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Genetic Research on Egg Production Performance in Poultry: From the Perspective of Whole Genome Association Analysis

Kelin Pan
Modern Agricultural Research Center of Cuixi Academy of Biotechnology, Zhuji, 311800, Zhejiang, China
Corresponding author email: 177242186@qq.com
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Abstract With the growth of global food demand, improving the egg production performance of poultry has become an important goal in animal husbandry and genetic research. This study comprehensively analyzed the application and achievements of whole genome association analysis (Genome-wide association study, GWAS) in revealing the genetic basis of poultry egg production performance, highlighting the important contribution of GWAS technology in identifying key genetic markers and associated regions that affect egg production performance. By reviewing and analyzing recent research cases, this study demonstrates how GWAS can help scientists gain a deeper understanding of the genetic mechanisms underlying poultry egg production performance and provide targeted strategies for genetic improvement in poultry. We also discussed the challenges faced by current methods, including the complexity of statistical correction, the interaction between genetic and environmental factors, and how to effectively apply GWAS findings to breeding practices. This study provides prospects for the future development of genetic research on poultry egg production performance, emphasizing the importance of integrating emerging genetic editing technologies, improving individual genome selection accuracy, and developing precision animal husbandry. It not only provides scientific basis for genetic improvement of poultry egg production performance, but also contributes new ideas to the sustainable development of animal husbandry.
Keywords Genome-wide association study; Poultry egg production performance; Genetic markers; Genetic improvement; Precision animal husbandry

Poultry, especially chickens and ducks, as the main egg-producing animals in the world, their egg-laying performance is not only related to the economic efficiency of the livestock industry, but also has a direct impact on the nutritional intake and food safety of human beings. Eggs, as foods rich in high quality proteins, vitamins and minerals, have been an integral part of several cultures and diets around the world. Improving the egg-laying performance of poultry means that the growing global demand for food can be met more efficiently, while increasing the productivity and economic returns of the livestock industry.

Genetic factors play a decisive role in the improvement of poultry laying performance. Historically, humans have optimized the egg-laying capacity of poultry to some extent by selecting and breeding top-performing poultry breeds (Figure 1). However, this traditional breeding method is often time-consuming, inefficient, and does not allow for precise control of improved genetic traits. With the rapid development of molecular biology and genetics, scientists have begun to explore more precise methods to analyze the genetic mechanisms affecting poultry egg-laying performance (Chen et al., 2021).

The emergence of genome-wide association study (GWAS) technology has provided a powerful tool for unraveling the genetic basis of complex traits, which can help scientists identify key genetic variants that affect poultry egg production performance by analyzing the association between thousands of single nucleotide polymorphisms (SNPs) and specific traits. In the genome and specific traits, GWAS can help scientists identify key genetic variants that affect poultry egg-laying performance. Compared with traditional breeding, GWAS not only accelerates the process of genetic improvement, but also improves the accuracy of the improvement, providing new ideas and methods for poultry breeding (Huang et al., 2022).

Figure 1 Egg laying process of poultry in water

The application of GWAS in animal genetic research goes far beyond the improvement of poultry laying performance. It has been widely used to study a variety of economic traits, such as growth rate, meat quality, disease resistance, etc., which has greatly contributed to the genetic improvement and scientific development of animal husbandry. Through comprehensive genome analysis, GWAS is able to reveal the complex genetic networks behind traits, providing a scientific basis for precision breeding and sustainable utilization of genetic resources.

Although GWAS shows great potential in animal genetic studies, it faces many challenges in its practical application, such as the processing and analysis of large-scale genomic data, the biological interpretation of the results, and the effective use of discovered genetic markers. Continuing to optimize the analysis methods of GWAS, as well as combining GWAS results with other bioinformatics tools and functional genomics studies, will be an important direction for future research. Studying the genetic mechanism of poultry egg-laying performance through genome-wide association analysis can not only promote the innovation of poultry breeding technology, but also provide a strong scientific support to meet the increasing global food demand (Gao et al., 2023). With the continuous advancement of molecular biology technology and the increasing abundance of genetic information, future research on the genetic improvement of poultry egg-laying performance will be more in-depth and precise, contributing to the sustainable development of the livestock industry.

In this study, we comprehensively explored the genetic resolution of poultry disease resistance through the perspective of genome-wide association studies (GWAS), which involves the economic and social impacts of poultry diseases, the role of genetics in poultry disease resistance, and the importance and application of GWAS. These research results are not only of great significance for the sustainable development of the poultry industry, but also provide a new scientific basis and methodology for the prevention and control of poultry diseases, which is an important contribution to the improvement of global food safety and the protection of public health.

1 Genetic Background of Poultry Egg Production Performance

1.1 Genetic variation of poultry egg-laying performance

Poultry egg production performance as an important economic trait in animal husbandry, its improvement and optimization has been the core of poultry breeding research. The genetic background of poultry egg-laying performance is complex, involving the interaction of multiple genes and the influence of environmental factors.

Genetic variation in poultry egg-laying performance refers to the differences in traits such as number of eggs laid, egg weight, eggshell quality, etc. among different individuals in a poultry population. These differences are caused by genetic factors, including genetic variation, chromosome structure variation and so on. Genetic variation is the basis of natural and artificial selection, and is the raw material for poultry breeding improvement. By studying the genetic variation in poultry egg-laying performance, genes or genetic markers that are important for egg-laying performance can be identified, providing important genetic information for poultry breeding (Mengesha et al., 2022).

1.2 Main genetic factors affecting egg production performance

The major genetic factors affecting poultry egg-laying performance are multifaceted and include genetic variation, chromosomal rearrangements, and regulation of gene expression. In numerous studies, scientists have identified specific genes and genetic markers that are closely related to the number of eggs laid, egg size, eggshell quality, and yolk and protein composition in poultry. A number of specific genetic variants affect ovarian development and function, which in turn affects egg production. Genes related to sex hormone synthesis and metabolism also have a direct impact on egg production performance. The mechanisms of action of these genetic factors are complex and varied and include, but are not limited to, influencing hormone levels, regulating metabolic pathways, and controlling cell proliferation and differentiation.

Laying performance is also genetically linked to other economic traits in poultry, such as growth rate, feed efficiency, and disease resistance. Such correlations suggest that certain genetic factors may affect more than one trait at the same time, or that there are genetic synergistic or antagonistic effects between different traits. For example, fast-growing poultry breeds may affect egg production due to differences in energy partitioning, whereas excellent feed efficiency not only improves growth rate, but may also indirectly increase egg production by improving nutritional status. A deeper understanding of these genetic factors and their interactions is important for balancing and optimizing multiple economic traits in poultry and can guide more precise and efficient poultry breeding strategies (Figure 2).

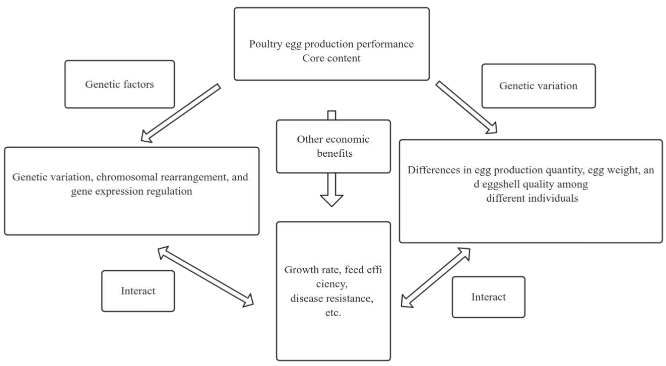

Figure 2 The interaction relationship between genetic variations in poultry egg production performance

1.3 Genetic association between egg production performance and other economic traits

Poultry egg production performance does not exist in isolation, and it is genetically linked to other economic traits, such as growth rate, feed efficiency, meat quality traits, and so on, in a complex way. This means that improving one trait during breeding may affect the performance of other traits. For example, excessive pursuit of increased growth rate may reduce egg-laying performance because rapid growth may consume energy and resources that could be used for egg production (Wang et al., 2021). Improvements in feed efficiency also need to be considered along with their possible effects on egg production performance. Poultry breeding should not only consider the improvement of a single trait, but also the balance and coordination among economic traits. Through methods such as genetic correlation and path analysis, the genetic relationship between different economic traits can be revealed, providing a scientific basis for the development of comprehensive breeding strategies.

The genetic background of poultry egg-laying performance is complex, involving the interaction of multiple genes and genetic factors. In-depth study of the genetic variation of poultry egg-laying performance, the main genetic factors affecting egg-laying performance, as well as the genetic association between egg-laying performance and other economic traits can provide scientific guidance and basis for poultry breeding. With the development of molecular biology and genetics technology, the future of poultry breeding will be more accurate and efficient, and it is expected to breed poultry breeds with high egg-laying performance and other economic traits to meet the growing demand for food.

2 Principles and Applications of Genome-Wide Association Analysis (GWAS)

2.1 Principles and methods of GWAS

Genome-wide association analysis (GWAS) is based on finding associations between specific traits and genetic markers. The process begins with the collection of samples of individuals with or without a particular trait, which are then extensively genotyped to identify tens of thousands of single nucleotide polymorphisms (SNPs). By comparing the difference in frequency of SNPs between individuals with a particular trait and those without that trait, GWAS aims to discover genetic variation associated with the trait. The advantage of this approach is that it does not require prior in-depth knowledge of the genetic background, making it a powerful tool for exploring genetic causes and traits.

As technology has evolved, the analytical power of GWAS has increased dramatically. The use of high-throughput sequencing technology and high-density microarrays has allowed researchers to more accurately cover the entire genome, thereby increasing the chances of discovering genetic markers associated with target traits. The success of this approach relies on large sample sizes, as large-scale samples increase the accuracy and reliability of discovering truly relevant genetic variants.

2.2 Application of GWAS in poultry genetic studies

Emrani et al. (2017) team conducted GWAS in 2017 using an F2 generation chicken population derived from a fast growing line and a local slow growing chicken crossed with each other to look for genes and genomic regions affecting growth traits. This study identified nine SNPs significantly associated with body weight traits.

The research team of Khalil et al. (2021) in 2021 reviewed molecular approaches in poultry genetic improvement programs emphasizing the use of GWAS to identify causative genes affecting economic traits in poultry. This included the identification of many genes that affect growth and egg production.

Wang et al. (2020) performed GWAS and pathway analyses to identify biological mechanisms involved in the heterophilic lymphoid ratio (H/L) of chickens, which reflects the state of their immune system. The study identified SNPs that were significantly associated with the Heterophilic lymphoid ratio in chickens, contributing to the understanding of the genetic regulation of this trait (Figure 3).

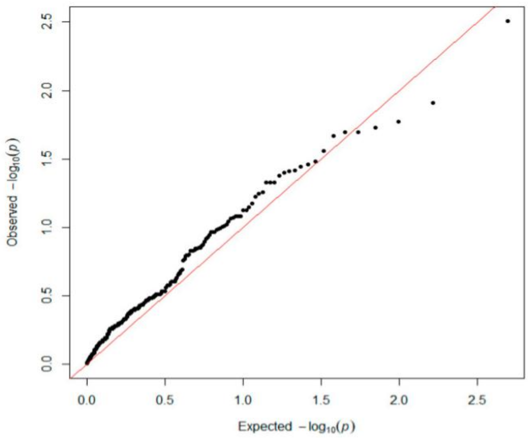

Figure 3 Quantile – quantile (Q – Q) plot of the GWAS results with GAPIT 3.0 (Wang et al., 2020)

Note: The x-axis shows the expected p-values under the null hypothesis and the y-axis shows the observed p-values

Using the GWAS approach, researchers have identified genetic markers that affect eggshell quality and egg size, which has significant implications for improving egg quality and reducing losses. GWAS has also been used to explore the genetic basis of disease resistance in poultry, which is valuable for breeding healthier poultry breeds and reducing the use of antibiotics.

2.3 Technological advances in GWAS and data analysis methods

Technological advances in GWAS have greatly advanced its application in poultry genetic research. In particular, the development of high-density SNP microarrays and next-generation sequencing technologies has enabled researchers to explore the genome at a more detailed level and discover more genetic variants associated with traits. The application of these technologies has not only improved the resolution of GWAS, but also enabled the exploration of rare variants that were previously undetectable, providing new opportunities to understand the genetic basis of complex traits.

Along with technological advances, data analysis methods have also been revolutionized in GWAS research. To meet the challenges of large-scale data analysis, researchers have developed a variety of complex statistical models and computational tools, such as multi-locus mixed linear models and machine learning algorithms (Han et al., 2023). These methods not only improve the accuracy and efficiency of analysis, but also can solve the problems of complex genetic background and traits controlled by multiple genes. With these advanced analytical tools, GWAS can more accurately identify genetic factors associated with traits and facilitate the development of poultry genetic improvement and breeding strategies.

3 Case Study of GWAS Research on Poultry Egg-Laying Performance

3.1 Study design and sample selection

The research team of Liu et al.(2019) conducted a GWAS in 2019 to understand the genetic architecture of egg-laying performance by measuring the age at first egg (AFE) and the number of eggs laid per week (Egg number, EN) at different stages in 1078 Rhode Island Reds. This study identified important SNPs associated with egg-laying traits, providing promising genes and SNP markers for marker-based breeding selection (Table 1).

Table 1 Descriptive statistics for age at first egg and egg number in different stage (Liu et al, 2019)

Traits	Nnumber of samples	Mean	Standard deviation	Coefficient of variance (%)	Pedigree-based heritability (standard error)
Age at first egg	1 063	137.37	5.7	4.15	0.51 (0.09)
From egg laying to 23 weeks	1 063	24.15	5.48	22.67	0.53 (0.08)
From 23 to 37 weeks	1 063	95.16	2.16	2.27	0.16 (0.06)
From 37 to 50 weeks	1 063	84.58	6.07	7.17	0.24 (0.07)
From 50 to 61 weeks	1 060	64.71	11.17	17.27	0.23 (0.07)
From 61 to 80 weeks	1 004	105.57	27.33	25.89	0.14 (0.06)
Total number of eggs from spawning to 80 weeks	1 063	368.13	47.84	13.00	0.09 (0.05)

Lien et al. (2020) performed (Quantitative trait locus, QTL) QTL localization and GWAS to identify genetic markers and chromosomal regions associated with egg laying in a tropical climate in a cross between Taiwanese Country Hens and Rhode Island Red Laying hens. The study identified 11 QTL and 102 SNP effects associated with egg-laying traits.

When conducting a genome-wide association analysis (GWAS) study of poultry egg-laying performance, careful study design is key to ensuring the success of the study. The design phase includes defining the study objectives, selecting appropriate poultry breeds, determining sample size, and choosing appropriate analytical methods. A good study design maximizes the detection of genetic markers associated with egg-laying performance while reducing the rate of false-positive findings.

Sample selection is critical to the success of a GWAS. Researchers need to select poultry populations with sufficient genetic diversity to capture genetic variation that affects egg-laying performance. Selecting individuals that exhibit extreme differences in egg-laying performance improves the efficiency of the study, helps enhance the genetic contrast of the study, and makes the detection of relevant genetic markers more sensitive.

3.2 Specific effects of genetic factors on egg production performance

There are various ways in which genetic factors identified by GWAS affect poultry egg production performance, including regulating ovarian development, affecting hormone levels, and altering eggshell formation. For example, a genetic variation may indirectly affect the maturation of follicles in the ovaries by affecting the synthesis and secretion of estrogen, thereby affecting the egg laying cycle and egg size (Ou et al., 2021).

These discovered genetic factors provide new strategies for poultry breeding. By using these genetic markers as selection indicators, breeders can more accurately select individuals with excellent egg production performance for breeding, thereby improving the egg production performance of the entire population. This also provides the possibility of using gene editing technology to directly improve the genetic traits of poultry.

3.3 Limitations and challenges of research

Although GWAS provides powerful tools to identify genetic factors that affect poultry egg production performance, this method also has limitations. Due to genetic linkage phenomena, GWAS may mark genetic markers that are only physically close to the genes that truly affect the trait, rather than direct genetic variations. The complex interactions between environmental factors and genotypes may also be overlooked.

To overcome these challenges, researchers are adopting more comprehensive methods for analysis, such as combining GWAS results with functional genomics data (such as transcriptomics, proteomics, etc.) to validate the biological functions of genetic markers. By conducting repeated studies under different environmental conditions, it is possible to better understand the impact of environmental factors on egg production performance.

The GWAS research on poultry egg production performance is a constantly evolving field that has made significant progress. Despite the challenges and limitations, scientists are gradually revealing the complex genetic networks that affect poultry egg production performance by continuously optimizing research designs and methods, and integrating multiple bioinformatics tools. These studies not only provide valuable insights into the genetic basis of poultry production traits, but also open up new avenues for future poultry breeding and genetic improvement.

4 Technological Progress in Genetic Research on Egg Production Performance

4.1 Application of high-throughput sequencing technology in genetic research of poultry

High throughput sequencing technology, the next generation sequencing (NGS) technology, has completely changed the face of poultry genetic research. These technologies can quickly and accurately sequence the entire genome of poultry, providing unprecedented depth and breadth for studying genetic variations in poultry (Xu et al., 2020). Compared with traditional sequencing techniques, high-throughput sequencing greatly reduces costs, making it possible to perform whole genome analysis on a wider sample set. This is crucial for identifying complex genetic factors that affect poultry egg production performance.

The application of high-throughput sequencing technology has greatly promoted the study of genetic diversity in poultry, including the identification of genetic variations and genes related to egg production performance. For example, by conducting whole genome sequencing on high-yielding and low yielding egg varieties, researchers can identify specific genetic markers significantly associated with egg production performance, which is of great significance for breeding and genetic improvement.

4.2 The role of functional genomics methods in explaining GWAS results

Functional genomics methods, such as transcriptomics, proteomics, and epigenetic analysis, play an important role in explaining how genetic variations discovered in GWAS results affect poultry egg production performance. These methods can reveal how specific genetic variations affect gene expression, protein function, and cellular metabolic pathways, thereby affecting egg production performance.

Through transcriptome analysis, researchers can compare the differences in gene expression levels among poultry populations with different egg production performance, thereby identifying key genes and regulatory networks related to egg production performance. These pieces of information help to understand the biological mechanisms behind the genetic markers discovered by GWAS, providing targets for genetic improvement.

4.3 Potential applications of genome editing technology in genetic improvement of poultry

CRISPR-Cas9 technology, as a revolutionary gene editing tool, provides the possibility for precise modification of poultry genomes. By designing specific guiding RNAs (gRNAs) to locate specific sequences in the genome, CRISPR-Cas9 can accurately cleave DNA, thereby achieving gene knockout, insertion, or modification (Tang et al., 2024).

By utilizing CRISPR-Cas9 technology, scientists can perform targeted editing on key genes that affect egg production performance, in order to increase egg production rates, improve egg quality, or enhance disease resistance in poultry. For example, by knocking out genes that have a negative impact on egg production performance or enhancing genes that have a positive impact, the economic traits of poultry can be directly improved. The advantage of this method lies in its efficiency and accuracy, which can achieve genetic improvement without introducing exogenous DNA, thus avoiding controversy over genetically modified organisms.

With the development and application of high-throughput sequencing, functional genomics methods, and CRISPR-Cas9 technologies, genetic research on poultry egg production performance is facing unprecedented opportunities. These technologies not only provide tools for a deeper understanding of the genetic basis of poultry egg production performance, but also open up new avenues for genetic improvement in poultry. In the future, with more research and technological progress, it is expected to achieve more efficient and precise poultry breeding strategies to meet the growing global food demand.

5 Strategies and Challenges for Genetic Improvement of Egg Production Performance in Poultry

5.1 Breeding strategy based on GWAS results

Genome-wide association analysis (GWAS) provides a powerful tool for genetic improvement of poultry egg production performance, enabling researchers to identify genetic markers significantly associated with egg production performance. Based on GWAS results, breeding strategies can more accurately select individuals with excellent genetic traits, thereby improving breeding efficiency and effectiveness. This method relies on large-scale genetic information and complex data analysis, aiming to accelerate the breeding process, improve egg production rate and other related traits through genetic marker assisted selection (MAS) (Ru et al., 2023).

In practical applications, breeding based on genetic markers discovered by GWAS requires comprehensive consideration of the efficacy of genetic markers, genetic background, and environmental factors. With the advancement of sequencing technology and the reduction of costs, genome-wide selection (GWS) has become possible. This method not only considers individual markers, but also utilizes whole genome information, providing a more comprehensive genetic prediction for improving poultry egg production performance. However, how to accurately evaluate the association between genetic markers and trait performance, and effectively apply this information to practical breeding, remains an important challenge in current research and application.

5.2 The balance between genetic diversity protection and genetic improvement

While pursuing improved egg production performance in poultry, protecting genetic diversity is crucial for maintaining population health, adaptability, and long-term breeding potential. Overreliance on a few genotypes with high egg production performance may lead to the loss of genetic diversity, thereby increasing the population's vulnerability to environmental changes and diseases. Finding a balance between genetic improvement and genetic diversity conservation is a major challenge faced by poultry breeding.

One balancing strategy is to implement rotation mating and multi variety hybrid breeding programs to maintain genetic diversity while improving egg production performance. In addition, modern genetic tools such as genome selection can accurately select favorable genetic variations without sacrificing genetic diversity. By monitoring genetic diversity indicators and considering them in the breeding process, genetic resources can be effectively managed to ensure the long-term sustainable development of poultry populations.

5.3 Ecological and ethical considerations

The genetic improvement of poultry egg production performance is not only a scientific issue, but also an ecological issue. Breeding plans need to consider the impact on ecosystems, including the interaction between genetically modified poultry and local wild populations, as well as potential impacts on biodiversity. Appropriate ecological assessment and monitoring are necessary to ensure that genetic improvement activities do not have adverse effects on the natural environment.

With the development of genetic technology, ethical issues are becoming increasingly prominent. Genetic improvement should consider ethical principles such as animal welfare, genetic diversity protection, and food safety. Transparent research and development processes, public participation, and comprehensive assessment of potential risks are key to ensuring social acceptance of genetic improvement activities. In this process, it is necessary to balance scientific innovation and ethical responsibility to ensure the sustainable and responsible use of genetic improvement technologies.

In summary, genetic improvement of poultry egg production performance is a multidimensional challenge that involves multiple aspects such as science, technology, ecology, and ethics. By considering these factors comprehensively and adopting innovative and responsible methods, continuous improvement of poultry egg production performance can be achieved, while protecting genetic diversity and ensuring long-term ecological and social well-being.

6 Conclusion

Genome-wide association study has become an important tool for revealing the genetic basis of egg production performance in poultry, providing strong scientific support for genetic improvement and breeding practices in poultry. This article reviews the application of GWAS in the genetic research of poultry egg production performance, and analyzes its important contributions in revealing genetic markers, understanding genetic mechanisms, and promoting genetic improvement. At the same time, this article also explores the main scientific and practical challenges currently faced, as well as prospects for the future poultry industry and genetic research.

Through GWAS, researchers have successfully identified several genetic markers and association regions that are significantly associated with poultry egg-laying performance. These findings not only enrich the understanding of the genetic basis of poultry egg-laying performance, but also provide specific molecular targets for genetic improvement. More importantly, the application of GWAS has facilitated the close integration of genetic information with breeding practices, improving the efficiency and accuracy of poultry breeding.

Despite the remarkable achievements of GWAS in genetic studies of poultry laying performance, many challenges remain.The complexity of GWAS results and the large number of false-positive findings call for more rigorous statistical correction and validation strategies. Causal relationships between genetic markers and phenotypes are often difficult to clarify and need to be explained by subsequent functional studies. The influence of the interaction between environmental and genetic factors on egg-laying performance is also a complex issue that requires more research to explore in depth.

Future poultry genetic studies will further rely on high-throughput sequencing technologies, precise genetic editing tools and advanced bioinformatics analysis methods. The development of these technologies can provide a deeper understanding of the impact of genetic variation on poultry laying performance, as well as new strategies and tools for genetic improvement. With the rise of individual genomic selection and precision animal husbandry, the future of the poultry industry will evolve in a more efficient, sustainable and personalized direction.

Interdisciplinary collaboration will be key to driving future poultry genetic research and industry development. Integration of knowledge and technologies from multiple fields, including genetics, bioinformatics, animal nutrition and ecology, will enable a more comprehensive solution to the challenges encountered in poultry egg-laying performance improvement, sustainable utilization of genetic resources and long-term development of the poultry industry (Bamidele et al., 2020).

In summary, GWAS has played a critical role in unraveling the genetic basis of poultry egg-laying performance, and future research will continue to rely on this tool to deepen understanding and address practical issues in genetic improvement. As science and technology continue to advance, the outlook for the poultry industry and genetic research is promising, heralding the arrival of more efficient and sustainable poultry production systems.

References

Bamidele O., Sonaiya E.B., Adebambo O.A., and Dessie T., 2020, On-station performance evaluation of improved tropically adapted chicken breeds for smallholder poultry production systems in nigeria, Tropical Animal Health and Production, 52: 1541-1548.
https://doi.org/10.1007/s11250-019-02158-9

Chen C.B., Xu L.J., Yu H.J., Zou B.C., Long F., and Qu M.R., 2021, Research advances on application of trace elements zinc in poultry production, Ciliao Yanjiu (Feed Research), 44(5): 105-108.

Emrani H., Torshizi R., Masoudi A., and Ehsani A., 2017, Identification of new loci for body weight traits in F2 chicken population using genome-wide association study, Livestock Science, 206: 125-131.
https://doi.org/10.1016/j.livsci.2017.10.016

Gao G.L., Zhang K.S., Zhao X.Z., Xu G.Y., Xie Y.H., Zhou L., Zhang C.L., and Wang Q.G., 2023, Identification of molecular markers associated with goose egg quality through genome-wide association analysis, Zhongguo Nongye Kexue (Scientia Agricultura Sinica), 56(19): 3894-3904.

Han G.F., Bai Z.C., Li Y.S., and Li C.M., 2023, Current approaches and applications for in ovo sexing of eggs: a review, Zhinenghua Nongye Zhuangbei Xuebao Zhongyingwen (Journal of Intelligent Agricultural Mechanization), 4(1): 26-35.

Huang S.S., Wen X.J., Wang G.P., Yu K., Song B.W., Zheng W., and Zhang Y.H., 2022, The effects of different selenium sources on the physiology and production performance of poultry, Zhongnan Nongye Keji (South-Central Agricultural Science and Technology), 43(5): 184-188.

Khalil M., Iraqi M., and Saleh M., 2021, Molecular approaches of candidate genes in genetic improvement programs in poultry, Livestock Science, 18: 334.

Lien C., Tixier-Boichard M., Wu S., and Chen C., 2020, Identification of QTL and loci for egg production traits to tropical climate conditions in chickens, Livestock Science, 234: 103980.
https://doi.org/10.1016/j.livsci.2020.103980

Liu Z., Yang N., Yan Y., Li G., Liu A., Wu G., and Sun C., 2019, Genome-wide association analysis of egg production performance in chickens across the whole laying period, BMC Genetics, 67: 20.
https://doi.org/10.1186/s12863-019-0771-7

Mengesha Y., Kebede E., and Getachew A., 2022, Review of chicken productive and reproductive performance and its challenges in Ethiopia, All Life, 15(1): 118-125.
https://doi.org/10.1080/26895293.2021.2024894

Ou S.Y., Ou Y.C., and Yao C.H., 2021, Research progress of polysaccharide extraction and its effect on poultry growth,immunity and egg production, Ciliao Yanjiu (Feed Research), 44(4):141-143.

Ru M., Zeng W.H., Peng J.L., Zeng Q.J., Yin C., Cui Y., Wei Q., Liang H.P., Xie X.H., and Huang J.Z., 2023, Esearch progress on follicles development of hens and its epigenetic regulatory mechanism, Xumu Shouyi Xuebao (Acta Veterinaria et Zootechnica Sinica), 54(9): 3613-3622.

Tang X.X., Zheng J.M., Luo N., Ying F., Zhu D., Li S., Liu D.W., An B.X., Wen J., Zhao G.P., and Li H.G., 2024, Genetic mechanism of broiler leg disease based on genome-wide association analysis, Xumu Shouyi Xuebao (Acta Veterinaria et Zootechnica Sinica), 55(1):99-109.

Wang J., Zhu B., Wen J., Li Q., and Zhao G., 2020, Genome-wide association study and pathway analysis for heterophil/lymphocyte (h/l) ratio in chicken, Genes, 11:105.
https://doi.org/10.3390/genes11091005

Wang J.P., and Zhang K.Y., 2021, Effects of oxidative stress on follicular atresia in poultry and its mechanism, Dongwu Yingyang Xuebao (Chinese Journal of Animal Nutrition), 33(6): 3001-3009.

Xu R.S., Shang X.G., Chen W., Zhu X.P., and Zheng C.T., 2020, Research progress on threonine in poultry nutrition, Zhongguo Jiaqing (China Poultry), 42(1): 93-98.