


The genetic role of mitochondria in feed conversion efficiency and egg production in poultry

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Abstract

Mitochondria represent a central determinant in regulating feed conversion efficiency and egg production in poultry, given their central role in producing the cellular energy necessary for all metabolic and productive processes. Research has shown that differences in productive performance among birds are not only due to nutritional or environmental factors, but are closely related to genetic differences, particularly mitochondrial inheritance and the accompanying variation in oxidative phosphooxidation efficiency (OXPHOS) and the electron transport chain.

Cross-sectional studies have shown that birds with high feed conversion efficiency have more efficient mitochondria in producing ATP with relative energy loss in the form of heat and oxidative stress compared to birds with low efficiency. This balance between energy production and reducing oxidative stress is a crucial factor in improving feed utilization and reducing food waste, which positively impacts the economic performance of poultry projects.

The research also showed that egg production is a vital process with high energy demands, and that mitochondrial efficiency directly and indirectly affects egg-laying rate, production continuity, and egg quality. Furthermore, scientific evidence indicates that the integrated interaction between mitochondrial and nuclear genes contributes to regulating energy distribution within the bird's body and determines whether it is directed towards growth or egg production.

The conclusion confirmed that maternally transmitted mitochondrial inheritance represents an important dimension that must be taken into account within genetic improvement programs, as molecular indicators associated with mitochondria can be used to select the most efficient and productive birds. The research also indicated that supporting mitochondrial health through balanced nutrition and antioxidant supplements may enhance productive performance and reduce the negative effects of metabolic stress.

Based on the above, it can be said that this research confirms. That improving feed conversion efficiency and egg production in poultry requires an integrated perspective that combines mitochondrial genetics, nuclear genetics, and proper nutrition, which opens up broad horizons for scientific research and practical application towards achieving more efficient and sustainable poultry production.

I. Introduction

The poultry industry is one of the most vital sectors in global food security because it provides cheap and affordable, high-quality protein sources such as meat and eggs. Therefore, researchers focus on improving productive traits directly related to economic profit, most notably feed conversion ratio (FCR) and egg production. Genetic improvement processes represent one of the most important axes concerned with refining traits of economic importance. Recent studies have focused on the genetic role of mitochondria as a major driver of cellular energy production and an essential component that affects bird performance (Gattenby, 2020a)

Mitochondria are characterized by having their own genome (*mtDNA*) separate from the nuclear genome and encoding 37 genes responsible for manufacturing proteins necessary for the electron transport chain, which is the primary source for the production of ATP energy molecules in animal cells Chinnery, P. F., & Schon, E. A. (2003)). This is of particular importance in birds with rapid growth rates, such as broiler chickens, as any slight defect in the efficiency of ATP production necessarily leads to a change in feed consumption and conversion rates. Mutations in the mt-ATP6 gene have been found to be associated with increased basal metabolism and energy waste, and consequently, decreased feed conversion efficiency (Jastrebski & Siegel, 2017)

traits across generations. This genetic pattern enhances the importance of genetic selection of maternal lines in improving growth and production traits. Recent studies on broiler chicken breeds have shown that the difference in mitochondrial haplotypes explains an important part of the variation in feed conversion efficiency between different production lines (Byrne et al., 2021)

On the other hand, mitochondria play an essential role in regulating cellular metabolism, as they control the oxidation of carbohydrates and fatty acids and manage the levels of free radicals within the cell. Research results have shown that birds with high feed conversion efficiency have high activity of electron transport chain enzymes such as complex I and complex IV enzymes, which increases the efficiency of ATP production compared to birds with low efficiency (Ohtsu et al., 2019). Conversely, an increase in free radicals (ROS) is one of the factors that leads to a decrease in production efficiency, as polymorphisms in the mt-ND2 gene have been linked to an increase in these radicals and a decrease in conversion efficiency in chickens (Chen et al., 2020; Surai, 2016)

The importance of mitochondria is also evident in egg production, as the follicular cells within the ovary require large amounts of energy during the stages of yolk and shell formation. High-producing strains exhibit higher levels of mitochondria and greater activity of oxidative phosphorylation enzymes compared to low-producing strains (Reddy et al., 2019). Furthermore, some mt-tRNA mutations have been found to affect the cells' ability to transport calcium ions necessary for eggshell formation, leading to differences in shell quality and thickness (Xu et al., 2021)

The response to environmental stress, especially heat, is no less important in the field of egg production, as genetic studies have indicated that some haplotypes of mtDNA give the bird a higher ability to maintain production under high-temperature conditions by stabilizing mitochondrial function and reducing damage to its proteins (Liu et al., 2020)

With the development of modern genomic technologies, it has become clear that there is a complex interaction between the nuclear genome and the mitochondrial genome known as Mitonuclear interactions. This interaction has been shown to play a key role in regulating productive traits such as growth and egg production, as a set of nuclear genes has been found to control the expression of mitochondrial proteins and is associated with important egg traits (Johnson et al., 2021; Wallace, 2018)

Based on the above, it is clear that mitochondria are not just an energy production factory, but a pivotal genetic element that contributes to determining the bird's productive efficiency through its influence on metabolic processes, oxidative stress, reproductive cell function, and environmental response. With the accumulation of modern genetic knowledge, the integration of mtDNA into selection programs has become a necessary step in developing more efficient and profitable poultry lines.

This research aims to study and analyze the genetic role of mitochondria in influencing feed conversion efficiency and egg production in poultry birds by highlighting the molecular and functional mechanisms associated with mitochondrial inheritance and demonstrating their impact on the productive and economic performance of poultry. This general objective branches into a set of detailed objectives, which are:

1 -Clarifying the Scientific Basis of Mitochondrial Inheritance

This research aims to explain the nature of mitochondria, their genetic genome, the characteristics of their maternal inheritance, and their role in cellular energy production, linking these characteristics to metabolic processes in poultry.

2 -Analyzing the Relationship Between Mitochondrial Function and Feed Conversion Efficiency

This research seeks to demonstrate how oxidative phosphorylation efficiency, the electron transport chain, and oxidative stress affect the ability of birds to utilize feed and convert it into energy for growth or production.

3- Studying the effect of mitochondrial genetics on egg production

The research also aims to clarify the role of mitochondrial energy in egg formation processes and production continuity, and to demonstrate its relationship to productive traits such as egg laying rate, quality, and productive lifespan of laying hens.

First: Mitochondrial Genetic Structure and its Relationship to Performance

Mitochondria contain a circular genome approximately 16–17 kilobases long, encoding 37 genes. Mitochondria are not just energy factories; they are also sensors for stress and inflammation. responsible for synthesizing essential proteins in the electron transport chain (mt-ND1, mt-ND2, mt-ATP6), which are among the most important pathways for ATP synthesis in the cell (Chinnery, P. F., & Schon, E. A. (2003), Raimundo, N. (2014).

Since ATP is the primary energy currency, any change in its production efficiency directly affects growth rate and egg production. Genetic studies in chickens have shown that mt-ATP6 mutations are associated with an increased basal metabolic rate, leading to higher feed consumption without a corresponding increase in growth (Jastrebski & Siegel, 2017), which negatively impacts feed conversion efficiency.

Second: Maternal Inheritance and its Role in Poultry Traits

Mitochondria are inherited exclusively maternally. Therefore, selection should be based on mitochondrial efficiency maternal lineage can improve energy-related traits. A study on broiler chicken breeds showed that FCR differences between genetic lines were clearly associated with variations in mitochondrial haplotypes (mtDNA haplotypes) (Byrne et al., 2021)

Furthermore, studies on domesticated bird breeds have demonstrated that mitochondrial genetic variation increases the physiological capacity for feed conversion by improving oxidative phosphorylation (OXPHOS) efficiency (Wallace, 2018)

Third: The role of mitochondria in feed conversion efficiency

1. Regulation of metabolic processes

Mitochondria are responsible for the oxidation of fatty acids and carbohydrates, and therefore their efficiency in energy production determines the amount of feed required to produce one growth unit. An experiment on broiler chickens recorded that birds with high conversion efficiency have higher levels of activity levels complex I and complex IV enzymes compared to birds with low efficiency (Ohtsu et al., 2019)

2-Oxidative Stress

High levels of free radicals within mitochondria lead to damage to proteins and lipids, reducing food conversion efficiency Oke et al. (2024). A study found that polymorphisms in the mt-ND2 gene are associated with high ROS levels and reduced FCR (Chen et al., 2020)

3. -Appetite control and metabolic efficiency

Mitochondria interact with appetite-regulating hormones such as leptin. A study in laying hens showed that birds with mutations in the mt-CYB gene have higher leptin levels with reduced feed consumption and increased production (Du et al., 2022)

Fourth: The role of mitochondria in egg production

1 -Energy production within the ovarian cell

The egg production process requires large amounts of ATP, especially in the early stages of yolk formation. A molecular histological study has shown that follicular cells of high-producing oocytes contain a greater number of mitochondria and higher OXPHOS enzyme activity compared to low-producing strains (Reddy et al., 2019)

2 - Effect of mtDNA on Shell Quality

A study reported that mt-tRNA mutations may affect calcium transport processes within shell cells, leading to variations in shell hardness and thickness (Xu et al., 2021)

3 -Response to Heat Stress

Egg production is significantly affected by heat stress, and birds carrying a specific haplogroup (Haplogroup E) have been shown to have a greater ability to maintain egg production under high temperatures due to higher mitochondrial stability (Liu et al., 2020)

Fifth: Applications of mtDNA-Based Genetic Selection

1. -Using Haplotypes as Genetic Markers

Studies have demonstrated the potential of using mtDNA haplotypes as ideal markers for assessing production efficiency without the need for whole-genome analysis (Byrne et al., 2021)

2. -Maternal Line-Based Crosses

Crossing two lines, one with high energy efficiency, yields better production results even when the parents have identical nucleotide traits (Wallace, 2018)

3. - Improving Laying Traits

Based on the results of recent studies, mitochondrial activity has been included among the criteria for selecting hens in some commercial laying flocks (Du et al., 2022)

Sixth: Interaction Between Nuclear and Mitochondrial Genes

Integrated genome studies have revealed a complex interaction between mitochondrial (mtDNA) and nuclear (nDNA) genes in regulating energy production processes. A study in chickens identified 12 nuclear genes that influence the expression of mitochondrial proteins and are associated with egg production traits (Johnson et al., 2021)

This interaction, known as mitonuclear interactions, is one of the most important genetic drivers of FCR variation among breeds.

Seventh: Review of Global Studies on the Topic

Jastrebski & Siegel	2017	demonstrated the correlation between conversion efficiency and mt-ATP6
Ohtsu et al	2019	clarified the role of complex I and IV enzymes in FCR.

The study by Reddy et al. (2019) linked egg production to the number of mitochondria in follicles.

The study by Chen et al. (2020) showed the relationship between elevated ROS and mt-ND2.

The study by Du et al. (2022) demonstrated the effect of mt-CYB on egg production and appetite.

II. Conclusion

Mitochondria play a pivotal role in determining the productive traits of poultry, especially feed conversion efficiency and egg production, through their influence on energy production, oxidative stress, metabolism, and reproductive cell capabilities. With the increasing number of genetic studies, it has become clear that productive traits do not depend solely on the nuclear genome but are directly affected by the mitochondrial structure, which is inherited through the maternal line, making it a promising target in genetic selection programs.

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