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The Role of MicroRNAs in Livestock Production and Health: A Comprehensive Review

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Abstract

MicroRNAs (miRNAs) are being more recognized as significant modulators of gene expression in livestock, controlling a range of biological processes, including immunological responses, growth, and development. With an emphasis on their potential uses to boost productivity, enhance disease resistance, and function as biomarkers for health evaluation. This review article focuses on the role of miRNAs in livestock production systems and animal health. Deciphering miRNAs' diverse roles may open the door to more efficient and sustainable animal production methods.

Keywords: microRNAs, livestock production, animal health, growth regulation, immune response, disease resistance, biomarkers, genetic improvement.

Introduction: As the world's population rises and nutritional preferences shift, there is an increasing demand for animal products worldwide. The cattle sector is crucial to the economies of many nations as well as to food security. Farmers and researchers must increase the efficiency of livestock production in this changing scenario while maintaining the health and welfare of the animals. Recent developments in molecular biology, particularly the study of microRNAs (miRNAs), have shed new light on the intricate regulatory mechanisms governing the development, growth, and disease resistance of cattle.

miRNAs are small, non-coding RNA molecules with an average of 18–25 nucleotides. According to Bartel (2004), miRNAs bind to complimentary areas on target mRNAs to promote degradation or impede translation. This process is known as post-transcriptional regulation. Numerous biological processes, such as cell proliferation, differentiation, apoptosis, and stress responses have been connected to miRNAs since their discovery. New methods for enhancing

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production qualities and managing health in livestock may result from an understanding of miRNA function.

miRNAs in Growth and Development

Understanding how miRNAs impact the growth and development of livestock species is necessary to optimize production aspects like muscle growth and fat deposition.

1.1. Muscle Development

The primary factor affecting meat quality and production efficiency is muscle growth. These three miRNAs are important for muscle development: miR-1, miR-133, and miR-206. It has been demonstrated that miR-1 and miR-133 control myoblast differentiation and proliferation. These miRNAs target a number of transcription factors that are essential for muscle cell differentiation and hypertrophy, including myocyte enhancer factor 2 (MEF2) and histone deacetylase 4 (HDAC4) (McCarthy et al., 2011; Chen et al., 2013).

In livestock, for example, altering these miRNAs can promote muscle growth. Cattle that overexpress miR-1 may gain more muscle mass and have higher-quality meat, according to transgenic research (Feng et al., 2018). It is also possible to target miR-206 to improve muscle recovery and growth rates in livestock because its expression is linked to muscle regeneration and repair.

1.2. Adipogenesis

miRNAs also play a critical role in controlling the growth of adipocytes and the accumulation of fat in animals. Targeting the Peroxisome Proliferator-Activated Receptor gamma (PPARγ), a crucial transcription factor involved in fat cell differentiation, miR-27a has been found to be a major regulator of adipogenesis (Zhou et al., 2013). Livestock producers may be able to increase feed conversion ratios and optimize body composition for meat output by modifying the expression of miRNAs involved in lipid metabolism.

Certain miRNAs have been linked to growth characteristics associated with fat accumulation in pigs. Another miRNA that affects lipid metabolism and is linked to the control of muscle and fat gene expression is miR-208 (Zhao et al., 2012). It may be possible to increase growth efficiency and improve meat quality across species by focusing on these miRNAs through dietary methods or genetic selection.

1.3. Growth Efficiency

Livestock producers are highly intended to discover and control miRNAs linked to growth efficiency. Certain miRNAs have been connected to the overall growth performance and feed conversion efficiency. For example, studies have shown a correlation between improved feed

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efficiency features in pigs and over expression of miR-141 (Wang et al., 2014). Hence, Understanding the specific miRNA profiles that contribute to superior growth traits can help in developing breeding strategies focused on enhancing productivity.

Table 1: Key miRNAs Involved in Growth and Development in Livestock

miRNA	Function	Target Genes	Species
miR-1	Muscle differentiation	HDAC4, MEF2	Cattle, Pigs
miR-133	Muscle cell proliferation	MEF2	Cattle, Pigs
miR-27a	Adipogenesis	PPARγ	Pigs
miR-208	Fat metabolism	Genes regulating lipid synthesis	Pigs
miR-141	Feed efficiency	IGF2, IGF1	Pigs
miR-206	Muscle regeneration	Myf5, MyoD	Cattle, Sheep

Through focus on the modification/manipulation of these important miRNAs via biotechnological methods, nutritional interventions, or genetic selection may make it feasible to greatly increase growth rates and raise the general effectiveness of animal production.

2. miRNAs in Immune Responses and Disease Resistance

The integrity of the immune system is highly essential for maintaining the productivity and health of animals. miRNAs are crucial for regulating immunological responses, impacting immune cell growth and function, and consequently affecting disease resistance.

2.1. Regulation of Immune Cells

The differentiation and activity of diverse immune cell types, including as T-cells, B-cells, and macrophages, are crucially regulated by miRNAs. For instance, miR-155 plays a significant role in T-cell activation and differentiation, fostering the growth of Th1 cells, which are crucial against intracellular infections (O'Connell et al., 2010). Improved immune responses against pathogens can result from increased expression of miR-155, according to studies, which suggests that miR-155 may be a promising therapeutic target for improving livestock disease resistance.

Furthermore, by focusing on signaling pathways implicated in immunological activation, miR-146a functions as a negative regulator of the inflammatory response. By regulating the synthesis of pro-inflammatory cytokines and supporting immunological homeostasis, this miRNA helps avoid excessive inflammation that compromise animal health (Zhao et al., 2019).

2.2. Pathogen Resistance

Global research on influence of specific miRNAs affecting disease resistance is of considerable interest. The function of miRNAs in regulating host susceptibility has been

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emphasized by studies on the porcine reproductive and respiratory syndrome virus (PRRSV). For example, many studies evidenced that downregulating certain miRNAs increases the susceptibility to PRRSV infection (Zhuang et al., 2018). Understanding the specific miRNA profiles associated with disease susceptibility can facilitate breeding strategies aimed at enhancing pathogen resistance in livestock.

Li et al. (2015) in their studies revealed that expression of miR-149 is markedly changed in response to avian influenza virus infection, suggesting that this miRNA may be involved in the immune system's response to viral infections. Targeting particular miRNAs might be a valuable tool for vaccine development as well therapeutic interventions against infectious diseases in livestock.

2.3. Anti-Inflammatory Roles

Certain miRNAs also have protective functions by limiting inflammation in addition to enhancing immune responses. For example, miR-146b, which targets particular mRNAs implicated in the NF-κBsignaling pathway, has anti-inflammatory properties and also suppresses the release of pro-inflammatory cytokines (Zhao et al., 2019). miRNA control of inflammatory responses may improve animal welfare and production efficiency by promoting better recovery from and infections and diseases.

miRNAs as Biomarkers for Health Monitoring

miRNAs have potential as biomarkers for evaluating cattle health because of their stability in bodily fluids and their unique expression profiles in response to health status. miRNAs are health monitoring biomarkers as their profile may provide early indicators of illness, facilitating prompt management, intervention and management decisions.

3.1. Stability and Detection

miRNAs have been found to be remarkably stable in a variety of biological fluids, including serum, plasma, milk, and saliva (Huang et al., 2013). This stability is due to their resistance to RNase degradation and encapsulation within vesicles or protein complexes in circulation. As a result, technologies for detecting miRNAs, including as quantitative RT-PCR and microarray analysis, have been developed to efficiently profile these molecules.

3.2. Disease Biomarkers

Specific miRNA profiles associated with various diseases have been explored, facilitating early diagnosis. For example, miR-21 was identified as a potential biomarker for early detection of foot-and-mouth disease (FMD) in cattle (Zhang et al., 2020). Early intervention based on mi3.2. Disease Biomarkers (Continued)

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Furthermore, miRNA profiling has been used successfully to detect mastitis, a common illness in dairy cows. miR-146 has been linked to the inflammatory response associated with mastitis, and its expression levels can be used to predict disease severity (Zhao et al. 2019). Tracking miRNA levels in milk or blood allows producers to implement timely treatments,, increasing animal welfare and economic benefits.

3.3. Health Monitoring in Livestock Production

The potential use of miRNAs as health biomarkers extends beyond detection of diseases. Regular monitoring of miRNA profiles can form part of a comprehensive health management strategy in livestock production. Implementing miRNA-based diagnostics allows producers to assess the overall health status of their animals, identifying those at risk of disease/stress. This proactive manage mental approach leads to improved animal welfare, reduced mortality rates, and enhanced productivity.

For example, recent research has explored the role of miRNAs in stress responses. **miR-233** has been associated with heat stress in livestock, revealed altered expression patterns in response to thermal challenges (Sadek et al., 2020). Hence, by monitoring expression of stress-related miRNAs, farmers can manage environmental conditions better and mitigate the negative impacts of thermal stress on livestock health and productivity.

Table 2: Potential miRNA Biomarkers for Disease Detection and Health Monitoring

miRNA	Associated Disease	Species	Reference
miR-21	Foot-and-mouth disease	Cattle	Zhang et al., 2020
miR-146	Mastitis	Dairy Cattle	Zhao et al., 2019
miR-233	Heat stress	Swine	Sadek et al., 2020
miR-155	PRRSV susceptibility	Pigs	Zhuang et al., 2018

Applications in Breeding and Genetic Improvement

The incorporation of miRNA studies into breeding programs holds promise for increasing livestock productivity and health. Understanding the genetic basis of miRNA expression and its correlation to desirable traits will facilitate more targeted selection strategies.

4.1. Genomic Selection and miRNA Discovery

Genomic selection uses molecular data to improve the precision and effectiveness of breeding programs. Recent advancements in high-throughput sequencing technology have enabled the identification of new miRNAs and regulatory networks in livestock (Meyer et al., 2015).

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Identifying miRNAs that control essential qualities like growth performance, illness resistance, and reproductive success can help enhance the selection process.

4.2. Marker-Assisted Selection

Marker-assisted selection (MAS) is a breeding approach that uses molecular markers to choose desirable traits in livestock. Breeders can improve the selection process by associating certain miRNAs or their target genes to phenotypic features using MAS. For example, miRNAs that have been demonstrated to influence muscle growth and feed efficiency could be employed as molecular markers in breeding programs aiming at increasing meat production in cattle and pigs.

4.3. Transgenic Approaches

Transgenic technologies provide an alternate way to manipulate miRNA expression in animals. Researchers can investigate the effects of individual miRNAs in influencing production qualities by generating transgenic animals that overexpress or shut down those miRNAs. For example, transgenic pigs overexpressing miR-1 and miR-133 showed enhanced muscle mass, demonstrating the viability of miRNAs in practical breeding applications (Feng et al., 2018). However, ethical and regulatory considerations must be carefully addressed when developing and introducing genetically modified organisms (GMOs) into livestock systems.

5. Future Directions and Challenges

While the potential applications of miRNA research in livestock production are promising, several challenges and areas for future research need to be addressed.

5.1. Understanding miRNA Interactions

miRNAs do not act in isolation; instead, they are part of complex networks that include many targets and transacting elements. Future research should focus on unraveling these intricate miRNA-mRNA interactions using systems biology approaches, which will lead to a better understanding of how miRNAs govern biological processes in livestock.

5.2. Standardization of miRNA Profiling Techniques

Standardizing miRNA detection and quantification methodologies is critical for assuring consistency and reproducibility of results across research. Development of consistent methodologies/protocols and reference datasets would improve the comparability of findings and accelerate the translation of miRNA research into practical applications.

5.3. Regulatory and Ethical Considerations

As with any biotechnology application, the use of miRNAs in livestock breeding raises ethical and regulatory concerns. Stakeholders, including producers, consumers, and regulatory

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agencies, must collaborate to develop appropriate frameworks and guidelines for the use of miRNA technology in cattle. Transparency and public trust will be important in the acceptance of genetic modifications and their implications for food safety, animal welfare, and ecosystem health.

5.4. Translation to Livestock Production Practices

There is a need to bridge the gap between basic research and practical applications in the livestock business. Collaboration among researchers, veterinarians, and producers can help integrate miRNA knowledge into animal breeding, health management, and feed optimization procedures. Producers can better monitor their herds' health and productivity by creating user-friendly systems that incorporate miRNA data.

5.5. Longitudinal Studies

In-depth longitudinal studies are necessary to establish a clear understanding of the temporal dynamics of miRNA expression in relation to various physiological and environmental stresses. These studies will provide insights into how miRNAs adaptively respond to these determinants, enhancing our capacity to predict their impact on livestock health and productivity over time.

Conclusion

MicroRNAs have the potential to revolutionize livestock production and health management. Their numerous roles in regulating growth, development, immunological responses, and stress adaptability make them critical targets for improving livestock efficiency and resilience. As our understanding of miRNA biology advances, so will their potential applications in breeding strategies, health monitoring, and disease resistance, resulting in more sustainable livestock production systems.

Collaborative research efforts will be required to address the challenges associated with miRNA applications, including as comprehending complicated miRNA interactions, standardizing profiling methodologies, and the formulation of regulatory guidelines. As we harness the potential of miRNAs, we get closer to a future of livestock production that meets the growing demand for food security, animal welfare, and sustainable agricultural practices.

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