climate change. Advancements in quantitative genomics and machine learning will enhance the precision of forecasts for intricate traits. Machine learning algorithms have the ability to examine extensive datasets, offering breeders vital knowledge about the connections between genetic and environmental factors that affect resilience and robustness [42,43].

8. CONCLUSION

Particularly for evaluating the health, welfare, and productivity of animals on an individual and collective level, a multitude of criteria are available. The bulk of these indicators, nevertheless, were created to function as "snapshot" indicators. It becomes feasible to incorporate these traits into future breeding programs when resilience is quantified on an individual basis. As a result, illness and other environmental stresses might have a less negative effect on animal wellbeing by enhancing the animals' ability to adapt to their changing surroundings. Also, by using this kind of quantification, the farmer can modify their management approach to help each animal adjust to the disturbance, which lowers the need for medication and lessens the animal's level of suffering.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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