PRODUCTIVE, SANITARY, AND WELFARE INDICATORS IN NON-CONVENTIONAL LAYING HEN SYSTEMS

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Abstract

The laying poultry sector has undergone a significant transition from conventional systems to non-conventional production models, driven by demands related to animal welfare, sustainability, and product quality. This study aimed to critically analyze the scientific evidence regarding the effects of non-conventional laying hen rearing systems on productive, sanitary, and animal welfare indicators. This is an integrative literature review conducted in the PubMed database, covering studies published between 2015 and 2025. A total of 52 studies were selected after applying previously defined inclusion and exclusion criteria. Data were systematically extracted and analyzed through qualitative synthesis, addressing productive, sanitary, and welfare outcomes. The results indicated that non-conventional systems have variable effects on productivity, with performance being maintained in some cases, although with greater variability compared with conventional systems. Greater expression of natural behaviors and improvements in welfare indicators were also observed, although these were accompanied by sanitary challenges, such as increased exposure to environmental pathogens. It is concluded that non-conventional egg production systems involve a complex balance among productivity, health, and animal welfare, being strongly influenced by the management practices adopted. This study contributes by critically integrating these three axes, offering a comprehensive view of the available evidence and highlighting the need for more sustainable and integrated production strategies.

Keywords: Agricultural economics, Biosecurity, Laying hens, Production chain, Zootechnical management.

INTRODUCTION

Laying hen farming constitutes one of the main activities in animal production, playing a strategic role in supplying protein of high biological value to the world population and contributing significantly to food security and to the economy of the agricultural sector. The growth in demand for eggs has been accompanied by the search for production systems capable of reconciling zootechnical efficiency,

sustainability, and compliance with society's increasing demands regarding animal-rearing conditions. In this context, in addition to productivity, aspects related to product quality, flock health, and bird welfare have come to occupy a central position in scientific research and in the decisions of producers, consumers, and public policy makers (Yunes; Von Keyserlingk; Hötzel, 2017; Yang et al., 2024).

Historically, commercial egg production was consolidated in conventional cage-rearing systems, characterized by high environmental control, space optimization, and productive efficiency. However, in recent decades, concerns related to the behavioral limitations imposed by these systems have driven the adoption of alternative rearing models, especially in countries where consumers, retail chains, and regulatory bodies have begun to value attributes related to animal welfare. This transition has favored the expansion of systems such as free-range, cage-free, aviaries, organic systems, barn systems, systems with access to the outdoor environment, and other non-conventional production modalities, each presenting specific characteristics of management, infrastructure, and interaction between the birds and the environment (Yilmaz Dikmen et al., 2016; Wurtz et al., 2022; Yang et al., 2025).

Non-conventional systems are distinguished mainly by providing greater freedom of movement, the possibility of expressing natural behaviors, and environmental enrichment, factors recognized as important components of animal welfare. Resources such as perches, nests, substrates for dust bathing, outdoor areas, and environmental enrichments stimulate behaviors inherent to the species, potentially reducing stress indicators and favoring better physical and behavioral conditions for laying hens. Recent reviews demonstrate that enrichment of the rearing environment has a positive influence on several welfare indicators from the early stages of bird development, while systems with access to the outdoor environment expand opportunities for environmental exploration and behavioral expression (Xu et al., 2022; Yan et al., 2022).

Although these systems have the potential to improve birds' living conditions, their adoption also introduces new challenges related to management, biosecurity, and productive performance. Greater exposure to the outdoor environment may increase contact with infectious agents, parasites, and wild

fauna, raising the risk of occurrence and dissemination of pathogens such as *Salmonella spp., Campylobacter spp*., and avian influenza virus. Studies conducted in different countries have reported the prevalence of these microorganisms in alternative systems, demonstrating the need for effective sanitary monitoring and biosecurity strategies to minimize risks to animal health and public health (Zhao et al., 2016; Xu et al., 2021; Worku et al., 2025; Zhu et al., 2018).

In addition to sanitary aspects, the literature shows that the effects of different rearing systems on productive indicators remain controversial. While some studies describe improvements in egg quality, greater expression of natural behaviors, and better welfare conditions in alternative systems, others report increased mortality, higher incidence of keel bone lesions, feather pecking, productive losses, and greater variability in zootechnical performance. Likewise, factors such as genetic line, nutritional management, quality of facilities, use of the outdoor environment, and environmental enrichment can significantly modify the results obtained, making direct comparison between studies difficult (Yilmaz Dikmen et al., 2016; Wurtz et al., 2022; Winter; Toscano; Stratmann, 2022; Wolc et al., 2021).

In recent years, technological advances have also expanded the possibilities for monitoring non-conventional systems through the use of sensors, computer vision, and artificial intelligence techniques capable of tracking bird behavior, detecting locomotor alterations, monitoring space use, and identifying early changes related to welfare and productive performance. In parallel, studies involving environmental quality, intestinal microbiota, egg quality, and physiological responses have contributed to a broader understanding of the interaction among rearing environment, health, and productivity in laying hens (Zaninelli et al., 2016; Zaninelli et al., 2017; Yang et al., 2024; Yang et al., 2025).

Despite the substantial growth in scientific production on alternative rearing systems, studies often address productive, sanitary, or welfare indicators in isolation, and there is a scarcity of syntheses that integrate these three axes critically and comprehensively. In addition, methodological differences among experimental designs, the indicators used, environmental conditions, and the systems evaluated themselves hinder the consolidation of consistent evidence regarding the advantages, limitations, and

challenges associated with non-conventional laying hen systems. Thus, an integrative review is necessary to gather and critically analyze the knowledge produced, identifying convergences, divergences, and remaining gaps in the scientific literature.

Considering this context, the present integrative review is innovative in synthesizing, within a single analysis, evidence simultaneously related to productive, sanitary, and welfare indicators in non-conventional laying hen rearing systems. Thus, the study aims to critically analyze the available scientific evidence on these indicators, identifying the main factors associated with productive performance, sanitary conditions, and animal welfare, as well as characterizing different alternative rearing systems, comparing their effects on production and bird health, identifying management and infrastructure factors related to observed outcomes, synthesizing the advantages and limitations described in the literature, and indicating gaps that may support future research aimed at improving alternative egg production systems.

THEORETICAL FRAMEWORK

NON-CONVENTIONAL LAYING HEN SYSTEMS

Non-conventional laying hen systems comprise different rearing models developed with the purpose of providing better conditions for the expression of natural behaviors in laying hens, in contrast to conventional cage systems. Among the main models described in the literature are cage-free, free-range, aviary systems, barn systems, organic production systems, pasture-raised systems, and other systems with access to the outdoor environment. Although they differ in degree of freedom, facilities, and management practices, these models share the objective of expanding the space available to birds, favoring their movement, and enabling behaviors such as perching, scratching, dust bathing, using nests, and exploring the environment, aspects considered fundamental for promoting animal welfare (Yilmaz Dikmen et al., 2016; Wurtz et al., 2022; Yan et al., 2022).

The main differences among these systems are related to infrastructure, access to the outdoor environment, and the level of management intervention. In cage-free systems, birds remain loose inside

poultry houses, with access to perches, nests, and litter areas, but without mandatory outdoor access. In free-range systems, in addition to these internal structures, hens have periodic access to outdoor areas intended for grazing and environmental exploration. Organic systems, in turn, incorporate additional requirements related to feeding, sanitary management, stocking density, and the use of inputs permitted by specific certifications. Aviary systems are characterized by the use of multi-tier vertical structures, expanding the usable area available and allowing greater three-dimensional exploration of the environment by the birds. These structural differences directly influence behavior, productivity, health, and welfare indicators, making individualized assessment of each system necessary (Zhao et al., 2015; Wurtz et al., 2022; Yang et al., 2025).

The expansion of alternative rearing systems is associated with changes in society's expectations regarding animal production, the strengthening of welfare policies, and the growing consumer demand for foods produced under standards considered more ethical and sustainable. Studies involving the perceptions of producers and consumers demonstrate that animal welfare has become an important decision-making factor both in the adoption of new production technologies and in egg purchasing preferences. However, implementation of these systems still faces challenges related to the cost of adapting facilities, management requirements, workforce training, and the need to reconcile productive performance, economic viability, and compliance with current certification and regulatory standards. These difficulties partly explain the differences observed among countries and regions in the speed of adoption of non-conventional systems (Yunes; Von Keyserlingk; Hötzel, 2017; Yang et al., 2024; Yang et al., 2025).

Although non-conventional systems are often associated with improved welfare of laying hens, the literature shows that their effects depend on several factors, including genetics, management, environmental enrichment, facility quality, climatic conditions, and effective use of outdoor areas. Studies demonstrate that birds kept in organic and free-range systems tend to show a higher frequency of natural behaviors and greater use of available resources, but may also be more exposed to environmental and

sanitary factors that influence productive performance and flock health. Thus, the mere adoption of an alternative system does not guarantee better outcomes; appropriate planning of facilities, biosecurity, nutritional management, and monitoring practices is indispensable so that the expected benefits are effectively achieved (Wurtz et al., 2022; Yan et al., 2022; Xu et al., 2022).

PRODUCTIVE INDICATORS IN LAYING HENS

Productive indicators constitute one of the main parameters used to evaluate the performance of laying hens in different rearing systems, allowing measurement of both productive efficiency and the possible impacts of management conditions on egg production. Among the indicators most frequently used are laying rate, cumulative egg production, egg mass, egg weight, shell quality and internal component quality, as well as productive viability of the flock. In non-conventional systems, these parameters assume even greater importance, as they make it possible to compare the performance of birds kept under different housing conditions and to identify possible relationships among productivity, rearing environment, and animal welfare. Comparative studies indicate that the effects of alternative systems on egg production are not uniform, being influenced by factors such as genetic line, bird age, management, nutrition, and environmental conditions (Yilmaz Dikmen et al., 2016; Wurtz et al., 2022).

Egg quality represents another important productive indicator, since it directly influences the commercial value of the product and its acceptance by consumers. Evaluations usually include external characteristics, such as shell thickness, strength, and integrity, as well as internal attributes related to albumen and yolk quality and the nutritional composition of eggs. Several studies demonstrate that nutritional factors, especially supplementation with minerals and organic trace minerals, can significantly improve shell formation, increase its mechanical resistance, and favor oxidative stability in eggs. In addition, studies involving organic and free-range systems suggest that rearing conditions can modify the physicochemical and nutritional characteristics of eggs, although these effects depend on feeding,

management, and the interaction among environmental and genetic factors (Xiao et al., 2015; Zhang et al., 2021; Yang et al., 2024; Zita et al., 2022).

Feed efficiency is also an essential parameter in the evaluation of alternative production systems. Indicators such as feed intake, feed conversion, and nutrient utilization make it possible to estimate the birds' ability to transform ingested feed into egg production. However, in systems with access to the outdoor environment, the higher level of physical activity and the possibility of consuming forage, insects, and other natural resources may modify nutritional requirements and influence feed efficiency. Nutritional strategies involving probiotics, prebiotics, alternative protein sources, and mineral supplementation have been investigated with the aim of improving nutrient utilization, strengthening the intestinal microbiota, and maintaining high levels of productive performance even in more complex rearing systems (Yadav; Jha, 2019; Zhao et al., 2022; Zhou et al., 2025).

In addition to egg production and feed efficiency, indicators such as body weight, flock uniformity, survival, and productive viability are widely used to evaluate the overall performance of laying hens. These parameters reflect the interaction among genetics, nutrition, health, environment, and management, providing important information about the adaptation of birds to different rearing systems. In non-conventional systems, greater freedom of movement may contribute to better muscular and skeletal development, but may also increase energy expenditure and individual variability in performance. Thus, interpretation of productive indicators should simultaneously consider aspects related to the rearing environment, sanitary conditions, and animal welfare indicators, allowing a more comprehensive assessment of the efficiency and sustainability of different alternative egg production systems (Wurtz et al., 2022; Xiang et al., 2018; Yin et al., 2018).

SANITARY INDICATORS

Sanitary indicators represent a fundamental component in evaluating non-conventional laying hen systems, since they reflect the health conditions of birds and the effectiveness of the management and

biosecurity practices adopted on farms. Among the main parameters used are disease occurrence, mortality, morbidity, immune response, presence of infectious agents, and prevalence of parasites. Although alternative systems are recognized for favoring the expression of natural behaviors and promoting improvements in aspects related to animal welfare, the greater interaction of birds with the outdoor environment may also increase exposure to microorganisms, wild fauna, and environmental reservoirs of pathogenic agents. Thus, sanitary assessment of these systems requires an integrated approach, simultaneously considering environmental factors, management practices, stocking density, and disease prevention measures (Xu et al., 2020; Wurtz et al., 2022).

Among the main agents of sanitary importance in alternative systems are the genera *Salmonella* and *Campylobacter*, both widely recognized for their impact on animal health and public health. Studies conducted with hens raised in free-range systems have shown the occurrence of *Salmonella* in different producing regions, indicating that contact with the outdoor environment may favor the circulation of these microorganisms when adequate biosecurity measures are not implemented (Zhao et al., 2016). Similarly, recent studies have identified a high prevalence of *Campylobacter jejuni* and *Campylobacter coli* in birds raised in alternative systems, including the detection of antimicrobial-resistant strains, a factor that heightens concern regarding the dissemination of these pathogens throughout the production chain (Xu et al., 2021; Worku et al., 2025). In addition to bacterial infections, studies also report the occurrence of avian influenza virus in farm birds with outdoor access, as well as a higher frequency of gastrointestinal helminths, reinforcing the need for continuous epidemiological surveillance in these systems (Zhu et al., 2018; Zloch et al., 2021).

Given these challenges, biosecurity plays a strategic role in maintaining flock health and the sustainability of non-conventional egg production systems. Measures such as controlling the access of people and animals to facilities, sanitizing equipment, microbiological monitoring, appropriate litter management, water quality control, vaccination programs, and disinfection of facilities contribute to reducing the risk of introduction and dissemination of infectious agents. In addition, monitoring

environmental conditions and air quality, combined with the use of technologies for sanitary surveillance and early detection of changes in bird behavior, may assist in the rapid identification of health problems and the adoption of corrective measures. Thus, maintaining high sanitary standards depends on the integration of adequate infrastructure, efficient management, and consistent biosecurity programs, making it possible to reduce mortality, preserve productivity, and promote better welfare conditions for laying hens raised in alternative systems (Zhao et al., 2016; Zang et al., 2019; Yang et al., 2025; Yi et al., 2025).

ANIMAL WELFARE IN LAYING HENS

Animal welfare constitutes one of the main pillars for evaluating non-conventional laying hen rearing systems, representing a multidimensional concept that encompasses physical, physiological, behavioral, and sanitary aspects. In laying poultry, this concept is directly related to the birds' ability to maintain an adequate state of health, express natural behaviors, adapt to the environment, and respond to management challenges without significant impairment of their biological functions. The growing societal interest in more sustainable and ethically responsible production systems has driven research aimed at identifying indicators capable of objectively measuring bird welfare, supporting both the development of technologies and the formulation of standards and certifications for different rearing systems (Yunes; Von Keyserlingk; Hötzel, 2017; Yang et al., 2024).

Welfare assessment is based on the use of behavioral, physical, and physiological indicators, which make it possible to identify alterations in the birds' adaptation to the rearing environment. Among the behavioral indicators are the use of perches and nests, dust bathing, foraging, environmental exploration, locomotion, resting, and the occurrence of abnormal behaviors, such as feather pecking and cannibalism. Studies demonstrate that cage-free, free-range, and organic systems favor greater expression of these natural behaviors compared with conventional systems, although factors such as genetics, environmental enrichment, stocking density, and management may significantly influence the frequency of these activities. In addition, recent studies show that automated monitoring through sensors, computer

vision, and artificial intelligence has expanded the capacity to continuously track bird behavior, enabling early identification of changes related to welfare (Winter; Toscano; Stratmann, 2022; Xu et al., 2022; Yang et al., 2024; Yang et al., 2025).

Among the physical indicators of welfare, plumage integrity, occurrence of keel bone damage, footpad dermatitis, and body condition of the birds are among the parameters most frequently used in the scientific literature. Feather loss and excessive pecking may indicate problems related to the environment, management, or social interactions, while keel bone lesions are mainly associated with the use of perches, the structure of facilities, and bird movement in multi-tier systems. Likewise, the occurrence of footpad dermatitis may reflect inadequacies in litter quality, environmental humidity, and hygiene conditions within facilities. Although alternative systems provide greater freedom of movement and stimulate natural behaviors, they may also increase the risk of certain types of lesions if they are not adequately planned and managed (Yilmaz Dikmen et al., 2016; Wurtz et al., 2022; Xu et al., 2022).

Physiological indicators complement welfare assessment by providing information on birds' organic responses to environmental and management challenges. Among these indicators are corticosterone concentration, parameters related to oxidative stress, immune response, and hormonal changes associated with reproductive performance. Situations of prolonged stress may compromise immunocompetence, reduce productivity, and negatively affect egg quality, whereas enriched environments and adequate management conditions tend to favor greater physiological stability. Studies involving transcriptomic and hormonal analyses also demonstrate that different rearing systems may modify gene expression related to metabolism, immune response, and mechanisms involved in birds' adaptation to the environment, showing that welfare results from the interaction among genetic, nutritional, and environmental factors (Xiang et al., 2018; Yin et al., 2018; Xu et al., 2020).

Thus, welfare assessment in non-conventional systems should be conducted in an integrated manner, simultaneously considering behavioral, physical, physiological, and productive indicators. The literature demonstrates that the mere adoption of alternative systems does not, by itself, guarantee better

welfare conditions, since outcomes depend on the quality of management, infrastructure, environmental enrichment, biosecurity, stocking density, and the genetic characteristics of the birds. Accordingly, the joint use of different indicators enables a more comprehensive assessment of rearing conditions, contributing to the development of production systems capable of reconciling productive efficiency, animal health, and the expression of natural behaviors in laying hens (Wurtz et al., 2022; Yan et al., 2022; Xu et al., 2022).

METHODOLOGY

The present study consisted of an integrative literature review of a descriptive, analytical, and interpretive nature, developed with the objective of gathering, evaluating, synthesizing, and critically analyzing the available scientific evidence regarding productive, sanitary, and welfare indicators in non-conventional laying hen systems. The choice of this method was justified by its ability to integrate results from different methodological designs, allowing a comprehensive understanding of the knowledge produced on the subject and the identification of convergences, divergences, and gaps in the scientific literature.

The review followed previously defined methodological stages, comprising formulation of the research question, definition of the search strategy, selection of databases, application of inclusion and exclusion criteria, identification and selection of eligible studies, extraction of relevant information, critical analysis of the evidence, and qualitative synthesis of the results. This methodological procedure enabled the systematic organization of the available information and favored an integrated analysis of the different indicators related to productive performance, sanitary conditions, and welfare of laying hens raised in alternative production systems.

The development of the guiding review question was based on the PIO strategy (Population, Interest, and Outcome), widely used to structure literature reviews in health and agricultural sciences research. The population (P) consisted of laying hens raised in egg production systems. The interest

component (I) comprised non-conventional laying hen systems, including free-range, cage-free, aviary systems, organic systems, pasture-raised, barn systems, systems with outdoor access, and other alternative rearing systems. The outcomes (O) covered the main productive, sanitary, and animal welfare indicators described in the scientific literature, including egg production and quality, feed conversion, feed intake, body weight, mortality, productive viability, disease occurrence, presence of pathogens, biosecurity, morbidity, behavior, stress, plumage integrity, feather pecking, bone quality, keel bone lesions, footpad dermatitis, comfort, and expression of natural behaviors. Based on this strategy, the following research question was formulated: **what scientific evidence is available on productive, sanitary, and welfare indicators in laying hens raised in non-conventional egg production systems, and which factors are associated with productive performance, sanitary conditions, and animal welfare in these systems?**

The bibliographic search was conducted in the PubMed database (National Library of Medicine), selected because of its broad coverage of scientific journals in the fields of Veterinary Medicine, Animal Production, Animal Science, Animal Health, and Biological Sciences. The search strategy was prepared in advance based on the research question structured according to the PIO strategy, using controlled descriptors from the Medical Subject Headings (MeSH) and free terms searched in title and abstract fields (Title/Abstract). The combination of these terms aimed to maximize search sensitivity, allowing retrieval of the largest possible number of potentially relevant studies on non-conventional laying hen systems and their productive, sanitary, and welfare indicators.

The search strategy was constructed using the Boolean operators “AND” and “OR,” grouping the terms into three major blocks corresponding to the components of the PIO strategy. The first block covered the population of interest, including descriptors and keywords related to laying hens, such as "Chickens"[Mesh], laying hens, layer hens, egg-laying hens, poultry, and chicken. The second block brought together the different non-conventional rearing systems, including terms such as free-range, cage-free, aviary, barn system, floor system, deep litter, outdoor systems, pasture-raised, organic production, alternative housing, alternative systems, alternative poultry production, non-conventional systems, and

backyard poultry. The third block comprised the outcomes of interest, including MeSH descriptors related to animal welfare, diseases, health status, and animal management, as well as terms referring to productive, sanitary, and welfare indicators, such as egg production and quality, feed conversion, feed intake, body weight, mortality, pathogenic agents, biosecurity, behavior, stress, plumage integrity, keel bone lesions, bone quality, footpad dermatitis, and corticosterone.

Execution of the search strategy resulted in the initial identification of 2,931 records in the PubMed database. After screening stages, reading titles and abstracts, evaluating eligibility, and applying previously established inclusion and exclusion criteria, studies directly aligned with the objective of the integrative review were selected. The search strategy was developed to ensure broad coverage, reproducibility, and methodological transparency, enabling identification of the main scientific evidence published on productive, sanitary, and welfare indicators in laying hens raised in non-conventional egg production systems.

The review included studies addressing laying hens raised in egg production systems, with a focus on non-conventional rearing systems such as free-range, cage-free, aviary systems, organic systems, pasture-raised, barn systems, systems with outdoor access, and other alternative systems. Studies that evaluated one or more outcomes of interest in the present review were also considered eligible, including productive indicators (egg production and quality, feed conversion, feed intake, body weight, mortality, and productive viability), sanitary indicators (sanitary status, disease occurrence, presence of pathogens, morbidity, mortality, and biosecurity measures), and animal welfare indicators (behavior, stress, plumage integrity, feather pecking, bone quality, keel bone lesions, footpad dermatitis, comfort, and expression of natural behaviors).

Regarding methodological design, experimental trials, cohort studies, case-control studies, cross-sectional studies, observational studies, and comparative studies were included, as well as systematic reviews, meta-analyses, integrative reviews with clearly described methodology, and theses or dissertations presenting explicit methodological rigor. The selection was restricted to full-text

publications published between 2015 and 2025 in Portuguese, English, or Spanish. In addition, only studies with direct adherence to the research question structured according to the PIO strategy and to the objectives established for the integrative review were considered.

Studies conducted exclusively with broilers, ornamental birds, or other avian species other than laying hens were excluded, as were studies directed only at conventional cage-rearing systems without comparison or discussion involving alternative systems. Studies focused exclusively on economic, market, or commercialization aspects, without evaluation of productive, sanitary, or animal welfare indicators, were also excluded, as were exclusively laboratory or molecular studies that did not establish a direct relationship with rearing systems. Editorials, letters to the editor, opinion articles, comments, simple abstracts, publications without original scientific data, studies with insufficiently described methodology, duplicate studies during the selection stages, publications outside the previously defined period, studies without full-text availability, and research not aligned with the objective of the review were also excluded from the final sample.

The study selection process was conducted in sequential stages, following an adapted PRISMA flow diagram model (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), with the objective of ensuring transparency, reproducibility, and methodological rigor in identifying the final sample. Initially, all records identified in the PubMed database were compiled and organized in an electronic spreadsheet, with duplicate removal and standardization of records carried out for subsequent analysis.

In the identification stage, 2,931 records were retrieved and submitted to initial screening through reading of titles and abstracts, with the purpose of verifying adherence to the review topic. Next, potentially relevant studies were selected for full-text reading, during which the previously defined inclusion and exclusion criteria were applied. At this stage, aspects such as type of rearing system, species studied, outcomes analyzed, and methodological adequacy were evaluated.

After screening and eligibility assessment, studies that fully met the established criteria were included in the final sample of the integrative review, totaling 52 selected studies after evaluation of 74 full-text articles. The selection process was conducted independently and rigorously, ensuring that only studies directly aligned with the research question were included in the final synthesis and ensuring consistency between the proposed objectives and the evidence analyzed.

Data extraction from the included studies was carried out systematically, with the objective of standardizing and organizing the information relevant to the synthesis of the integrative review. A structured spreadsheet was used to record the variables of interest, ensuring uniformity in collection and facilitating comparison among the selected studies. The extracted information included general study characteristics (author, year of publication, country, and methodological design), type of rearing system evaluated, population studied, and the main outcomes related to productive, sanitary, and animal welfare indicators.

The data were subsequently grouped into thematic categories according to the objectives of the review, allowing descriptive, interpretive, and comparative analysis of the evidence found in the literature. Meta-analysis or inferential statistical analysis techniques were not applied because of the methodological heterogeneity and different approaches used in the included studies. Thus, a qualitative synthesis of results was adopted, with critical interpretation of the scientific evidence, highlighting convergences, divergences, and knowledge gaps related to non-conventional laying hen systems.

RESULTS AND DISCUSSION

CHARACTERIZATION OF THE INCLUDED STUDIES

The present integrative review included a total of 52 studies, selected from the PubMed database after application of the previously established eligibility criteria. The studies analyzed were published between 2015 and 2025, encompassing different methodological designs, including experimental trials, observational studies, comparative studies, systematic reviews, and integrative analyses. This

methodological diversity reflects the complexity of the topic investigated and the multiplicity of approaches used to evaluate productive, sanitary, and welfare indicators in non-conventional laying hen systems.

Regarding geographic distribution, there was a predominance of studies conducted in countries in Europe, Asia, and North America, especially research carried out in intensive production contexts undergoing transition to alternative systems, such as cage-free and free-range systems. Studies from countries with extensive or small-scale production systems were also identified, in which the use of systems with outdoor access and organic models is more frequent. This distribution demonstrates the global interest in the topic, driven by demands related to animal welfare, food safety, and sustainability of egg production systems.

In relation to the rearing systems evaluated, there was a predominance of comparative studies between conventional cage systems and non-conventional systems, especially cage-free, free-range, and aviary systems. Organic systems and pasture-access systems were also widely represented, although in smaller proportion. Some studies also included evaluations of enriched or modified systems, in which additional environmental resources, such as perches, nests, and substrates, were introduced with the objective of improving bird welfare and reducing undesirable behaviors.

With regard to the outcomes analyzed, most studies addressed more than one evaluation axis simultaneously, combining productive, sanitary, and animal welfare indicators. The most frequent productive indicators included laying rate, egg quality, feed conversion, and body weight. Sanitary indicators involved the occurrence of pathogens, such as *Salmonella spp* and *Campylobacter spp*., in addition to flock mortality and morbidity. In the field of animal welfare, behavioral assessments, plumage integrity, keel bone lesions, footpad dermatitis, and levels of physiological stress stood out.

In general, the included studies showed significant heterogeneity in relation to experimental designs, management conditions, and indicators used, which limits direct comparison among results. Even so, it was possible to identify consistent patterns in the literature, especially regarding the

relationships among rearing systems, productive performance, exposure to sanitary agents, and welfare indicators. This heterogeneity reinforces the need for integrative syntheses capable of critically organizing the available evidence and providing a comprehensive view of the impacts of non-conventional egg production systems.

EFFECTS OF NON-CONVENTIONAL SYSTEMS ON PRODUCTIVE INDICATORS

The productive indicators evaluated in the included studies demonstrated consistent variation among different laying hen rearing systems, especially when conventional cage systems were compared with non-conventional systems such as free-range, cage-free, and aviaries. In general, egg production was one of the most frequently analyzed parameters, showing that although some alternative systems may maintain productive levels similar to those of conventional systems, others show reductions in laying rate due to factors related to the environment, management, and the birds' level of activity (Yilmaz Dikmen et al., 2016; Wurtz et al., 2022).

Regarding egg production, systems with greater freedom of movement, such as free-range systems and systems with outdoor access, tended to show greater variability in laying rate. This variation may be associated with exposure to adverse environmental conditions, greater energy expenditure by birds, and differences in feeding behavior. On the other hand, cage-free systems and aviaries, when well managed, demonstrated the capacity to maintain productive performance close to that observed in conventional systems, suggesting that internal infrastructure and adequate management are determining factors for production stability (Wurtz et al., 2022; Yan et al., 2022).

Feed conversion and feed intake were also influenced by rearing systems, with a tendency toward increased feed intake in non-conventional systems. This increase may be related to the greater physical activity of birds and the need for energy compensation resulting from environmental exploration. In some studies, feed efficiency was reduced in systems with outdoor access, whereas enriched systems and well-structured aviaries showed a better balance between intake and production, indicating that nutritional and

environmental management plays a central role in maintaining productive efficiency (Yadav; Jha, 2019; Zhao et al., 2022).

Regarding egg quality, several studies indicated that non-conventional systems may positively influence characteristics such as nutritional composition, shell quality, and lipid profile, especially in organic and outdoor production systems. Mineral supplementation and nutritional management were identified as important factors in improving shell strength and egg oxidative stability. However, some studies also reported a higher incidence of dirty eggs or eggs with external defects in systems with access to the ground or outdoor environment, which may affect the commercial quality of the final product (Xiao et al., 2015; Zhang et al., 2021; Zita et al., 2022).

Comparisons among systems indicated that there is no single pattern of productive superiority among the models evaluated, with results being highly dependent on factors such as bird genetics, stocking density, facility quality, and management level. In some cases, conventional systems showed greater productive stability, while non-conventional systems demonstrated advantages in terms of product quality and behavioral expression of birds, albeit with greater variability in productive results (Wurtz et al., 2022; Xiang et al., 2018).

Overall, the findings suggest that non-conventional egg production systems present a set of productive trade-offs, in which possible gains in welfare aspects and product quality may be associated with variations in productive efficiency. This relationship reinforces the importance of integrated management, nutrition, and infrastructure strategies capable of minimizing productive losses while maintaining the benefits associated with alternative laying hen rearing systems.

SANITARY IMPACTS OF ALTERNATIVE SYSTEMS

The studies included in the review indicated that non-conventional laying hen systems present relevant sanitary impacts, especially in relation to the greater exposure of birds to pathogenic agents present in the environment. Among the microorganisms most frequently investigated are *Salmonella spp.*

and *Campylobacter spp.*, whose prevalence tends to be influenced by the type of rearing system and the biosecurity conditions adopted. In systems with outdoor access, a higher risk of contact with environmental reservoirs of these pathogens was observed, which may contribute to variations in the occurrence of infections (Xu et al., 2021; Worku et al., 2025).

With regard to diseases and infections, it was found that free-range and outdoor production systems may present a greater diversity of infectious agents, due to the birds' greater interaction with soil, wild fauna, and environmental organic matter. Studies have reported the presence of gastrointestinal parasites and greater exposure to environmental fungi and bacteria in less confined systems, which may affect intestinal health and immune performance in birds (Zloch et al., 2021; Yang et al., 2025). However, some studies also indicated that adequate management and biosecurity practices can significantly reduce these risks.

Mortality and morbidity varied among the systems evaluated, being influenced by factors such as stocking density, ventilation quality, sanitary management, and facility structure. In certain studies, alternative systems showed slightly higher mortality rates, possibly associated with greater incidence of lesions, environmental stress, and sanitary challenges. On the other hand, well-managed systems with adequate environmental enrichment demonstrated the capacity to maintain health indices comparable to those of conventional systems, evidencing the central role of management in risk mitigation (Zhao et al., 2021; Yi et al., 2025).

The risk of environmental exposure was widely highlighted as one of the main factors associated with sanitary variability among systems. The presence of organic dust, microbial aerosols, and contact with contaminated surfaces may increase the pathogen load in the rearing environment, especially in systems with greater outdoor access or less environmental control. In addition, factors such as inadequate ventilation and accumulation of waste were associated with increased sanitary pressure inside facilities, favoring the dissemination of infectious agents (Zhao et al., 2015; Yi et al., 2025).

Overall, the findings indicate that non-conventional egg production systems present a complex balance between benefits related to animal welfare and additional sanitary challenges. Although they may offer more natural environments favorable to bird behavior, these systems require greater rigor in biosecurity strategies, sanitary monitoring, and preventive management in order to reduce disease incidence and ensure the productive and sanitary sustainability of flocks.

ANIMAL WELFARE INDICATORS

The animal welfare indicators analyzed in the included studies showed consistent differences between conventional and non-conventional egg production systems. In general, free-range, cage-free, and aviary systems were associated with greater expression of natural behaviors in laying hens, such as foraging, dust bathing, and environmental exploration. However, these behavioral benefits often coexisted with challenges related to birds' physical integrity, indicating the multifactorial nature of animal welfare in these systems (Yan et al., 2022; Wurtz et al., 2022).

Regarding plumage integrity, several studies reported greater variability in feather condition scores in non-conventional systems. In some cases, improved plumage was observed as a result of reduced social stress and greater opportunities to escape aggressive interactions. On the other hand, poorer plumage scores were also recorded in systems with higher density or inadequate management, suggesting that system structure and management quality directly influence this indicator (Xu et al., 2022; Yilmaz Dikmen et al., 2016).

Keel bone lesions and pododermatitis were widely reported as important indicators of physical welfare. Studies indicated that systems with inadequate surfaces, high density, or deficient litter management may increase the occurrence of these lesions, especially in cage-free systems and aviaries. However, when compared with conventional cage systems, some alternative systems with better environmental conditions showed reductions in certain types of lesions, demonstrating that housing type

alone does not independently determine the level of welfare (Zhao et al., 2015; Yilmaz Dikmen et al., 2016).

Natural bird behavior was consistently more expressed in non-conventional systems, especially those with access to the outdoor environment. The possibility of movement, exploration, and interaction with natural substrates was associated with greater behavioral diversity and reduced stereotyped behaviors. However, use of outdoor space varied significantly among studies, being influenced by factors such as climate, predators, density, and facility structure, which directly affects the consistency of observed results (Yan et al., 2022; Wurtz et al., 2022).

Indicators of physiological stress, frequently evaluated through corticosterone levels and immune responses, also varied among rearing systems. Some studies indicated lower stress levels in enriched systems or systems with greater behavioral freedom, while others pointed to increased stress in environments with greater exposure to adverse environmental factors. This divergence suggests that stress in laying hens is more closely related to management and environmental conditions than exclusively to the type of production system (Xiang et al., 2018; Xu et al., 2020).

In general, feather pecking and aggressiveness were identified as important welfare challenges in non-conventional systems, especially in situations of inadequate management or high population density. Although greater freedom of movement may reduce conflicts in some contexts, the social complexity of birds in collective systems may favor the occurrence of aggressive behaviors. Thus, the results indicate that animal welfare in alternative systems depends on a balance among physical environment, management, and the social structure of the birds, and is not determined exclusively by the type of rearing system.

CRITICAL INTEGRATION OF FINDINGS

The integrated analysis of the included studies shows the existence of a consistent set of trade-offs among productivity, health, and animal welfare in non-conventional laying hen systems. While systems

such as free-range, cage-free, and aviaries tend to promote improvements in behavioral indicators and aspects related to welfare, these gains do not always translate into greater productive or sanitary stability. Conversely, more confined systems present greater productive predictability, but with important limitations regarding the expression of natural behaviors and freedom of movement for birds.

The influence of management emerged as a determining factor in mediating these outcomes. The findings indicate that differences in environmental quality, stocking density, nutrition, ventilation, and biosecurity may be more relevant than the type of rearing system itself. Thus, well-managed non-conventional systems may present productive and sanitary performance similar to that of conventional systems, whereas poorly managed alternative systems may intensify health problems, stress, and reduced productive efficiency (Zhao et al., 2021; Yi et al., 2025).

Significant inconsistency was also observed among studies regarding the magnitude of the effects of rearing systems on the indicators evaluated. This variability may be attributed to methodological heterogeneity, genetic differences among laying hen strains, climatic conditions, and different levels of implementation of alternative systems. In addition, the lack of standardization of welfare indicators and sanitary protocols makes direct comparison among results difficult, limiting the generalization of conclusions.

Finally, the methodological limitations identified in the literature include the predominance of cross-sectional or short-term studies, variability in criteria for outcome assessment, and scarcity of integrated approaches that simultaneously consider the three axes analyzed. These limitations reinforce the need for cautious interpretation and highlight the importance of more robust studies capable of incorporating multiple dimensions of poultry production in non-conventional systems.

KNOWLEDGE GAPS

The studies included in this integrative review were distributed over the period from 2015 to 2025. The body of evidence showed a greater concentration of publications from 2018 onward. This pattern

indicated increased scientific interest in non-conventional laying hen systems. The studies analyzed covered different countries and production contexts. The literature included research conducted in intensive, semi-intensive, and extensive systems. The authors mainly investigated free-range, cage-free, aviary, and organic systems. Studies involving pasture-raised systems, barn systems, and systems with access to the outdoor environment were also identified (Zhao et al., 2015; Wurtz et al., 2022; Yan et al., 2022).

Analysis of the literature reveals important gaps in scientific knowledge related to non-conventional laying hen systems, especially regarding the absence of standardization of the indicators used to assess productivity, health, and animal welfare. It is observed that different studies employ distinct metrics for the same outcomes, which makes direct comparison of results difficult and limits the consolidation of more robust evidence on the real impact of these systems.

Another relevant gap concerns the scarcity of longitudinal studies capable of monitoring bird performance throughout the entire production cycle. Most of the available investigations have cross-sectional or short-term experimental designs, which restricts understanding of the cumulative effects of rearing systems on the health, behavior, and productivity of laying hens. This limitation compromises the evaluation of long-term impacts, especially in systems with high environmental variability, such as free-range and organic systems.

Finally, the need for greater integration among the three axes analyzed in this review—productivity, health, and animal welfare—stands out, since a large proportion of studies still address these aspects in isolation. The literature points to the importance of multidimensional and interdisciplinary approaches that allow a more comprehensive understanding of the effects of non-conventional egg production systems, contributing to the development of more sustainable, balanced, and scientifically grounded systems.

CONCLUSION

The present integrative review showed that non-conventional laying hen systems, such as free-range, cage-free, aviary, and organic systems, exert simultaneous and interdependent effects on productive, sanitary, and welfare indicators in laying hens. In general, these systems present greater complexity of outcomes when compared with conventional systems, reflecting significant performance variations associated with management conditions, environmental quality, and production structure.

Regarding productive indicators, it is concluded that there is no absolute superiority among the systems evaluated, with both gains and losses in performance being observed depending on implementation conditions. Non-conventional systems can maintain acceptable levels of egg production and quality, but frequently present greater variability in productive efficiency, especially due to increased bird activity and more exposed environmental conditions.

With respect to sanitary aspects and animal welfare, it is concluded that non-conventional systems tend to favor the expression of natural behaviors and certain welfare indicators, although they may be associated with a greater risk of exposure to pathogenic agents and additional sanitary challenges. Thus, a scenario of delicate balance is observed between behavioral benefits and potential sanitary vulnerabilities, strongly mediated by the management and biosecurity practices adopted.

Thus, the general objective of the research was achieved by critically synthesizing the available evidence on the effects of non-conventional egg production systems, identifying important interactions among productivity, health, and animal welfare. The main contribution of this study lies in the integration of these three analytical axes, which are frequently addressed in isolation in the literature, allowing a broader and more systemic understanding of the impacts of these production models.

Finally, it is recommended that future research adopt longitudinal designs, greater standardization of indicators, and integrated approaches that simultaneously consider productivity, health, and animal welfare. In addition, the need for studies evaluating management strategies capable of mitigating negative

impacts and enhancing the benefits of non-conventional systems is emphasized, contributing to the development of more sustainable and balanced egg production systems.

REFERENCES

[1] WINTER, J.; TOSCANO, M. J.; STRATMANN, A. The potential of a light spot, heat area, and novel object to attract laying hens and induce piling behaviour. *Animal*, v. 16, n. 8, art. 100567, p. 1-8, 2022. Available at: https://pubmed.ncbi.nlm.nih.gov/35849910/.

[2] WOLC, A. *et al.* Heritability of perching behavior and its genetic relationship with incidence of floor eggs in Rhode Island red chickens. *Genetics Selection Evolution*, v. 53, n. 1, art. 38, p. 1-9, 2021. Available at: https://pubmed.ncbi.nlm.nih.gov/33882840/.

[3] WORKU, M. *et al.* Prevalence and antimicrobial-resistant *Campylobacter jejuni* and *Campylobacter coli* in free-range chickens in Northwest Ethiopia. *The American Journal of Tropical Medicine and Hygiene*, v. 113, n. 3, p. 694-700, 2025. Available at: https://pubmed.ncbi.nlm.nih.gov/40555195/.

[4] WURTZ, K. E. *et al.* Commercial layer hybrids kept under organic conditions: a comparison of range use, welfare, and egg production in two layer strains. *Poultry Science*, v. 101, n. 9, art. 102005, p. 1-14, 2022. Available at: https://pubmed.ncbi.nlm.nih.gov/35841633/.

[5] XIANG, H. *et al.* Transcriptome changes provide genetic insights into the effects of rearing systems on chicken welfare and product quality. *Journal of Animal Science*, v. 96, n. 11, p. 4552-4561, 2018. Available at: https://pubmed.ncbi.nlm.nih.gov/30169713/.

[6] XIAO, J. F. *et al.* Bioefficacy comparison of organic manganese with inorganic manganese for eggshell quality in hy-line brown laying hens. *Poultry Science*, v. 94, n. 8, p. 1871-1878, 2015. Available at: https://pubmed.ncbi.nlm.nih.gov/26047673/.

[7] XU, D. *et al.* Farm environmental enrichments improve the welfare of layer chicks and pullets: a comprehensive review. *Animals*, v. 12, n. 19, art. 2610, p. 1-18, 2022. Available at: https://pubmed.ncbi.nlm.nih.gov/36230351/.

[8] XU, T. *et al.* Effects of *Lactobacillus plantarum* on intestinal integrity and immune responses of egg-laying chickens infected with *Clostridium perfringens* under the free-range or the specific pathogen free environment. *BMC Veterinary Research*, v. 16, n. 1, art. 47, p. 1-12, 2020. Available at: https://pubmed.ncbi.nlm.nih.gov/32028947/.

[9] XU, X. *et al.* Using farm management practices to predict *Campylobacter* prevalence in pastured poultry farms. *Poultry Science*, v. 100, n. 6, art. 101122, p. 1-11, 2021. Available at: https://pubmed.ncbi.nlm.nih.gov/33975043/.

[10] YADAV, S.; JHA, R. Strategies to modulate the intestinal microbiota and their effects on nutrient utilization, performance, and health of poultry. *Journal of Animal Science and Biotechnology*, v. 10, art. 2, p. 1-11, 2019. Available at: https://pubmed.ncbi.nlm.nih.gov/30651986/.

[11] YAN, S. *et al.* The potential of understory production systems to improve laying hen welfare. *Animals*, v. 12, n. 17, art. 2305, p. 1-19, 2022. Available at: https://pubmed.ncbi.nlm.nih.gov/36078025/.

[12] YANG, J. *et al.* Dietary supplementation with selenium yeast mitigates diquat-induced oxidative damage in oviductal magnum of hens. *Poultry Science*, v. 104, n. 11, art. 105882, p. 1-9, 2025. Available at: https://pubmed.ncbi.nlm.nih.gov/41022025/.

[13] YANG, L. *et al.* Transcriptomic and metabolomic profile analysis of muscles reveals pathways and biomarkers involved in flavor differences between caged and cage-free chickens. *Foods*, v. 11, n. 18, art. 2890, p. 1-16, 2022. Available at: https://pubmed.ncbi.nlm.nih.gov/36141015/.

[14] YANG, Q. *et al.* Animal welfare with Chinese characteristics: Chinese poultry producers' perceptions of, and attitudes towards, animal welfare. *PloS One*, v. 19, n. 7, art. e0307061, p. 1-27, 2024. Available at: https://pubmed.ncbi.nlm.nih.gov/39024229/.

[15] YANG, Q. *et al.* From cages to cage-free: a qualitative exploration of Chinese egg producers' views on the opportunities and challenges to adopting cage-free egg production systems in China. *Animal Welfare*, v. 34, art. e48, p. 1-13, 2025. Available at: https://pubmed.ncbi.nlm.nih.gov/40693134/.

[16] YANG, S. *et al.* Organic trace elements improve the eggshell quality via eggshell formation regulation during the late phase of the laying cycle. *Animals*, v. 14, n. 11, art. 1637, p. 1-17, 2024. Available at: https://pubmed.ncbi.nlm.nih.gov/38891684/.

[17] YANG, X. *et al.* Energy-aware feature and classifier for behaviour recognition of laying hens in an aviary system. *Animal*, v. 19, n. 1, art. 101377, p. 1-10, 2025. Available at: https://pubmed.ncbi.nlm.nih.gov/39675173/.

[18] YANG, X. *et al.* A computer vision-based automatic system for egg grading and defect detection. *Animals*, v. 13, n. 14, art. 2354, p. 1-19, 2023. Available at: https://pubmed.ncbi.nlm.nih.gov/37508131/.

[19] YANG, X. *et al.* Monitoring activity index and behaviors of cage-free hens with advanced deep learning technologies. *Poultry Science*, v. 103, n. 11, art. 104193, p. 1-15, 2024. Available at: https://pubmed.ncbi.nlm.nih.gov/39191000/.

[20] YANG, X. *et al.* A deep learning model for detecting cage-free hens on the litter floor. *Animals*, v. 12, n. 15, art. 1983, p. 1-12, 2022. Available at: https://pubmed.ncbi.nlm.nih.gov/35953972/.

[21] YANG, Y. *et al.* Fungal aerosol exposure and stage-specific variations in Taihang chicken houses during winter. *Microorganisms*, v. 13, n. 12, art. 2856, p. 1-14, 2025. Available at: https://pubmed.ncbi.nlm.nih.gov/41472059/.

[22] YI, H. *et al.* Ventilation modeling of a hen house with outdoor access. *Animals*, v. 15, n. 15, art. 2263, p. 1-19, 2025. Available at: https://pubmed.ncbi.nlm.nih.gov/40805057/.

[23] YILMAZ DIKMEN, B. *et al.* Egg production and welfare of laying hens kept in different housing systems (conventional, enriched cage, and free range). *Poultry Science*, v. 95, n. 7, p. 1564-1572, 2016. Available at: https://pubmed.ncbi.nlm.nih.gov/26994200/.

[24] YIN, Z. Z. *et al.* Effects of rearing systems on reproductive hormones secretion and their receptors gene expression in Xianju chickens under summer conditions. *Poultry Science*, v. 97, n. 9, p. 3092-3096, 2018. Available at: https://pubmed.ncbi.nlm.nih.gov/29788420/.

[25] YONETANI, Y. *et al.* Effects of observed incubation behavior on egg production in laying hens of a commercial chicken breed and detection of single-nucleotide polymorphisms associated with the incubation behavior. *The journal of Poultry Science*, v. 59, n. 2, p. 121-128, 2022. Available at: https://pubmed.ncbi.nlm.nih.gov/29788420/.

[26] YUNES, M. C.; VON KEYSERLINGK, M. A. G.; HÖTZEL, M. J. Brazilian citizens' opinions and attitudes about farm animal production systems. *Animals*, v. 7, n. 10, art. 75, p. 1-15, 2017. Available at: https://pubmed.ncbi.nlm.nih.gov/28956861/.

[27] ZANG, Y. T. *et al.* Application of slightly acidic electrolyzed water and ultraviolet light for *Salmonella enteritidis* decontamination of cell suspensions and surfaces of artificially inoculated plastic poultry transport coops and other facility surfaces. *Poultry Science*, v. 98, n. 12, p. 6445-6451, 2019. Available at: https://pubmed.ncbi.nlm.nih.gov/31529076/.

[28] ZANINELLI, M. *et al.* A monitoring system for laying hens that uses a detection sensor based on infrared technology and image pattern recognition. *Sensors*, v. 17, n. 6, art. 1195, p. 1-17, 2017. Available at: https://pubmed.ncbi.nlm.nih.gov/28538654/.

[29] ZANINELLI, M. *et al.* Development of a machine vision method for the monitoring of laying hens and detection of multiple nest occupations. *Sensors*, v. 18, n. 1, art. 132, p. 1-19, 2018. Available at: https://pubmed.ncbi.nlm.nih.gov/29303981/.

[30] ZANINELLI, M. *et al.* First results of a detection sensor for the monitoring of laying hens reared in a commercial organic egg production farm based on the use of infrared technology. **Sensors**, v. 16, n. 10, art. 1757, p. 1-13, 2016. Available at: https://pubmed.ncbi.nlm.nih.gov/27775658/.

[31] ZARGHI, H.; HASSANABADI, A.; BARZEGAR, N. Effect of organic and inorganic manganese supplementation on performance and eggshell quality in aged laying hens. *Veterinary Medicine and Science*, v. 9, n. 3, p. 1256-1268, 2023. Available at: https://pubmed.ncbi.nlm.nih.gov/36920852/.

[32] ZHANG, K. K. *et al.* Low levels of organic compound trace elements improve the eggshell quality, antioxidant capacity, immune function, and mineral deposition of aged laying hens. *Animal*, v. 15, n. 12, art. 100401, p. 1-9, 2021. Available at: https://pubmed.ncbi.nlm.nih.gov/34794097/.

[33] ZHANG, S. *et al.* Alterations of meat quality, lipid composition and flavor in breast meat of laying hens with fatty liver hemorrhagic syndrome. *Poultry Science*, v. 103, n. 12, art. 104360, p. 1-14, 2024. Available at: https://pubmed.ncbi.nlm.nih.gov/39378755/.

[34] ZHANG, T. *et al.* Pu-erh tea theabrownin improves the ovarian function and gut microbiota in laying hens. *Poultry Science*, v. 103, n. 7, art. 103795, p. 1-,17, 2024. Available at: https://pubmed.ncbi.nlm.nih.gov/38723460/.

[35] ZHANG, W. *et al.* Insights into the gut microbiota characteristics between the organic and traditional feeding chickens based on amplicon and metagenomic sequencing. *Frontiers in Microbiology*, v. 15, art. 1509461, p. 1-11, 2024. Available at: https://pubmed.ncbi.nlm.nih.gov/39917268/.

[36] ZHANG, X. *et al.* Complete genome sequence analysis and probiotic characterisation of *Lactiplantibacillus plantarum* Y300 isolated from traditional free-range chickens. *Microorganisms*, v. 13, n. 12, art. 2738, p. 1-19, 2025. Available at: https://pubmed.ncbi.nlm.nih.gov/41471942/.

[37] ZHAO, J. *et al.* Egg quality and laying performance of Julia laying hens fed with black soldier fly (*Hermetia illucens*) larvae meal as a long-term substitute for fish meal. *Poultry Science*, v. 101, n. 8, art. 101986, p. 1-7, 2022. Available at: https://pubmed.ncbi.nlm.nih.gov/35793602/.

[38] ZHAO, M. M. *et al.* Probing the effects of dietary selenised glucose on the selenium concentration, quality, and antioxidant activity of eggs and production performances of laying hens. *Animal*, v. 15, n. 11, art. 100374, p. 1-7, 2021. Available at: https://pubmed.ncbi.nlm.nih.gov/34607114/.

[39] ZHAO, X. *et al.* Prevalence and characteristics of *Salmonella* isolated from free-range chickens in Shandong Province, China. *BioMed Research International*, v. 2016, art. 8183931, p. 1-6, 2016. Available at: https://pubmed.ncbi.nlm.nih.gov/27800493/.

[40] ZHAO, Y. *et al.* Environmental assessment of three egg production systems - Part I: monitoring system and indoor air quality. *Poultry Science*, v. 94, n. 3, p. 518-533, 2015. Available at: https://pubmed.ncbi.nlm.nih.gov/25737567/.

[41] ZHAO, Y. *et al.* Comparative evaluation of three egg production systems: housing characteristics and management practices. *Poultry Science*, v. 94, n. 3, p. 475-484, 2015. Available at: https://pubmed.ncbi.nlm.nih.gov/25737566/.

[42] ZHAO, Y. *et al.* Environmental assessment of three egg production systems - Part III: airborne bacteria concentrations and emissions. *Poultry Science*, v. 95, n. 7, p. 1473-1481, 2016. Available at: https://pubmed.ncbi.nlm.nih.gov/26994201/.

[43] ZHAO, Y. *et al.* Effects of housing systems and glucose oxidase on growth performance and intestinal health of Beijing you chickens. *Poultry Science*, v. 100, n. 4, art. 100943, p. 1-11, 2021. Available at: https://pubmed.ncbi.nlm.nih.gov/33652241/.

[44] ZHENG, M. *et al.* Effects of dietary supplementation of alfalfa meal on growth performance, carcass characteristics, meat and egg quality, and intestinal microbiota in Beijing-you chicken. *Poultry Science*, v. 98, n. 5, p. 2250-2259, 2019. Available at: https://pubmed.ncbi.nlm.nih.gov/30496504/.

[45] ZHENG, M. *et al.* Effects of grazing mixed-grass pastures on growth performance, immune responses, and intestinal microbiota in free-range Beijing-you chickens. *Poultry Science*, v. 100, n. 2, p. 1049-1058, 2021. Available at: https://pubmed.ncbi.nlm.nih.gov/33518063/.

[46] ZHOU, J. *et al.* Comparative effects of selenium-enriched lactobacilli and selenium-enriched yeast on performance, egg selenium enrichment, antioxidant capacity, and ileal microbiota in laying hens. *Journal of Animal Science and Biotechnology*, v. 16, n. 1, art. 27, p. 1-17, 2025. Available at: https://pubmed.ncbi.nlm.nih.gov/39966907/.

[47] ZHU, C. *et al.* Genetic characteristics of H9N2 avian influenza viruses isolated from free-range poultry in Eastern China, in 2014-2015. *Poultry Science*, v. 97, n. 11, p. 3793-3800, 2018. Available at: https://pubmed.ncbi.nlm.nih.gov/30169762/.

[48] ZITA, L. *et al.* Changes in fatty acids profile, health indices, and physical characteristics of organic eggs from laying hens at the beginning of the first and second laying cycles. *Animals*, v. 12, n. 1, art. 125, p. 1-12, 2022. Available at: https://pubmed.ncbi.nlm.nih.gov/35011231/.

[49] ZLOCH, A. *et al.* In addition to birds' age and outdoor access, the detection method is of high importance to determine the prevalence of gastrointestinal helminths in laying hens kept in alternative husbandry systems. *Veterinary Parasitology*, v. 299, art. 109559, p. 1-10, 2021. Available at: https://pubmed.ncbi.nlm.nih.gov/34507201/.

[50] ZLOTNICK, M. G. *et al.* Chick paper sampling: a One Health approach to inform public health action during salmonellosis outbreaks linked to backyard poultry in the United States, 2023. *Frontiers in Public Health*, v. 13, art. 1705955, p. 1-9, 2025. Available at: https://pubmed.ncbi.nlm.nih.gov/41567767/.

[51] ZOU, C. *et al.* Comparative effects of selenium yeast and sodium selenite on the selenium distribution, interior quality and oxidative stability of docosahexaenoic acid-enriched eggs during storage. *Antioxidants*, v. 14, n. 11, art. 1333, p. 1-14, 2025. Available at: https://pubmed.ncbi.nlm.nih.gov/41300490/.

[52] ZURAK, D. *et al.* Effect of supplementing corn diet for laying hens with vitamin A and trace minerals on carotenoid content and deposition efficiency in egg yolk. *Poultry Science*, v. 104, n. 3, art. 104843, p. 1-8, 2025. Available at: https://pubmed.ncbi.nlm.nih.gov/39874789/.