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Advances in Goat Disease Resistance Through Genetic Selection

Qiqi Zhou, Hui Liu, Shiqiang Huang
Tropical Animal Resources Research Center, Hainan Institute of Tropical Agricultural Resources, Sanya, 572000, Hainan, China
Corresponding author: shiqiang.huang@hitar.org

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Abstract This study explores the role of genetic selection in boosting disease resistance in goats, with a focus on the genetic mechanisms, selection methods, and current advances in breeding practices. It examines common goat diseases, including infectious and parasitic diseases, and discusses the genetic factors involved in resistance and susceptibility. The study also highlights the importance of traditional and molecular breeding techniques, with a particular case study on *Haemonchus contortus*, a parasitic infection that poses significant challenges to goat health. Furthermore, the study addresses the current challenges in genetic selection, such as inbreeding and genetic diversity loss, and the ethical, economic, and environmental considerations. Finally, future directions in goat disease resistance research are discussed, emphasizing innovations in genomics, omics technologies, and the integration of biotechnology to shape the future of breeding programs. This study underscores the potential of genetic selection to revolutionize goat disease management, but also highlights the need for continued research and strategic planning in breeding programs.

Keywords Goat disease resistance; Genetic selection; *Haemonchus contortus*; Breeding methods; Genomic technologies

1 Introduction

Disease resistance is a critical factor in goat farming, as it directly impacts productivity and profitability. Goats are susceptible to various diseases, including gastrointestinal nematode infections, pneumonia, and haemonchosis, which can lead to significant economic losses due to decreased production, increased mortality, and the cost of treatments (Aboshady et al., 2021; Shrivastava et al., 2022; Ateya et al., 2023). Traditional methods of disease control, such as the use of anthelmintics and vaccines, are becoming less effective due to the development of resistance in parasites and pathogens (Goetsch et al., 2021). Therefore, breeding goats for enhanced disease resistance offers a sustainable and long-term solution to these challenges, improving the overall health and productivity of goat herds (Mandal et al., 2018; Amayi et al., 2021).

Genetic selection has emerged as a powerful tool in livestock breeding, allowing for the enhancement of desirable traits such as disease resistance. This process involves identifying and selecting animals with genetic markers associated with resistance to specific diseases (Aboshady et al., 2020; Aboshady et al., 2021). Techniques such as RNA-sequencing and PCR-DNA sequencing have been employed to discover single nucleotide polymorphisms (SNPs) and other genetic variations that contribute to disease resistance in goats (Ateya et al., 2023). These genetic markers can then be used in breeding programs to select animals that are more resistant to diseases, thereby reducing the reliance on chemical treatments and improving herd health (Mandal et al., 2018; Tsukahara et al., 2021a). The integration of genomic data with traditional breeding practices has the potential to significantly advance the genetic improvement of livestock (Tsukahara et al., 2021b).

This study attempts to explore the advances in genetic selection for disease resistance in goats, discuss the current state of research on genetic markers associated with resistance to gastrointestinal nematode infections, pneumonia, and haemonchosis, and provide an overview of the effectiveness of various genetic selection methods and their application in breeding programs. By synthesizing recent findings, this paper aims to offer insights into the potential of genetic selection as a sustainable strategy for enhancing goat health and productivity.

2 Overview of Common Diseases in Goats

Goats, as vital livestock, face numerous health challenges that can impact their productivity and welfare. Understanding the common diseases affecting goats is crucial for developing effective management and breeding strategies to enhance disease resistance.

2.1 Infectious diseases: causes and impact

Infectious diseases in goats, such as pneumonia and caprine arthritis encephalitis (CAE), pose significant threats to goat health and productivity. Pneumonia, a prevalent issue in small ruminants, is influenced by genetic factors, with specific genes like SLC11A1 and TLRs being associated with susceptibility or resistance (Ateya et al., 2023). CAE, caused by a retrovirus, lacks effective vaccines, making genetic selection a viable strategy for resistance. Studies have shown considerable genetic variability in CAE resistance, suggesting that selective breeding could reduce its prevalence (Schultz et al., 2020). These diseases not only affect the health of goats but also have economic implications for farmers due to decreased productivity and increased veterinary costs.

2.2 Parasitic infections and management strategies

Parasitic infections, particularly gastrointestinal nematodes (GIN), are a major constraint in goat production. Genetic selection for resistance to GIN is a promising sustainable control strategy. Research has identified genomic variants in Creole goats that distinguish resistant from susceptible genotypes, with significant pathways like the T cell receptor signaling pathway being involved (Aboshady et al., 2021). Additionally, resistance to *Haemonchus contortus*, a common nematode, is linked to genetic variations in genes such as CD1D and IL12A, which are under selection in goats (Estrada-Reyes et al., 2019). These findings highlight the potential of using genetic markers in breeding programs to enhance resistance to parasitic infections.

2.3 Non-infectious diseases and their genetic components

Non-infectious diseases in goats, such as those related to genetic predispositions, also impact goat health. For instance, genetic resistance to transmissible spongiform encephalopathies (TSE) like scrapie has been explored, with specific alleles in the *PRNP* gene conferring resistance (Figure 1) (Ricci et al., 2017). Moreover, genetic studies have identified loci associated with disease resistance traits, such as the IL-33 gene, which is linked to increased nematode resistance (Asif et al., 2017). These genetic components provide valuable insights into breeding strategies aimed at improving overall goat health and resilience.

In summary, understanding the genetic basis of disease resistance in goats offers promising avenues for improving goat health through selective breeding. By focusing on both infectious and non-infectious diseases, breeders can develop more resilient goat populations, ultimately enhancing productivity and reducing economic losses.

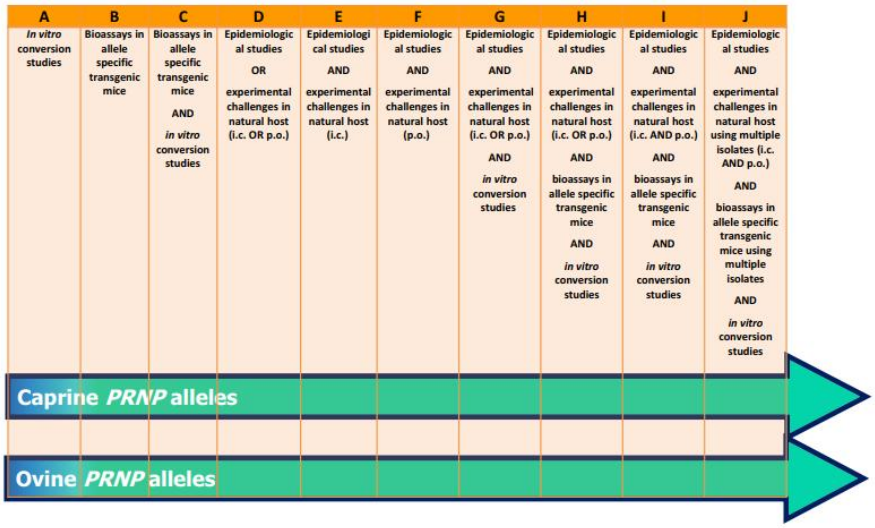

Figure 1 Scale of the weight of evidence on genetic resistance of the caprine and ovine *PRNP* genes (Adopted from Ricci et al., 2017)

3 Genetic Mechanisms of Disease Resistance in Goats

3.1 Role of the immune system in disease resistance

The immune system plays a crucial role in disease resistance in goats, as it is responsible for identifying and combating pathogens. Studies have shown that genetic variations can significantly influence the immune response in goats. For instance, the T cell receptor signaling pathway has been identified as a key differentiator between genotypes resistant and susceptible to gastrointestinal nematode (GIN) infections, with 78% of the genes involved in this pathway showing genomic variants (Aboshady et al., 2021). Additionally, the activation of immune responses, such as the Th1 and Th2 pathways, has been observed in resistant goats, indicating a robust immune response to infections like *Haemonchus contortus* (Aboshady et al., 2020).

3.2 Genetic basis of resistance and susceptibility

The genetic basis of disease resistance and susceptibility in goats is complex and involves multiple genes and genetic variations. Single nucleotide polymorphisms (SNPs) have been identified in various genes associated with resistance or susceptibility to diseases such as pneumonia and GIN infections. For example, SNPs in genes like SLC11A1, CD-14, and TLRs have been linked to pneumonia resistance in Baladi goats (Ateya et al., 2023). Similarly, genetic variations, including SNPs, insertions, and deletions, have been found to distinguish resistant and susceptible genotypes in Creole goats (Aboshady et al., 2021). These genetic differences underline the importance of understanding the genetic architecture of disease resistance for effective breeding programs.

3.3 Genetic markers for disease resistance traits

Genetic markers are essential tools for identifying and selecting disease-resistant traits in goats. The identification of specific SNPs and other genetic variations provides valuable markers for breeding programs. For instance, genome-wide association studies (GWAS) have identified candidate genes associated with GIN resistance in Creole goats, such as those related to immune response and inflammation processes (Silva et al., 2018). Additionally, the IL-33 gene has been highlighted for its role in enhancing immune resistance to nematode infections, serving as a potential genetic marker for breeding programs (Asif et al., 2017). These markers facilitate the selection of goats with enhanced disease resistance, contributing to more sustainable and profitable goat farming practices (Amayi et al., 2021).

In summary, the genetic mechanisms of disease resistance in goats involve a complex interplay of immune system functions, genetic variations, and identifiable genetic markers. Understanding these mechanisms is crucial for developing effective breeding strategies to enhance disease resistance in goat populations (Zheng et al., 2020).

4 Advances in Genetic Selection Methods

4.1 Traditional breeding practices for disease resistance

Traditional breeding practices have long been employed to enhance disease resistance in goats. These methods primarily rely on selecting individuals that exhibit desirable traits, such as resistance to specific diseases, and breeding them to propagate these traits in future generations. For instance, the genetic variability for resistance to diseases like caprine arthritis encephalitis (CAE) has been explored, indicating that direct genetic selection can effectively reduce disease prevalence in goat herds (Figure 2) (Schultz et al., 2020). Similarly, breeding programs targeting resistance to transmissible spongiform encephalopathies (TSE) have been proposed, focusing on alleles that confer resistance to classical scrapie8. These traditional methods, while effective, are often limited by the slow pace of genetic improvement and the complexity of accurately identifying resistant individuals.

4.2 Molecular tools in breeding: marker-assisted selection

Marker-assisted selection (MAS) represents a significant advancement over traditional breeding by utilizing molecular markers linked to disease resistance traits. This approach allows for more precise selection of individuals carrying favorable genetic variants. For example, single nucleotide polymorphisms (SNPs) associated with resistance to pneumonia in Baladi goats have been identified, providing a basis for selecting animals with enhanced innate resistance (Ateya et al., 2023). Similarly, genomic variants linked to resistance against gastrointestinal nematode infections have been discovered, offering valuable resources for molecular breeding

programs (Aboshady et al., 2021). These molecular tools enable breeders to make informed decisions, accelerating the development of disease-resistant goat populations.

Figure 2 Appearance of a goat infected with caprine arthritis encephalitis virus (advanced stage) in which the animal is hitting its head against the pen wall (left picture), is displaying depressive behavior (middle picture), and has joint inflammation (right picture) (Adopted from Schultz et al., 2020)

4.3 Genomic selection and its impact on breeding programs

Genomic selection further revolutionizes breeding programs by incorporating comprehensive genomic information to predict the breeding value of individuals. This method leverages genome-wide data to enhance the accuracy of selection, particularly for complex traits like disease resistance. Studies have shown that genomic selection can significantly improve resistance to various diseases, such as *Haemonchus contortus* infections, by identifying loci with divergent allelic frequencies under selection6. Additionally, genomic insights into disease resistance, such as those provided by RNA-seq analysis, have identified key pathways and genetic variants that distinguish resistant from susceptible genotypes (Mandal et al., 2018; Aboshady et al., 2021. The integration of genomic selection into breeding programs holds the potential to rapidly advance the genetic improvement of disease resistance in goats, offering a sustainable solution to disease management challenges (Ricci et al., 2017).

In summary, the integration of traditional breeding practices with molecular and genomic tools has significantly advanced the genetic selection for disease resistance in goats. These methods provide a robust framework for developing resilient goat populations, ultimately enhancing productivity and sustainability in goat farming.

5 Case Study: The Role of Genetic Selection in Resistance to Parasites (*Haemonchus contortus*)

5.1 Biology and impact of *Haemonchus contortus* in goats

Haemonchus contortus, a gastrointestinal nematode, is a significant parasite affecting goats worldwide, leading to severe health issues and economic losses in the small ruminant industry (Babar et al., 2015). This parasite thrives in warm, humid environments, making regions like the southern United States particularly vulnerable (Estrada-Reyes et al., 2019). The infection results in clinical diseases such as anemia and reduced productivity due to blood loss and nutrient deprivation3 6. The prevalence and intensity of infection can vary based on factors such as breed, age, and environmental conditions (Mpofu et al., 2022).

5.2 Genetic selection strategies for parasite resistance

Genetic selection has emerged as a promising strategy to enhance resistance to *Haemonchus contortus* in goats. This involves identifying and breeding individuals with genetic traits that confer resistance to the parasite (Estrada-Reyes et al., 2019; Omar et al., 2019; Tsukahara et al., 2021). Studies have identified specific genes and single nucleotide polymorphisms (SNPs) associated with resistance, such as those involved in immune response pathways. Breeding programs often utilize phenotypic indicators like fecal egg count (FEC) and packed cell volume (PCV) to select resistant individuals. Additionally, molecular tools are being developed to facilitate the identification of resistant genotypes, focusing on genes related to immunoregulatory mechanisms (Shrivastava et al., 2018; Mpofu et al., 2022).

5.3 Outcomes and implications of breeding programs for parasite resistance

Breeding programs aimed at enhancing resistance to *Haemonchus contortus* have shown promising results. For instance, certain goat breeds, such as the Spanish and Kiko, have demonstrated lower FECs and improved

resistance following selective breeding (Tsukahara et al., 2021). The identification of genetic markers and the use of molecular techniques have further refined these programs, allowing for more targeted selection (Estrada-Reyes et al., 2019; Omar et al., 2019). The success of these programs not only reduces reliance on anthelmintic drugs, which face increasing resistance issues, but also improves overall herd health and productivity (Kotze et al., 2016). The presence of genetic resistance within breeds like the Yichang white goat highlights the potential for developing resistant populations through selective breeding.

In summary, genetic selection for resistance to *Haemonchus contortus* in goats is a viable strategy that leverages genetic diversity and molecular insights to combat parasitic infections, offering a sustainable alternative to chemical treatments.

6 Current Challenges and Limitations in Genetic Selection for Disease Resistance

6.1 Risks of inbreeding and loss of genetic diversity

One of the primary challenges in genetic selection for disease resistance in goats is the risk of inbreeding, which can lead to a loss of genetic diversity. This is particularly concerning when selection pressure is applied to specific alleles associated with disease resistance, such as those for transmissible spongiform encephalopathies (TSE) resistance. High selection pressure on alleles like K222, D146, and S146, which confer resistance to classical scrapie, can reduce genetic diversity, especially in small or rare breeds (Ricci et al., 2017). Additionally, the fixation of certain alleles, such as those related to gastrointestinal nematode resistance, can inadvertently reduce the overall genetic variability within a population, potentially leading to inbreeding depression (Estrada-Reyes et al., 2019; Aboshady et al., 2021).

6.2 Economic and ethical considerations in genetic selection

Economic and ethical considerations also pose significant challenges in the genetic selection for disease resistance. The inclusion of disease resistance traits in breeding goals can increase profitability, as demonstrated in smallholder dairy goat production systems where breeding for resistance to diseases like mastitis and helminthosis improved economic outcomes (Amayi et al., 2021). However, the cost of implementing genetic selection programs, including the necessary infrastructure for genetic evaluations and phenotyping, can be prohibitive for some farmers. Ethically, there is a concern about the welfare implications of selecting for specific traits, which may inadvertently affect other important traits such as reproduction or growth. Moreover, the potential for unintended consequences, such as the emergence of new disease susceptibilities, must be considered (Mandal et al., 2018).

6.3 Environmental and management factors affecting resistance

Environmental and management factors significantly influence the effectiveness of genetic selection for disease resistance. The expression of genetic resistance can be affected by environmental conditions, such as climate and nutrition, which can alter the immune response of goats (Estrada-Reyes et al., 2019). For instance, the prevalence of *Haemonchus contortus*, a major gastrointestinal nematode, is influenced by environmental conditions, and genetic resistance to this parasite may vary accordingly6. Additionally, management practices, such as housing and feeding, can impact the health and disease resistance of goats, necessitating a holistic approach that combines genetic selection with optimal management strategies (Schultz et al., 2020). The integration of genetic and environmental data is crucial for accurately predicting and enhancing disease resistance in diverse goat populations (Mandal et al., 2018).

The genetic selection for disease resistance in goats faces several challenges, including the risks of inbreeding and loss of genetic diversity, economic and ethical considerations, and the influence of environmental and management factors. Addressing these challenges requires a balanced approach that considers genetic diversity, cost-effectiveness, ethical implications, and the integration of environmental data to optimize disease resistance in goat populations.

7 Future Directions in Goat Disease Resistance Research

7.1 Innovations in genomic and omics technologies

Recent advancements in genomic and omics technologies have opened new avenues for enhancing disease resistance in goats. Techniques such as RAD-seq and RNA-seq have been instrumental in identifying genetic markers and selection signatures associated with disease resistance. For instance, RAD-seq technology has been used to identify genes related to immunity and disease resistance in Yunling goats, providing a scientific basis for breeding programs aimed at enhancing disease resistance (Chen et al., 2022). Similarly, RNA-seq has facilitated the discovery of genomic variants in Creole goats that are resistant to gastrointestinal nematode infections, highlighting the potential of these technologies in molecular breeding (Aboshady et al., 2021). These innovations allow for a more precise selection of traits, thereby improving the overall health and productivity of goat populations.

7.2 Integrated approaches for enhancing disease resistance

An integrated approach combining quantitative and functional genomics with large-scale data collection and epidemiological prediction is crucial for advancing disease resistance in goats. This approach enables breeders to select for enhanced resistance to a variety of diseases by understanding the genetic control of resistance and genetic variations (Mandal et al., 2018). Studies have shown that genetic selection for resistance to diseases such as caprine arthritis encephalitis and gastrointestinal nematode infections can be effective when combined with proper management strategies (Estrada-Reyes et al., 2019; Schultz et al., 2020). By integrating these methods, breeders can develop more resilient goat populations that are better equipped to withstand disease pressures.

7.3 The role of biotechnology in shaping future breeding programs

Biotechnology plays a pivotal role in shaping future breeding programs for disease resistance in goats. The use of molecular genetic tools, such as PCR-DNA sequencing, has identified SNPs associated with disease resistance, providing a practical management technique for selective breeding (Ateya et al., 2023). Additionally, the identification of specific alleles, such as those conferring resistance to transmissible spongiform encephalopathies, underscores the potential of genetic resistance as a tool for controlling diseases in goat populations (Ricci et al., 2017). By leveraging biotechnological advancements, breeding programs can be tailored to enhance disease resistance, ultimately leading to more sustainable and profitable goat production systems (Amayi et al., 2021).

In summary, the future of goat disease resistance research lies in the integration of genomic technologies, comprehensive breeding strategies, and biotechnological innovations. These approaches promise to enhance the genetic resilience of goat populations, ensuring their health and productivity in the face of evolving disease challenges.

8 Concluding Remarks

Research into genetic selection for disease resistance in goats has revealed significant insights. Studies have identified numerous genes and pathways associated with immunity and disease resistance, such as those found in Yunling goats, which exhibit strong disease resistance and adaptability. Similarly, genetic markers linked to pneumonia resistance have been identified in Baladi goats, highlighting the potential for using genetic tools to enhance disease resistance. The identification of genomic variants in Creole goats resistant to gastrointestinal nematodes further underscores the role of genetic selection in improving disease resistance. Additionally, the positive selection of genes like IL-33 in Chinese goats suggests a genetic basis for enhanced immune responses.

The future of goat disease resistance through genetic selection looks promising, with ongoing research likely to uncover more genetic markers and pathways that can be targeted for breeding programs. The integration of genomic technologies, such as RAD-seq and RNA-seq, will continue to enhance our understanding of the genetic basis of disease resistance. Moreover, the development of breeding programs that incorporate genetic resistance to diseases like scrapie and gastrointestinal nematodes will be crucial in improving herd health and productivity. As genetic selection becomes more refined, it will play a pivotal role in sustainable goat farming practices.

Future research should focus on expanding the genetic databases for various goat breeds to identify additional resistance markers. Studies should aim to understand the interaction between genetic resistance and environmental factors to optimize breeding strategies. Policymakers should support the development of breeding programs that prioritize disease resistance, ensuring that these programs are tailored to local conditions and breed characteristics. Additionally, there should be a focus on maintaining genetic diversity to prevent adverse effects from high selection pressure. Collaboration between researchers, breeders, and policymakers will be essential to implement effective strategies for enhancing disease resistance in goats.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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