

Biological, nutritional, and environmental factors affecting of growth and physiological productivity in poultry: a review.

Abstract:

Poultry work period and productivity are of paramount importance for a successful, efficient and sustainable contemporary poultry industry. The magnitude of genetic progress achieved in poultry during recent decades, which has improved growth potential, is primarily limited by biological, nutritional and environmental constraints. This paper provides an overview of the recently available information of the biological drivers affecting growth, primarily the genetic make-up, endocrine balance, muscle development, immunity and gut health. It emphasizes the significance of nutrition: energy consortium of the diet and balanced provision of amino acids, lipid quality and functioning, and sufficiency of micronutrients and applications of functional feed additives. Furthermore, attention is paid to other environmental effectors such as temperature, humidity, air quality and stocking density as well as lighting programs housing system and hygiene on growth performance and feed efficiency. The evidence support that the integrated management system will provide optimal performance in poultry through precision nutrition and a controlled environment to optimize the genetic potential. Knowledge about the mechanism these interacting factors can be impacted is crucial in elevating productivity, animal welfare and sustainability within poultry production.

Keywords: Biological, nutritional, environmental, growth, productivity, poultry

Introduction

Poultry production science plays a strategic role in strengthening food security, meeting the growing global demand for animal protein, and promoting more sustainable livestock production systems. In response to the rapid increase of demand, intensification of production systems and a tightening sustainability agenda, a novel focus on maximizing growth rate, feed efficiency and overall productivity has been placed on poultry flocks (Attia et al., 2022). Recent advances in genetics, feed formulation, housing and health management have created the opportunity for improved performance but achieving genetic potential under commercial conditions depends on the integration of input factors related to nutritional, environmental and management inputs, activity since multi-factorial constraints often compromise realized growth and productivity (Korver, 2023).

Genetics is one of the major growth factors affecting broilers and other poultry species still at that stage. Lines with high growth and good Feed Conversion Ratio (FCR) have been achieved from modern breeding programs, but the consequent improvement is easily coupled with high metabolic demands and a high sensitivity to environmental stressors and metabolic disorders. The phenotypic expression of growth may also be influenced by endocrine regulators (e.g. growth hormone, insulin-like growth factors), nutrient partitioning and immune status - subsequent to interactions among these biological systems, through maintenance and immune responses, a bird achieves either poor or successful feed conversion to lean tissue. Genetic $\times$ environment interactions are still important, but high-performing genotypes may not perform well under sub-optimal environmental or nutritional conditions (Selim et al., 2022).

Diet is the most immediate and controllable factor influencing growth. Optimal supply of energy and amino acids with emphasis on digestible lysine (Lys), methionine, and branched-chain amino acids is essential to optimize muscle

accretion as well as feed efficiency (Urgessa et al., 2024). Besides the macronutrient composition of feed, micro-nutrient parameters as well as the feed form (i.e. particle size and structure) and processing of raw materials affect digestibility and gut physiology. Various feed additives, such as phytases and different enzymes, probiotics and prebiotics acting directly or indirectly with gut microbiota (e.g., short-chain fructo-oligosaccharides [FOS]), and phytogenic compounds, have been widely used in pig production to improve nutrient availability, promote gut health, and reduce susceptibility to enteric pathogens, especially after the ban of antibiotic growth promoters (Selim et al., 2022). Recently published meta-analyses and controlled trials demonstrate that phytase (and multi-enzyme) formulations can lead to a measurable improvement in P utilization along with growth performance, whereas the use of probiotic, prebiotic and symbiotic strategies frequently results in improved gut integrity and immune competence accompanied with associated productivity improvements (Urgessa et al., 2024).

Environmental conditions—temperature, humidity, ventilation, light intensity, packing density and litter quality—are important determinants of the expression of growth potential. Heat stress emerges as one of the most pressing challenges: it not only decreases feed consumption, changes nutrient utilization, disturbs gut integrity and increases maintenance energy requirement but also depresses growth and quality (Brugaletta et al., 2022). Entailed with global warming (Ker et al., 2019), heat episodes are becoming more frequent and severe, requiring nutritional and managerial mitigation strategies to maintain productivity in many production areas (Oluwagbenga & Fraley, 2023).

Gut-health and microbiome as key moderators in the regulation between nutrition, immunity, and growth. Gut microbiota that is stable and diverse assists with nutrient digestion and absorption, prevents pathogen colonization, and aids the

84 regulation of mucosal immunity. On the contrary, gut dysbiosis can hinder the
85 utilization of nutrients and maximize energy expenditure for immune activation,
86 thereby reducing growth performance. Due to the importance of early-life
87 microbial modulation and the possibility that such manipulations could be long-
88 term in their beneficial effects on growth and disease resistance, interventions
89 including maternal microbiota management, in ovo inoculation, targeted starter
90 diets, and specifically-provided probiotics/ prebiotics have gained increasing
91 attention (Idowu et al., 2025).

92 Lastly, the modern poultry production should challenge face for maximum
93 productivity to work simultaneously with the health and welfare of the animals,
94 food safety and environmental sustainability. This is countering short term
95 management based systems that may maximise gain but create long term counter
96 productivity in the long term in terms of welfare and resilience — internationally
97 push for precision nutrition (having the correct right diet and not maximum growth
98 which may in turn magnify metabolic diseases), and environmental control and
99 genomics to be better able to drive sustainability with improved
100 productivity (Korver et al., 2023). Emerging technologies and feeding strategies —
101 including precision feeding, sensor-based environmental monitoring and the use of
102 alternative feed ingredients that require fewer resources such as carbon or
103 phosphorus — offer the opportunity that animal production grow is having over
104 the enabling regulatory or consumer need (Selim et al., 2022).

105 Considering these interactions, a comprehensive review summarizing the recent
106 advances in biological, nutritional, and environmental aspects of growth in poultry
107 is warranted at this point. This review synthesizes new research (post-2015) on
108 genetic selection, nutrient strategies and functional feed additives, microbiome
109 interventions, and heat-stress alleviation and management interventions to guide

actionable and research priorities for sustainable intensification of poultry production.

Biological Factors Affecting Growth in Poultry

Genetic factors are most important in controlling growth rate, feed efficiency and overall performance of poultry. These are genetic, physiological, endocrine, immunological and developmental factors which act in combination to determine whether or not birds under commercial production can attain the full expression of their growth potential. An understanding of these biological drivers is key to maximizing poultry performance, whilst mitigating against health and welfare issues.

Genetic Background and Growth Potential

One of these biological factors is genetic selection which is crucial for poultry growth, as seen in broiler chickens. Modern broiler strains have been selected for very fast rates of growth, high muscle development and feed efficiency. However, this severe selection has also modified physiological and hierarchical functions such that it may raise the likelihood of, for example, metabolic illnesses, bone malformations and oxidative pressure (Selim et al., 2022). Due to variations in genetic factors, nutrient use efficiency, bioactive compound action, myofiber development and immune competence directly affect growth performance. The findings also emphasize that genotype–environment interactions give rise to the high performing genetic lines failing to reach their maximum potential under less than ideal biological and environmental circumstances (Zhang et al., 2023).

Endocrine Regulation of Growth

Poultry growth is closely controlled by the the endocrine system, with a major role played by growth hormone (GH)–insulin-like growth factor (IGF) axis. GnRH1 also activates hepatic IGF-1 stimulated by GH, which aside from driving muscle cell hyperplasia and protein synthesis further facilitates skeletal growth (Musigwa et al., 2024). T3 and T4 represent thyroid hormones and also control basal metabolic rate as well as nutrient utilization affecting growth performance. A severe disruption in both hormonal balance and growth performance may arise from stress, disease or nutritional deprivation. The predominant avian stress hormone, corticosterone, is especially harmful when levels are maintained chronically because it drives protein catabolism and suppresses anabolism (Scanes, 2016).

Muscle Development and Myogenesis

Muscle development in birds is predominantly a result of hypertrophy of the muscle fibers, as the number of fibers have been determined in majority during embryogenesis. Satellite cells are central to post-hatch muscle growth as they provide new nuclei to developing muscle fibers. Their proliferation and differentiation are regulated by genetic background, early nutrition and hormones (Velleman, 2015). Inhibition of satellite cell function would decrease muscle gain and body weight potential. High growth rates are also associated with muscle abnormalities, such as wooden breast and white striping, which are distinctive of the imbalance between muscle growth and vascularization(Petracci et al., 2019).

Immune Status and Growth Trade-Offs

The immune system represents a significant source of biological cost in poultry production. Immune activation has to compete against growth for limited nutrients and energy. Subclinical infections and poor biosecurity or dysbiosis resulting in

continuous immune activation are associated with reduced growth performance and feed efficiency. Conversely, the beneficial effects of well-composed immunity promote growth through gut integrity and the salvage of nutrients. Divergent immune competence also in part explains sample growth rates of poultry lines and therefore supports balanced selection schemes in breeding(Kogut & Arsenault, 2016).

Gut Development and Microbiota

The GI tract is a physiological modifier of growth as it controls the digestion and absorption of nutrients. Intestinal shape (villus height, crypt depth, enzyme activity) of the early post-day-old broiler is a major factor in the growth path which it will take. Moreover, the gut microbiota also provides a minor contribution by fermenting non-digestible substrates, producing short-chain fatty acids and displacing pathogens. Potential modifying factors include microbial dysbiosis that may change the digestibility of nutrients and heightened pro-inflammatory activity that needs to reduce growth. Recent corroboration has re-confirmed a suggestion per evidence showing allergenic early microbial programming of growth performance(Gadde et al., 2017).

Sex and Age-Related Biological Differences

Biological differences dependent on sex can also affect patterns of growth in poultry. The female broiler should grow lesser than a male one due to hormonal levels and muscle deposition velocities. Thus, the growth responses are differentially shaped by aging effects on metabolic efficiency, immune maturity and digestive capacity. The inability to perform such interpolations at any time in the growth curve also must be considered when interpreting growth performance as

well as when establishing either feeding or management schemes(England et al., 2022).

Oxidative Stress and Cellular Metabolism

Increased growth rate raises metabolic and mitochondrial activity and consequently raises ROS production. When antioxidant defenses are inadequate, oxidative stress can lead to damage of cellular constituents, inhibit muscle development and decrease feed conversion. Genetic components determining antioxidant armory and mitochondrial functionality are thus key biological factors of sustained growth(Surai et al., 2019).

Nutritional Factors Affecting Growth in Poultry

Of all the factors that influence growth and productivity in poultry, diet is one that goes hand-in-hand with the body's metabolism, tissue accretion, immune competence and feed efficiency. Nutritional needs have changed quickly due to rapid genetic progress in birds for optimal performance. Nutritional factors additionally encompass the shape of feeding, availability, restriction and time of supply of nutrients alongside the amount of feeding(El-Katcha et al., 2024).

Energy Supply and Growth Efficiency

Energy is the primary growth rate limiting dietary nutrient in birds, because it feeds the basal metabolic and thermoregulatory demands of homeothermic endotherms, and energy is required for all anabolic activity. A birds response to metabolizable energy density influences feed intake, meaning that chickens consume feed based on a response to meet energy demands. However, excess fat deposition or restricted muscle growth, in the face of dietary energy imbalances

with other nutrients, particularly protein, is likely to occur. High energy diets stimulate protein deposition if amino acids and protein are not limiting but excess energy decreases carcass quality, potentially increases metabolic stress (Leeson & Summers, 2019).

Protein Quantity and Quality

Protein is called a pivotal nutrient due to its importance in respect to muscle development and maintenance, so it is crucial for all to get enough dietary protein as it plays an essential role not only in enzyme synthesis but also in immune process. Poultry growth depends on the amount of total crude protein in the diet as well as its quality (digestibility and AA profile). Essential amino acids lysine, methionine, threonine, tryptophan are especially important for muscle accretion and feed conversion efficiency. There is a slow growth rate and an increase in nitrogen excretion if amino acids are deficient or imbalanced, thereby affecting the efficiency of protein synthesis. Optimizing growth performance of the animal without negatively impacting the environmental footprint of poultry production has become a focus of recent research endeavors. In this respect, amino acid-based diet formulations seem to have some advantages on formulations which are mainly based on crude protein levels. Improved nutrient utilization, lower nitrogen excretion, and efficient, sustainable growth are achieved with a precise balance of essential amino acids (Maharjan et al., 2021).

Lipids and Fatty Acid Composition

Dietary lipids constitute a concentrated source of energy and, together with carbohydrates and proteins, serves as the major structural component of cellular membranes and precursor of hormones. Dietary fat type and quality also influence growth performance, nutrient utilization and oxidative stability. Polyunsaturated

fatty acids (PUFA), particularly omega-3 PUFA, may be beneficial for growth performance and immune function when used correctly. On the negative side, large amounts of unsaturated fats in the diet increases the sensitivity to lipid oxidation and if the antioxidant defense system is compromised, growth will be limited(Fouad & El-Senousey 2014).

Vitamins and Mineral Nutrition

Although small amounts are required, vitamins and minerals are essential for normal growth and development. Although all vitamins play a role in health, some vitamins like A, D, E, and B-complex vitamins are important in skeletal development, energy metabolism, and antioxidant defense. Their consumption of vitamins falls short, causing growth retardation, defects in their skeleton, and improper immune function. Similarly, minerals such as calcium, phosphorus, zinc, iron, selenium, etc are essential for bone mineralization, enzyme-mediated and oxygen transport among others. Organic minerals have a higher bioavailability than the inorganic source in some cases and have been the focus of more research recently with respect to trace mineral bioavailability and have yielded more beneficial effects on growth performance(Bao & Choct, 2009).

Feed Additives and Growth Modulation

Recently, feed additives have become more important in the shaping of nutrition to improve growth and feed efficiency with the decline of antibiotic use. Phytase and xylanase enzymes will effect nutrient digestibility through the destruction of antinutritional factors thereby improving the accessibility of phosphorus, amino acids and energy (Sommerfeld et al., 2019). Inclusion of such probiotics, prebiotics and symbiotics are capable of modulating the gut microbiota which further receives advantages of improving intestinal integrity and reducing pathogen load

that eventually comprise overall enhancement of growth performance(Markowiak & Śliżewska, 2018).

Antioxidants and Oxidative Balance

High growth rates of contemporary poultry are related to higher metabolism and greater generation of reactive oxygen radicals. Dietary antioxidants such as vitamin E, selenium, carotenoids, natural plant phenols also play an important role in maintaining the redox balance and protect tissues from oxidative stress. Sufficient nutrients, such as antioxidant vitamins, are closely associated with the growth performance of animals, feed utilization and meat quality (Surai et al., 2019).

Feeding Strategies and Nutrient Timing

Besides the nutrient profile, feeding practices in terms of both quality and quantity are very impactful to growth performance. Phased feeding, however that can provide the nutrient supply at the right time on an age-specific basis, improves efficiency and reduces nutrient losses. One point that I use to highlight during my lectures is the importance of early nutrition (the first week after hatch) as a major factor in gut functionality and hence future growth potential. The role of early protein nutrition and muscle growth is reviewed elsewhere and even delayed access to feed post-hatch has a deleterious effect on the subsequent growth and development of muscle in the neonate(Batal & Parsons, 2003).

Environmental Factors Affecting Growth in Poultry

Growth performance, health status and productivity in poultry are influenced greatly by environmental conditions. It is likely that birds with optimal genetic potential and adequate nutrition can still have depressed growth if other

environmental challenges are not sufficiently mitigated. Environmental factors are constituted out of temperature, humidity, air quality, lighting, stocking density as well as housing systems and hygiene. These factors have direct impacts on physiological homeostasis, feeding consumption, immune competence and metabolic utilization, which would determine the profile of growth in poultry production settings (Menchetti et al., 2024).

Ambient Temperature and Thermal Stress

Temperature is the most important factor of environmental impact on poultry growth. Birds are homeothermic animals with poor ability to lose/reject excessive heat and thus are vulnerable to both heat and cold stress. High ambient temperatures decrease feed intake and hormone responses, increase maintenance of energy requirements which impact negatively the growth rate and sperm production, resulting in reduced body weight gain and low FE (Lara & Rostagno, 2013). The hormone corticosterone (CORT) is released into circulation with HS and can disturb acid–base balance, impairing protein synthesis and muscle growth. Conversely, much more of dietary energy is used to generate heat to maintain body temperature and thus thermoregulatory processes are only marginally established during cold stress, and less energy is available for growth due to the diversion of nutrients and energy to thermoregulation. As a result, to achieve optimal growth performance, it is necessary to keep pigs in their thermoneutral zone (Nawab et al., 2018).

Relative Humidity and Ventilation

Humidity, in conjunction with air temperature, has an effect on thermal comfort and respiration. Dust and respiratory irritation is another consequence of low humidity, while high humidity worsens heat stress by limiting evaporative cooling.

Moreover, proper ventilation is essential as regard to controlling humidity, excessive heat generation and oxygen supply. Inadequate ventilation also causes accumulation of ammonia, carbon dioxide and airborne particulates, which are harmful to the respiratory epithelium and growth efficiency (David et al., 2015).

Air Quality and Ammonia Exposure

Ammonia is considered one of the noxious gas pollutants in poultry houses. It is a product of decomposition of nitrogenous waste from litter and manure. High AN contents will result in damage to the tracheal epithelium, slow the mucociliary clearance process and make birds susceptible to respiratory diseases and retarded growth. Research has reported that standard rearing diets with up to 30 ppm, or higher, of ammonia can reduce broiler growth performance and feed efficiency. Good litter management, sufficient ventilation, and proper stocking density are important factors for reducing ammonia levels(Beker et al., 2004).

Stocking Density and Space Allowance

Growth is directly affected by stocking rate via access to food and water, physical activity, and social behavior. Intensive stocking densities escalate competition, stress and occurrences of skeletal and footpad lesions, thus impairing growth performance. Overcrowding also exacerbates heat stress and causes floor space reduction, which adds to litter quality deterioration and growth impairment. Greater densities, while potentially economically efficient, can be detrimental to growth and welfare when decision makers favor unbalanced policies(Estevez, 2007).

Lighting Programs and Photoperiod

Intensity, length and wave-length of light are important environmental influence on growth and behavior of poultry. Circadian rhythm, human hormone secretion and feeding activity are affected by lighting programs. Long day lengths cause increases in feed intake and growth, especially early in life; but long periods of light may lead to stress and metabolic disorders. Furthermore, it is still a common practice for broilers to use step down or intermittent lighting programs to encourage maximum growth and decrease leg problems resulting from sudden death syndrome(Olanrewaju et al., 2016).

Housing Systems and Litter Quality

In addition to good housing design and litter management, the yield potential is also highly dependent on this. Moist or microbial-contamination litter quality can contribute to the emergence of footpad dermatitis and hock burns which are local lesions by itself further mediating systemic inflammation decreasing growth. Drier litter that is well-maintained insulates against cold, limits ammonia production and makes the birds happier. All of them work to harness adequate air exchange, temperature modification and sanitation to create the most optimal growth environment in housing facilities(Shepherd & Fairchild, 2010).

Hygiene, Biosecurity, and Disease Pressure

Although the impact is more indirect than that of environmental hygiene, biosecurity modulating disease pressure also plays an important role for growth. Poor sanitation exposes women to more pathogens and parasites, which triggers immunity that deposits nutrients to fight pathogens instead of for growth. Sub-clinical infections cause substantial loss because they may not be arrested but relentlessly lowering the production performance of animals. Higher pathogen

loads are linked to cleanliness and sanitary conditions, together with the related uniformity of growth(Kogut & Arsenault, 2016).

Noise and Human Disturbance

More unexplored but economically compelling from that point of view, environmental noise and familiar anthropogenic disturbances can construct a stressing factor in poultry. Chronic stress elevates the level of corticosterone, food intake and growth inhibition. A stress free environment of gentle treatment and continual management techniques creates for a high benefit(Fidan et al., 2015).

Conclusion

Growth and productivity of poultry are the result of interactions among a complex array of biological, nutritional and environmental factors. Content involves genetic potential, physiological control & intestinal health, but nutrition balance is crucial for its optimal expression. The environment affects feed intake, health and metabolic efficiency so it is important in terms of temperature, air quality and housing as well as management practices. Dampening performance occurs because disruption of either one or several areas may impede growth, and reduced animal wellbeing. Adequate interventions (for control of poultry diseases) needs to be in place and it must be effective not only at the onset of a disease outbreak but also beyond its immediate effects which means that sustainable control strategies will be based on sound scientific principles. In the meantime, continued trend and improvement of accuracy agriculture tools will further increase growth efficiency without damage to the general health and output of the bird.

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