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Egg Quality in Laying Hens: Optimizing Genetic, Nutritional, Environmental, and Management Factors for Sustainable Layer Farming

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Abstract

This review paper provides a comprehensive analysis of the critical factors affecting egg quality in laying hens, focusing on the integration of genetic, environmental, nutritional, and management practices. Egg quality, including shell strength, albumen consistency, and yolk pigmentation, is a key determinant of both production efficiency and marketability. Genetic factors, such as selection for desirable traits, like shell integrity and yolk color, have a significant impact on the overall quality of eggs. Advances in genetic selection allow for the breeding of hens with improved reproductive performance and egg quality characteristics, leading to better outcomes in both small-scale and commercial production systems. Nutritionally, optimization of feed formulation plays a central role in ensuring an adequate supply of essential nutrients, such as calcium, protein, vitamins, and trace minerals, which directly influence egg composition and shell formation. Proper feeding strategies, especially during heat stress or peak production periods, are crucial for maintaining consistent egg quality. Environmental factors, including housing conditions, temperature, humidity, and ventilation, are equally vital. Proper management of these elements helps minimize stress and environmental impacts, ensuring hens' well-being and optimal egg production. Management practices, such as uniform feed distribution, consistent feeding schedules, and efficient disease control measures, further contribute to maintaining high-quality eggs. This paper synthesizes recent advancements in each of these domains and highlights the practical applications of these insights for economically viable poultry farming.

Keywords: Egg quality, environmental factors, genetic selection, laying hens, management practices, nutrition, sustainable farming

INTRODUCTION

Egg quality is a pivotal component of poultry production, significantly affecting the profitability of egg producers and the consumer acceptance of eggs. High-quality eggs are characterized by strong, intact shells, firm albumen, and well-pigmented yolks, all of which contribute not only to market appeal but also to nutritional value. The optimization of egg quality results from the complex interaction of genetic, nutritional, environmental, and management factors, each playing a distinct role in shaping the final product. For instance, genetics can influence traits, like shell strength and egg size, while nutrition impacts shell formation and internal consistency [1]. Environmental conditions, such as temperature and humidity, affect the hens' overall well-being, and management practices, including feeding and

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disease control, further influence egg quality [2]. Understanding and optimizing these factors is critical for meeting the growing global demand for eggs.

Genetic factors play a foundational role in determining the inherent potential of hens to produce high-quality eggs. Through selective breeding, traits, such as shell strength, egg size, and yolk pigmentation can be enhanced, leading to better overall egg quality [3]. Advances in genetic research have made it possible to tailor breeding programs that target specific egg quality characteristics, thus improving production outcomes. Nutritional factors are equally significant, as the quality of the feed directly affects the internal and external characteristics of the egg. Adequate provision of key nutrients, such as calcium, protein, and vitamins, is essential for proper eggshell formation and yolk consistency. Deficiencies in these nutrients can result in weaker shells and poorer internal quality, ultimately impacting the egg's marketability [4].

Environmental factors, including temperature, humidity, and housing conditions, also significantly affect egg quality. Stress induced by unfavorable environmental conditions can result in thin shells, reduced albumen viscosity, and even egg production failures [1, 5]. Management practices, including disease control, feeding strategies, and handling procedures, further contribute to the maintenance of optimal egg quality. This review aims to provide a comprehensive overview of these interrelated factors, offering insights into current research and practices aimed at optimizing egg quality in laying hens. By examining the roles of genetics, nutrition, environment, and management, this paper seeks to provide a holistic approach to improving egg production efficiency and sustainability in the poultry industry.

GENETIC FACTORS

Hen Breed or Strain

The breed or strain of a hen plays a major role in determining egg quality. Different breeds exhibit varying characteristics, such as shell strength, egg size, and yolk color [6]. Selective breeding for specific traits allows the improvement of egg quality, with some breeds being more predisposed to producing eggs with desirable external and internal characteristics.

Onset Age of the Laying Period

The age at which hens begin laying eggs is genetically influenced and affects overall egg quality. Early onset of lay can result in smaller eggs with thinner shells, whereas late onset can lead to larger eggs, but with a higher likelihood of shell quality decline with age [7]. Genetic selection for optimal laying age balances both egg size and shell strength.

Heritability of Internal Quality Traits

The heritability of internal quality traits, such as yolk color and albumen consistency, can influence egg quality over generations [8]. Breeding programs that focus on enhancing traits, like firm albumen and well-pigmented yolks, are essential for producing eggs with desirable internal characteristics. Genetic improvement of these traits can enhance both nutritional value and consumer preference.

Pigment Deposition Capacity

The genetic ability of hens to deposit pigments in the eggshell is important for eggs with consistent color and market appeal. In certain breeds, the hen's genetic makeup determines the intensity and uniformity of shell pigmentation [9]. This factor is particularly important in breeds that lay brown eggs, as consumers often prefer eggs with specific shell colors.

Resistance to Reproductive Disorders

Genetic resistance to reproductive disorders, such as ovarian cysts and infections of the oviduct, plays a vital role in maintaining the egg quality of the hen. Hens with enhanced genetic resistance are less likely to experience reproductive system failures, which can directly affect egg quality by leading to poor shell formation, yolk abnormalities, or inconsistent production [10].

Oviposition Time Within the Circadian Cycle

Genetic factors affect the timing of oviposition, which influences egg quality. Hens with genetic predisposition for laying eggs consistently within a certain timeframe tend to produce eggs with more uniform internal and external qualities. Disruptions to this cycle can lead to eggs with inconsistent shell strength and yolk quality.

Genetic Potential for Higher Performance

Genetic potential for reproductive performance impacts both egg production and quality. Hens with higher reproductive efficiency tend to produce a greater number of eggs for a longer period with fewer defects [11]. Selective breeding can enhance reproductive performance, improving the consistency and quality of eggs while reducing production costs by minimizing defective or non-marketable eggs.

Body Weight and Egg Quality Correlation

Genetic factors that influence body weight can also impact egg quality. Hens with optimal body weight, determined by genetics, are more likely to produce eggs with better shell strength, albumen consistency, and yolk quality [12]. Excessive body weight may lead to metabolic issues, which can negatively affect egg production and quality.

Genetic Variation in Feed Efficiency

Genetic variation in feed conversion efficiency affects egg quality by influencing how efficiently hens convert feed into egg production. Hens with better feed conversion efficiency tend to have better overall health, leading to stronger shells, improved albumen quality, and more consistent egg production [13]. Selecting for efficient feed conversion can indirectly improve egg quality through better metabolic balance.

Genetic Determination of Egg Shape

Egg shape is genetically controlled and is an important quality trait for both market acceptance and processing efficiency. Hens that consistently produce eggs with an optimal oval shape, rather than elongated or misshapen eggs, are preferred. Genetic selection for egg shape can improve packaging efficiency and meet consumer expectations for egg appearance.

Genetic Regulation of Hormonal Control

Genetic regulation of hormones, like estrogen, progesterone, and prolactin, plays a key role in egg production and quality. These hormones control ovulation and the formation of egg components, such as yolk and albumen [14]. Genetic selection for optimal hormonal balance can improve both egg production rates and the quality of the eggs produced.

Genetic Potential for Molting Behavior

Molting is a natural process where hens shed and regrow feathers, often accompanied by a temporary reduction in egg production. Genetic factors influencing the timing and duration of molt can affect egg quality. Hens with genetic traits for efficient molting can resume high-quality egg production faster after molting, leading to more consistent quality over time.

Genetic Influence on Yolk Color

Yolk color is a highly visible trait that consumers often use to judge egg quality. Genetic factors controlling pigment deposition in the yolk determine its color intensity. Selective breeding for hens with genetic traits that enhance yolk pigmentation can improve the appearance and market appeal of eggs, particularly in breeds where deep yellow or orange yolks are desired.

Genetic Resistance to Stress

Genetic resistance to environmental stressors, such as temperature extremes or social stress within the flock, can significantly influence egg quality. Hens that are genetically more resilient to stress are less likely to experience disruptions in egg production or quality, including issues like poor shell strength, soft eggs, or inconsistent albumen quality.

NUTRITIONAL FACTORS

Balanced Dietary Energy

Balanced energy levels in feed ensure hens receive sufficient calories to meet metabolic demands, egg production, and maintenance of body condition. Energy deficiencies can reduce laying rates, while excess energy can lead to obesity, reducing overall productivity [15]. Energy sources, such as grains, should be optimized, considering other nutrients to avoid imbalances that could negatively affect egg quality.

Adequate Dietary Protein

Adequate protein levels in the feed supply are essential amino acids like methionine and lysine for albumen and yolk formation. Protein deficiencies lead to smaller eggs with poor internal quality, while excessive protein can strain kidney function [16]. A carefully formulated diet supports egg production and ensures optimal yolk color and albumen consistency, improving both nutritional and market value.

Calcium-Phosphorus Ratio

Maintaining an appropriate calcium-to-phosphorus ratio is critical for shell strength and structural integrity. Calcium supports shell calcification, while phosphorus balances bone health and metabolism. Imbalances can result in thin or fragile shells and increase breakage rates [17, 18]. Fine and coarse calcium sources are often combined to meet immediate and sustained needs during shell formation.

Vitamin D3

Vitamin D3 enhances calcium absorption from the gut and supports its utilization for eggshell calcification. A deficiency leads to poor shell quality, soft or malformed eggs, and skeletal health issues [19]. Supplementing diets with adequate vitamin D3 ensure that calcium is metabolized efficiently, supporting hens' productivity and minimizing defects in eggshells.

Omega-3 Fatty Acids

Omega-3 fatty acids improve yolk quality by enriching their nutritional profile, particularly increasing DHA content. This enrichment not only enhances the egg's market value but also meets consumer demand for healthier food options [20, 21]. Dietary supplementation through sources, like flaxseed or fish oil, improve yolk lipid composition without adverse effects on the hen's performance.

Selenium for Antioxidants

Selenium serves as a vital antioxidant, protecting hens from oxidative stress and improving reproductive performance. Supplementation enhances egg quality by stabilizing yolk lipids and reducing spoilage [22]. Organic selenium forms are particularly effective in improving bioavailability, thereby contributing to both hen health and the internal quality of eggs.

NaCl for Osmoregulation

Sodium and chloride are essential electrolytes that regulate water balance, osmosis, and acid-base homeostasis. Proper balance ensures effective nutrient absorption, hydration, and cellular function, directly influencing egg size, eggshell quality, and internal quality [23]. Deficiencies or imbalances can result in reduced egg weights and impaired physiological processes, adversely affecting production efficiency.

Zinc for Shell Strength

Zinc plays a vital role in enzyme activation during shell formation, influencing shell thickness and strength. It supports collagen synthesis in the shell membrane, enhancing its structural integrity [24]. Zinc deficiencies often lead to thin or brittle shells, reducing marketability. Including bioavailable zinc in diets ensures optimal shell quality and minimizes losses due to breakage.

Phosphorus Bioavailability

Phytase enzymes improve phosphorus availability from plant-based feeds, reducing the need for inorganic phosphorus supplements. This optimization enhances bone health, shell quality, and

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environmental sustainability by lowering phosphorus excretion in manure [25]. Supplementing phytase ensures efficient utilization of feed phosphorus, supporting egg production while minimizing environmental pollution.

Water Quality

Clean, uncontaminated water is essential for hens' metabolic processes, directly impacting egg production and quality. Contaminated water can introduce pathogens or toxins, compromising hen health and reducing productivity. Ensuring consistent water quality improves albumen consistency, yolk freshness, and overall egg safety, preserving flock welfare.

ENVIRONMENTAL FACTORS

Ambient Temperature

Temperature extremes negatively affect hen's performance and egg quality. Heat stress reduces feed intake, shell thickness, and albumen consistency, while cold stress can impair laying rates and increase energy expenditure [26]. Maintaining an optimal range of 18–24°C in poultry houses ensures consistent production, minimizes stress, and preserves shell strength and internal egg characteristics [27].

Humidity Levels

Proper humidity levels (50–70%) ensure eggshell quality and hen comfort. High humidity increases ammonia levels, damaging respiratory health and reducing egg production [28]. Conversely, low humidity causes dry and brittle shells. Effective humidity control through ventilation and monitoring systems supports optimal environmental conditions, enhancing both hen's welfare and egg quality.

Seasonal Variations

Seasonal changes impact temperature, humidity, and natural light, influencing hen performance and egg quality. Summer heat stress reduces shell strength and laying rates, while winter cold increases energy demands [29]. Adjusting housing conditions, lighting, and feeding strategies to counter seasonal effects ensures continuous productivity and stable egg quality throughout the year.

Enrichment Practices

Enrichment, such as providing pecking blocks or straw bales, reduces stress and promotes natural behaviors in hens. Stress reduction improves overall productivity, egg quality, and welfare. Enrichment also decreases the occurrence of defects, like misshapen or brittle eggs, contributing to improved internal and external egg characteristics.

Ventilation Systems

Adequate ventilation prevents heat buildup, removes excess moisture, and controls harmful gases like ammonia and carbon dioxide. Poor ventilation leads to respiratory issues in hens and compromises egg production [30]. Modern systems with adjustable airflow ensure consistent air quality, reduce environmental stressors and maintain conditions conducive to high-quality egg production.

Lighting Intensity

Lighting intensity affects hens' vision and behavior, influencing egg production and quality. Excessively bright light can cause stress and feather pecking, while dim light reduces activity levels [31]. Maintaining optimal lighting intensity (10–20 lux) ensures natural behaviors and supports proper reproductive cycling, resulting in consistent laying rates and high-quality eggs.

Lighting Duration

Lighting duration regulates reproductive hormones and laying patterns. A consistent photoperiod of 14–16 hours stimulate oviposition, while abrupt changes disrupt egg production [32]. Proper lighting schedules mimic natural daylight cycles, supporting egg consistency, shell strength, and internal quality while preventing disruptions in laying behavior.

Dust Levels in Housing

Excessive dust in poultry housing compromises respiratory health and increases disease susceptibility in hens, indirectly affecting egg quality. Dust also contaminates egg surfaces, reducing cleanliness and market appeal. Regular cleaning, proper ventilation, and the use of dust-suppressing materials maintain hygienic conditions, egg safety, and hen wellbeing.

Air Ammonia Concentration

High ammonia levels (>25 ppm) irritate hens' respiratory tracts, reducing immunity and productivity [33]. Prolonged exposure also weakens shell strength and yolk quality. Managing litter moisture, optimizing ventilation, and employing ammonia-binding agents effectively reduce concentrations, ensuring healthier environments for hens and better egg quality.

Type of Housing System

Housing systems, i.e., cages, deep litter, and enriched cages, directly affect hen welfare and egg quality. Enriched systems improve behavioral expression and shell cleanliness but may increase shell breakage rates. Deep litter systems enhance yolk pigmentation but pose hygiene risks [34]. Tailoring housing systems to production goals balances welfare and egg quality.

Stocking Density

Overcrowding increases stress, competition for resources, and disease transmission, negatively affecting egg production and quality [35, 36]. Maintaining optimal stocking densities reduces aggression, ensures even feed and water access, and minimizes stress-induced defects like shell thinning. Proper space allocation promotes welfare and sustains egg productivity.

Perching Availability

Perches encourage natural behaviors, improving hen welfare and bone strength. Improved health translates into better egg quality, particularly shell integrity [37]. However, improper perch design can lead to injuries or stress. Providing well-designed, appropriately spaced perches enhances housing conditions and indirectly supports egg production.

PRODUCTION FACTORS

Phase Feeding

During peak production, hens require precise nutrient formulations to sustain high laying rates and optimal egg quality. Increased demands for energy, protein, calcium, and phosphorus are crucial for maintaining shell strength, yolk integrity, and albumen viscosity. Imbalances or deficiencies during this phase lead to production declines and compromised egg quality.

Age and Shell Quality

As hens age, eggshell strength deteriorates due to reduced calcium deposition efficiency and declining skeletal reserves [38]. This results in thinner, more fragile shells prone to breakage during handling. Managing calcium supplementation, incorporating vitamin D3, and ensuring optimal housing conditions minimize age-related shell quality decline.

Age and Egg Size

Egg size increases progressively with hen age, influenced by physiological changes and larger yolks [39]. While larger eggs are commercially desirable, they often have thinner shells, increasing breakage risk. Balancing feed formulations and managing body weight prevents excessive size while maintaining shell integrity, ensuring high-quality eggs throughout the laying cycle.

Alterations of Yolk Pigmentation

Yolk color can fluctuate over the production cycle due to dietary carotenoid availability and physiological changes in pigment deposition efficiency [40]. Early in the cycle, pigmentation is more intense, while later phases may show fading. Consistent dietary carotenoid supplementation and monitoring pigment sources ensure uniform yolk color throughout production.

Molting and Egg Quality

Molting, a natural process for rejuvenating laying capacity, temporarily halts egg production but often improves quality post-recovery. Eggs laid after molting typically exhibit stronger shells and higher albumen consistency [41]. Controlled molting programs with nutritional and environmental support optimize post-molt performance and egg quality.

Laying Cycle and Egg Quality

Eggs laid early in the production cycle are smaller but often have better shell strength and albumen quality. Late-cycle eggs are larger with thinner shells and variable internal consistency. Tailoring nutrition and management to each cycle phase ensures consistent quality, balancing early robustness and late-cycle size.

Hormonal Regulation of Oogenesis

Oogenesis, regulated by hormones, such as estrogen and progesterone, governs follicle development and yolk formation. Hormonal imbalances disrupt ovulation, leading to defects like double yolks or abnormal shells [14]. Maintaining optimal nutrition, stress management, and environmental stability supports hormonal health, ensuring efficient egg production and quality.

Age and Albumen Consistency

Albumen consistency declines with advancing hen age due to reduced protein quality and water retention capacity [42]. This impacts internal egg quality and consumer preference. Adjusting protein and amino acid levels in diets and minimizing stress factors help maintain albumen viscosity and improve overall egg quality as hens age.

Skeletal Calcium Mobilization

Efficient skeletal calcium mobilization is critical for eggshell formation, especially during peak laying periods. With age, calcium reserves deplete, reducing shell strength. Providing supplemental calcium and vitamin D3, particularly in late-laying hens, supports bone health and ensures consistent shell quality throughout the production cycle.

Duration of Egg Production

Lifetime egg production reflects a balance between consistent laying rates, health management, and age-related declines. Excessive early-cycle production can reduce long-term productivity and quality. Strategic flock management, including phased nutrition and disease control, maximizes lifetime yield without compromising shell integrity or internal egg characteristics.

HEALTH FACTORS

Vaccination Schedule

Adherence to a proper vaccination schedule protects hens against major infectious diseases, such as Newcastle disease and infectious bronchitis, that can compromise productivity and egg quality [43]. Vaccinations reduce mortality, maintain consistent laying rates, and prevent disease-induced defects like misshapen shells or poor albumen quality.

Metabolic Diseases

Metabolic diseases, like fatty liver syndrome, disrupt energy metabolism, reducing laying performance and egg quality. Affected hens may produce fewer eggs with thin shells and poor albumen consistency [44]. Preventive strategies, including balanced diets, avoiding excessive energy intake, and ensuring adequate choline and methionine levels, maintain metabolic health and optimize production.

Bacterial Infections

Bacterial infections, like Salmonella, compromise both hen health and egg safety, leading to reduced laying rates and potential public health risks. Preventive measures, including biosecurity, probiotics, and vaccination, minimize bacterial colonization [45]. Controlling infections improves egg cleanliness, internal quality, and consumer confidence in the product.

Viral Diseases

Newcastle disease is a highly contagious viral infection that reduces egg production and quality by causing misshapen shells, discolored yolks, and reduced laying rates [10]. Preventive vaccination and stringent biosecurity practices are critical for protecting hens from outbreaks, ensuring sustained productivity, and consistent egg quality.

External Parasites

External parasites, like mites and lice, cause irritation, anemia, and stress, reducing egg production and quality [46, 47]. Infested hens often produce eggs with thin or brittle shells due to nutrient diversion and compromised health. Regular monitoring and treatment with approved insecticides or natural remedies ensure parasite-free flocks, preserving hen welfare and egg quality.

Internal Parasites

Internal parasites, especially coccidia, damage the intestinal lining, impairing nutrient absorption crucial for egg production [48]. Suboptimal calcium or protein absorption due to parasitic infections reduces shell strength and internal egg quality. Preventive measures, such as anticoccidial agents and strict hygiene protocols, maintain gut health, ensuring optimal nutrient utilization and egg production.

Functional Gut Microbiota

A balanced gut microbiota supports nutrient absorption, immune function, and overall hen health, directly influencing egg quality. Dysbiosis leads to poor digestion, reduced egg size, and compromised shell integrity. Supplementing diets with prebiotics, probiotics, and organic acids fosters healthy microbiota, enhancing productivity and egg quality.

Reproductive Tract Infections

Infections in the reproductive tract, such as salpingitis, can lead to poor-quality eggs, including misshapen shells or abnormal yolks [44]. Preventive hygiene measures, routine health monitoring, and timely treatment with antibiotics or anti-inflammatory agents protect the reproductive system, ensuring consistent egg production and quality.

Anti-Inflammatory Interventions

Stress-induced inflammation reduces hen performance and compromises egg quality by affecting shell strength and albumen consistency. Anti-inflammatory interventions, such as dietary omega-3 fatty acids, antioxidants, and herbal extracts, mitigate stress effects, maintaining hen health and stable production even under challenging conditions [49].

Antioxidant Status of Hens

Antioxidants, like vitamin E and selenium, protect hens from oxidative stress, which can impair productivity and egg quality. A strong antioxidant status preserves yolk lipid integrity, maintains albumen viscosity, and supports reproductive health [50, 51]. Including antioxidants in the diet enhances egg quality while promoting hen longevity and welfare.

MANAGEMENT FACTORS

Feed Formulation

Heat stress reduces feed intake, leading to nutrient deficiencies that affect egg quality. Adjusting formulations to include higher energy density, electrolytes, and antioxidants during hot periods ensures hens meet their nutritional requirements [52]. Proper formulation enhances shell strength, yolk color, and overall production performance during heat stress.

Feeding Schedule

Maintaining a consistent feeding schedule aligns with hens' natural rhythms, ensuring optimal nutrient intake and egg quality. Irregular feeding disrupts digestion and metabolic balance, leading to shell defects and inconsistent yolks [53]. Establishing predictable feeding times stabilizes production and enhances egg uniformity.

Stress Minimization

Stress, triggered by noise or sudden movements, disrupts laying patterns, reduces egg quality, and compromises shell integrity. Providing a calm environment with minimal disturbances ensures hens maintain consistent production [54]. Training staff in careful handling and designing low-stress housing systems is essential to reduce stress-related production losses.

Litter Management

Maintaining clean, dry litter reduces microbial load, preventing infections, like Salmonella, that compromise egg safety and quality. Damp or soiled litter increases the risk of dirty eggs and pathogen transmission [55]. Regular litter replacement and proper ventilation promote hygiene and minimize egg contamination.

Biosecurity Measures

Biosecurity prevents the entry and spreads of diseases that compromise flock health and egg quality. Measures include restricting farm access, sanitizing equipment, and routine vaccination. Effective biosecurity minimizes disease-related egg defects like thin shells, poor albumen, and contamination risks, ensuring consistent quality and production.

Feeding Time Adjustment

Temperature management during feeding reduces heat stress, particularly in hot climates, improving feed intake and nutrient utilization. Feeding during cooler periods, such as early morning or evening, ensures hens consume sufficient nutrients to maintain egg quality, including strong shells and optimal yolk pigmentation, even under thermal challenges [56].

Cleaning of Nest Boxes

Clean nest boxes reduce egg contamination, shell damage, and microbial growth. Dirty or poorly maintained boxes lead to stained or fragile eggs, reducing marketability. Frequent cleaning and disinfection of nest boxes ensure a hygienic laying environment, preserving egg quality and safety.

Monitoring of Egg Weights

Regular monitoring of egg weights helps identify production trends and potential health or nutritional issues [57]. Deviations in weight may indicate dietary imbalances, disease, or age-related changes. Tracking weights allows for timely adjustments in feed formulation or management practices, ensuring consistent quality and size.

Avoidance of Feed Withdrawal

Abrupt feed withdrawal stresses hens and disrupts laying patterns, leading to reduced egg production and poor-quality eggs. Continuous feed availability ensures nutrient consistency, maintaining shell strength and yolk integrity [58]. Careful feed management supports uninterrupted egg production and high-quality output.

Molting Management Practices

Properly managed molting allows hens to rejuvenate their laying cycle, improving egg quality post-molt [59]. Controlled dietary and environmental adjustments during molting promote recovery and optimize shell strength, yolk consistency, and overall egg quality after resuming production.

Timely Culling of Non-Productive Hens

Culling non-productive hens prevents resource wastage and ensures flock efficiency. Retaining unproductive birds lowers overall production quality, as they may produce defective eggs [60]. Timely removal maintains flock uniformity, enabling better resource allocation and consistent, high-quality egg production.

Maintenance of Egg Conveyor Belts

Well-maintained conveyor belts prevent egg damage and contamination during collection. Faulty or dirty belts cause shell cracks, breakage, or microbial contamination. Regular cleaning, lubrication, and inspection ensure safe transport of eggs from laying to collection points, preserving quality.

Regular Calibration of Feeders and Drinkers

Calibrating feeders and drinkers ensure a consistent feed and water supply, preventing over- or under-consumption. Inaccuracies lead to nutrient imbalances, affecting egg production and quality. Routine calibration supports uniform intake, optimizing shell strength, yolk pigmentation, and albumen viscosity.

Keeping Hens in Uniform Age Groups

Grouping hens by similar ages facilitates tailored management practices, including feed formulations and disease prevention, suited to specific production stages [60]. Mixed-age flocks complicate resource allocation, impacting productivity and quality. Uniform age grouping ensures optimal care and consistent egg quality across the flock.

Maintenance of Feed Storage Quality

Proper feed storage prevents nutrient degradation, contamination, and spoilage, which can impact egg quality. Exposure to moisture, pests, or mold reduces feed efficacy, leading to shell defects and poor yolk color. Ensuring clean, dry, and pest-proof storage maintains feed integrity and supports consistent egg production.

Egg Cooling Rate Post-Laying

Rapid cooling of eggs after laying prevents microbial growth and maintains internal quality, including albumen viscosity and yolk integrity. Gradual cooling can lead to condensation, increasing the risk of bacterial contamination [61]. Immediate cooling within an appropriate temperature range preserves freshness and extends shelf life.

Handling Procedures for Eggs

Gentle handling minimizes shell damage and maintains internal quality. Rough handling increases the likelihood of cracks, contamination, and spoilage [62]. Training staff in proper egg-handling techniques, combined with the use of automated collection systems, ensures safe and efficient handling, preserving egg quality from farm to consumer.

Frequency of Egg Collection

Frequent collection reduces the risk of eggs being exposed to unfavorable conditions or damage in the nest. It also helps maintain cleanliness and minimizes shell contamination. Scheduling multiple daily collections ensures better preservation of egg quality, especially under intensive production systems.

Egg Packaging Quality

High-quality packaging protects eggs from physical damage, contamination, and environmental fluctuations. Materials, like cardboard or plastic, must provide cushioning and ventilation to prevent spoilage [63]. Proper labeling for traceability ensures consumer confidence, while well-designed packaging supports safe storage and transportation, preserving egg quality from farm to market.

Transport Conditions

Proper transport conditions, including vibration control, temperature regulation, and safe packaging, minimize breakage and preserve internal quality during transit [64]. Exposure to extreme temperatures or rough handling during transport can compromise freshness and shell integrity, emphasizing the need for specialized equipment and careful handling practices.

Nest Box Design

Well-designed nest boxes provide comfort and reduce stress during oviposition, preventing mislaid or cracked eggs. Features, like cushioned flooring, optimal size, and accessibility, improve laying behavior and egg cleanliness [65]. Regular maintenance and cleanliness of nest boxes ensure high egg quality and hygienic conditions.

Floor Cleanliness

A clean floor prevents eggs from becoming contaminated or damaged after being laid. Dirty environments increase the risk of bacterial contamination, reducing egg safety and marketability [55]. Regular removal of manure and debris from the housing area minimizes contamination, supporting both hen health and egg quality.

Collection Timing

Timely egg collection reduces the risk of contamination, breakage, and exposure to adverse environmental conditions. Frequent collection intervals also prevent hens from pecking or damaging eggs [66]. Establishing consistent collection routines improves overall cleanliness and quality, ensuring eggs reach markets in optimal condition.

CONCLUSIONS

Optimizing egg quality in laying hens requires a multifaceted approach that integrates genetic, environmental, nutritional, and management factors. Genetic improvements, such as selective breeding for traits, like shell strength, egg size, and albumen consistency, form the foundation of enhanced egg quality. Nutritional strategies that ensure adequate intake of essential nutrients, like calcium, protein, and vitamins, are crucial for maintaining optimal shell formation and internal egg quality. Environmental conditions, including temperature regulation, humidity control, and appropriate housing systems, must be carefully managed to minimize stress and promote consistent egg production. Additionally, sound management practices, such as efficient feed distribution, disease prevention, and regular health monitoring, may further contribute to maintaining high egg quality. By understanding and optimizing these factors, the poultry industry can improve both the quantity and quality of eggs produced, meeting the growing global demand while ensuring sustainability and economic viability.

Future Direction

Advances in genomic technologies can enable more precise genetic selection for traits associated with superior egg quality. Identifying specific genes related to shell strength, albumen quality, and reproductive performance will facilitate the development of laying hen breeds with enhanced egg characteristics. Further research is needed to optimize feed formulations, particularly in the use of alternative protein sources, novel micronutrients, and functional additives like prebiotics and probiotics. Exploring the role of nutrient bioavailability and how it impacts egg quality will be crucial for developing sustainable feeding strategies.

With climate change presenting challenges for poultry production, the development of more efficient environmental control systems, including smart climate monitoring and management tools, will be vital. This includes enhancing housing systems to reduce stress and improve egg quality during extreme weather conditions. The use of AI, machine learning, and big data analytics in monitoring and managing poultry production systems can provide insights into real-time environmental, health, and production data, allowing for timely adjustments to optimize egg quality. There is a growing demand for sustainable and ethical farming practices.

Future studies should focus on optimizing egg quality while minimizing environmental impact, such as reducing carbon footprints, improving waste management, and enhancing animal welfare. Developing strategies for improving the immune resilience of hens through selective breeding or dietary interventions will help reduce the risk of diseases that compromise egg quality. Research into non-invasive techniques for monitoring egg quality throughout the production cycle will enable better quality control and improve shelf life, leading to reduced food waste and better consumer satisfaction.

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