ID: 834

The Role Digital Economy in Enhancing Egg Quality

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Abstract

The main of this review was to examine the roles of digital economy in enhancing the egg quality. The leading global egg producing countries are China, India and United States, the bulk of the egg consumption varies over the past few decades due to changes in preferences and technology development. A Systemic approach was employed to identify the global sustainability and consumption patterns of eggs in developed countries, digital methods adopted, and branding. Egg nose detection, spectral analysis technology, computer fission technology, multi-fusion sensor technology, and artificial intelligence technology were the modern digital techniques employed to measure egg quality in developed countries. All these approaches were found to be effective in egg quality controls especially in terms of freshness and shell strength and other related attributes. The study concludes that holistic approaches ranging from nose electronic detection to current use of algorithms using artificial intelligence promotes the freshness, egg shell strength and other physical attributes of eggs in terms of quality in developed countries. The study recommends the needs for developing countries to adopt the modern digital methods using in developed countries for egg quality improvement.

Keywords: *digital economy, egg quality*

Introduction

Poultry eggs not only play the most fundamental nutritional role in national life but are also widely used in bread, pastry, baking, and other food industries, because of their exceptional processing qualities, such as foaming, emulsification, gel properties, and their active ingredients can be used to create new egg products and functional foods (Liu *et al.,* 2024). China dominated the global egg production in 2024, due to large-scale agricultural and technical improvements, accounting for 49% of the total (29.4 million tons), with low-cost feed and population increase, India produced 142.7 billion eggs, demonstrating notable growth. Flock reductions and avian influenza outbreaks caused a 3.9% decrease in U.S. production (76.8 billion eggs). The EU and Brazil contributed 6.66 million tons (−1.83%) and 45.8 billion eggs (+4.8%), respectively, reflecting regional issues such feed prices and animal welfare regulations. The average annual intake of eggs per person worldwide was 162, with differences across high-consumption areas (Patnaik *et al.* 2024). The sector faces substantial obstacles in maintaining quality across the supply chain. As perishable goods, eggs gradually lose their freshness from the farm to the table, which is made worse by improper temperature and humidity controls during storage and transit (Chi *et al.* 2024).

This deterioration raises the dangers to food safety and reduces their economic value. China currently lacks uniform laws for determining the shelf life of eggs, despite growing public awareness of food safety and nutritional health. Market practices rely on post-laying storage length as a freshness indicator, which is an inadequate metric that ignores handling-related mechanical damage or environmental factors that promote bacterial infection. The main quality factor, freshness, has a direct impact on the edibility, nutritional value, and processing appropriateness of eggs (Kapse et al. 2022). In particular, albumen proteins have functional qualities that are crucial for the production of food, such as the ability to foam and gel, which deteriorate with decreasing freshness. Since 1985, China, a sizable nation that both produces and consumes poultry eggs, has led the world in annual poultry egg production (Liu *et al.* 2024).

Processing poultry eggs has become a major problem since they are hard to transport, store, and preserve. By experimenting with various processing techniques and including nutrients that the human body need, new egg products can be produced. Additionally, egg products can be fortified and nutritionally modified to satisfy consumer expectations; examples of this include eggs that have been enhanced with iodine and selenium. Additionally, poultry eggs are a prominent topic of study for both domestic and international scholars due to their exceptional foaming, gelation, and emulsification capabilities in bread, cake, cream, and other consumables (Yang *et al.* 2023).

Egg Quality and physical factors

Several factors were connected to the poultry bird origin, food, flock age, or training technique which affects the quality of table eggs (Drabik *et al.* 2021). Regardless of them, eggs undergo biophysical and chemical changes shortly after laying, which have a detrimental impact on egg quality. According to Drabik *et al.* (2018), the primary cause of the change in egg mass is the evaporation of water from the contents of the egg through gas exchange between the contents and the external environment. Distributors and manufacturers of table eggs may face a variety of issues since weight loss during storage happens regardless of weight grade or storage circumstances.

Eggs with weights near the lower limits of the weight classes listed in the Regulation may lose weight during the trade; this change, even if it results from natural reasons, is regarded as adulteration. The quality variations also impact certain aspects of the egg's morphology. The albumen dense fraction is thinning, and its mass and pH have changed (Vlěcková, *et al.* 2019). Relative humidity is equally important in this regard because high levels of it prevent other changes in egg quality by reducing water evaporation from the egg content (Jones *et al.* 2005). Alternative techniques for protecting eggs from adverse quality changes during storage have also grown in favor. They can be divided into two major categories: those that use shell pore sealers (Drabik *et al.* 2021) or those that alter the atmosphere in the egg environment (Jia *et al.* 2019).

The main objective was to examine the roles of digital economy in enhancing the egg quality.

Thus, the purpose of this review is to: -

a. Examine existing literature: The goal of this review is to provide thorough research into sustainability and consumption eggs, modern digital methods adopted in developed economies, and branding of egg consumption pattern.

b. Composing relevant data from reliable sources and evaluating reputable articles are part of planned results synthesis.

The reputable research platform Research Gate is used in this review. An analysis of the research gate database was done. Target focus areas include global egg consumption, variation in egg consumption patterns, digital methods adopted for egg quality management, and branding of egg qualities in digital economies. We obtained pertinent material from several academic disciplines by using these keywords. Articles that were reviewed in a specific quantity included reports, conference proceedings, and journal articles.

Global Eggs consumption and sustainability

Chicken eggs are produced and consumed in large quantities in China. The country was ranked first in the globe in 2023 with 35.63 million tons of chicken eggs produced, coupled with a well-balanced combination of proteins, vitamins, minerals, trace elements, and other nutrients, poultry eggs are a natural source of life energy and complete nourishment. Customers from Brazil, China, India, Mexico, Spain, and the United States of America (USA) were interviewed for a recent study that assessed customers' willingness to pay for a more sustainable egg supply chain (Sánchez-Bravo *et al.*, 2021). The overall findings indicated that 34.8% of customers were willing to pay a premium of at least 20% and 47.8% were willing to pay at least 5% more for a more sustainable egg supply. Only a few numbers of customer said they would not be interested in paying extra for improvements in the sustainability of the egg supply; however, there were some disparities between the countries, with at least 25% of customers in the USA and Spain refusing to pay any premium. The consumers are now more concerned with the sustainability of the food chain and the effects of their decisions on the environment. The quality of eggs in developed economies like China, USA, and others were influenced by the sustainability behaviors of the consumers which are dependent trending development.

Global variation in Egg Consumption Quality patterns

The worldwide egg industry was able to produce an extra 46 eggs per person (+29.9%) between 2000 and 2020, despite the fact that the world's population increased by 26.9% and reached 7.795 billion in 2020. By running marketing and promotional programs that draw more customers to the egg category and raise the frequency of consumption, national associations of egg producers play a crucial role in boosting egg consumption (Guyonnet, 2019a). Large-scale marketing research studies offer incredibly useful customer insights, such as who they are, where they get eggs, when and where they eat them, and why they do or do not eat more eggs (Guyonnet, 2012). These businesses are able to divide the market into several consumer categories, such as egg lovers and non-consumers, based on the answers to these numerous questions, and then develop the most effective messages for each consumer category. These businesses can create highly successful campaigns to target every customer segment by combining print, social media, radio, and television advertising (Guyonnet, 2020a). For example, between 2010 and 2020, consumption of eggs increased by 119 in Brazil, 111 in Colombia, and 59 in Canada as a result of this all-encompassing approach to egg marketing and promotion (International Eggs Commission, 2021).

Digital methods adopted for Egg Quality

Electronic Nose Detection

Sensor arrays made up of several gas-sensitive components that are individually selectively responsive to particular volatile substances are used in electronic nose (e-nose) technology (Zhai, *et al.*, 2024). It evaluates odor patterns produced with the deterioration of egg freshness by simulating human olfaction (Yang *et al.*, 2023). Hydrogen sulfide, carbon dioxide, and organic acids are among the volatile substances that escape through the shell pores as eggs age, changing the composition of the gas (Konkol *et al.*, 2022). In order to assess freshness, the sensor array first detects these changes, converts them into electrical signals, and then uses pattern recognition algorithms to examine the data.

Spectral Analysis Technology

Spectral analysis technology is a non-destructive detection technique that provides information on chemical composition, structural features, and physical qualities by using the absorption, scattering, or emission characteristics of materials at particular wave lengths (Lu and Lu, 2017). Based on the principles of light interaction (transmission, refraction, and reflection), it evaluates the freshness of eggs by examining optical processes during light penetration and developing mathematical models for quality assessment (Huang *et al.*, 2024).

Computer Vision Technology

According to Wiley and Lucas (2018), computer vision technology uses image processing techniques to extract, analyze, and interpret visual information from picture data. Critical areas including the air cell and yolk undergo morphological changes when egg freshness declines (Rho and Cho, 2024). This method allows for accurate and effective freshness evaluation by analyzing egg photos using algorithms and models to extract important visual aspects and correlate them with freshness labels. Deep learning techniques and conventional methods make up the current computer vision-based image processing techniques.

Multi-Fusion Sensor Technology

Drayer and Howard, (2012) reported that in order eliminate systemic uncertainties and produce accurate observational results and integrated intelligence, multisensory fusion technology uses computational techniques to automatically analyze and synthesize information and data from multiple sensors or sources under specific criteria (Drayer and Howard, 2012). It has been extensively used in robotics, intelligent inspection, military systems, industrial monitoring, object identification and tracking, image analysis, and automatic target recognition. Based on the degree of information processing, the architecture of multi-sensor fusion detection systems can be divided into three hierarchical frameworks: data-level fusion (direct integration of raw sensor data), feature-level fusion (extraction and combination of salient features from preprocessed data), and decision-level fusion (aggregation of outputs from individual sensor-based decision models) (Karvir, 2010).

Artificial Intelligence (AI) Technology

Artificial intelligence is one of the modern techniques employed in developed countries to improve overall egg quality analysis and automate the egg mirage process, Helene *et al.* (2025) investigated conventional methods of poor egg quality by presenting a novel solution that combines Artificial Intelligence (AI) and Internet of Things (IoT) technologies. The web-based application uses a Convolutional Neural Network (CNN) algorithm to deliver real-time feedback on egg quality. In addition to revolutionizing egg quality monitoring in the poultry sector, this research's accomplishment establishes a standard for integrating AI and IoT to solve challenging issues in agricultural practices, such as power management. Artificial intelligence (AI) developments are driving an extraordinary technological transformation in the traditional egg deep-processing sector. Ali *et al.* (2024) observed that by examining spectrum characteristics associated with Haugh units, AI-powered hyperspectral imaging (HSI) improves freshness grading and defect detection related to eggs fractures and stains. Production line scheduling and operational efficiency are being optimized by AI technologies such as data analytics and machine learning algorithms. For example, real-time data analysis makes it possible to make predicted changes to production schedules that minimize waste and guarantee alignment with market expectations (Ameh, 2024). Artificial intelligence is using its special advantages to enable revolutionary advances in all facets of egg processing, including production, management, and sales. Thus, egg qualities are improved in developed countries with the introduction of basic algorithms.

Branding of Egg quality among consumers in Digital Economies

Guyonnet (2019b) asserts that the global sector will further improve its economic sustainability while offering consumers safe and nutritious foods by concentrating on marketing campaigns that highlight the value and advantages of branded shell eggs, either by national organizations of producers or by egg companies. The great

majority of shell eggs are sold in bulk, either by weight or by unit, in major egg-producing nations like China, India, and Indonesia (Guyonnet, 2020b). The need to convert consumers from these "generic" eggs to branded eggs will be one of marketing's main responsibilities because the sale of branded goods usually results in higher revenues for egg farmers and packers. There will be numerous potentials to increase the worldwide market share of beautifully packaged, branded shell eggs because younger generations of consumers no longer prioritize pricing when making purchases.

Conclusion and Recommendations

This study therefore concludes that egg consumption level had increase over the years globally and consumers are now concerned about the egg quality and well as the physical attributes which when properly managed during production could improve the freshness of the eggs. Holistic approaches ranging from nose electronic method to current use of algorithms using artificial intelligence promotes the freshness, egg shell strength, and other physical attributes of eggs in terms of quality in developed countries. The study recommends the needs for developing countries to adopt the modern digital methods using in developed countries for egg quality improvement. There is also need to train egg producers and consumers on the significance of egg quality measure to ensure sustainability from both ends.

References

Ali, F., Razzaq, A., Tariq, W., Hameed, A., Rehman, A., Razzaq, K., Sarfraz, S., Rajput, N.A., Zaki, H.E., & Shahid, M.S. (2024). Spectral Intelligence: AI-Driven Hyperspectral Imaging for Agricultural and Ecosystem Applications. Agronomy, 14, 2260.

Ameh, B. (2024). Digital tools and AI: Using technology to monitor carbon emissions and waste at each stage of the supply chain, enabling real-time adjustments for sustainability improvements. Int. J. Sci. Res. Arch. 13, 2741–2754.

Chi, Y., Ma, Z., Wang, R., & Chi, Y. (2024). A comprehensive review on freeze-induced deterioration of frozen egg yolks: Freezing behaviors, gelation mechanisms, and control techniques. Compr. Rev. Food Sci. Food Saf., 23, e70019.

Drabik, K., Batkowska, J., Próchniak, T., & Horecka, B (2021). Citric Acid as a Factor Limiting Changes in the Quality of Table Eggs during Their Storage. Poulty Science, 100, 100995.

Drabik, K., Próchniak, T., Kasperek, K., & Batkowska, J. (2021) The Use of the Dynamics of Changes in Table Eggs during Storage to Predict the Age of Eggs Based on Selected Quality Traits. Animals 11, 3192. https://doi.org/10.3390/ani11113192

Drabik, K., Chabroszewska, P., Vasiukov, K., Adamczuk, A., & Batkowska, J. (2018). Glycerin as a Factor for Moderating Quality Changes in Table Eggs during Storage. Arch. Anim. Breed. 61, 285–292.

Drayer, G.E., & Howard, A.M. (2012). A Granular Multi-Sensor Data Fusion Method for Life Support Systems that Enhances Situation Awareness. In Proceedings of the 2012 Global Space Exploration Conference, Washington DC, USA.

Georgiou, T., Liu, Y., Chen, W., & Lew, M. (2020). A survey of traditional and deep learning-based feature descriptors for high dimensional data in computer vision. Int. J. Multimed. Inf. Retr. 9, 135–170.

Guyonnet, V. (2012). Eggs and egg products: Consumers' attitudes, perceptions and behaviours [conference invited lec ture]. World's Poultry Science Congress. http://www.facta.org. br/wpc2012-cd/pdfs/plenary/Vincent_Guyonnet.pdf

Guyonnet, V. (2019b). Modern egg marketing geared toward younger generations. Poultry International, 58(3), 14–15

Guyonnet, V. (2020a). Egg associations key for sector's sustain able growth. Poultry International, 59(1), 30–31.

Guyonnet, V. (2020b). Indian egg production, consumption to keep rising. Poultry International, 59(3), 14–15.

Guyonnet, V.(2019a). Egg sector must play greater role in consumer education. Poultry International, 58(12), 20–21.

Helene, O. K., Kuradusenge, M., Sibomana, L., & Mwaisekwa, I. I. (2025). TinyML and IoT-enabled system for automated chicken egg quality analysis and monitoring. Smart Agricultural Technology, 12(1), 1-12.

Huang, Y., Xiong, J., Li, Z., Hu, D., Sun, Y., Jin, H., Zhang, H., & Fang, H. (2024). Recent Advances in Light Penetration Depth for Postharvest Quality Evaluation of Fruits and Vegetables. Foods. 13, 2688.

IEC (2021, November 9). International egg commission interac tive statistics, Country data. https://marketdata.internatio nalegg.com/graphs/

Jia, F., Yan, W., Yuan, X., Dai, R. & Li, X. (2019). Modified Atmosphere Packaging of Eggs: Effects on the Functional Properties of Albumen. Food Package Shelf Life, 22, 100377.

Jones, D.R., & Musgrove, M.T. (2005). Effects of Extended Storage on Egg Quality Factors. Poultry Science, 84, 1774–1777.

Kapse, S., Kausley, S., & Rai, B. (2022). Portable food diagnostic devices and methods: A review. J. Food Process Eng., 45, e14159.

Karvir, H (2010). Design and Validation of a Sensor Integration and Feature Fusion Test-Bed for Image-Based Pattern Recognition Applications. Ph.D. Dissertation, Wright State University, Dayton.

Konkol, D., Popiela, E., Skrzypczak, D., Izydorczyk, G., Mikula, K., Moustakas, K., Opali´nski, S., Korczy´nski, M., & Witek-Krowiak, A. (2022). Chojnacka, K. Recent innovations in various methods of harmful gases conversion and its mechanism in poultry farms. Environ. Res. 214, 113825.

Lu, Y., & Lu, R. (2017) Non-destructive defect detection of apples by spectroscopic and imaging technologies: A review. Trans. ASABE 60, 1765–1790.

Patnaik, U. The Many Republics of Hunger. Agrar. South J. Political Econ. 2024, 13, 489–505.

Prabowo, M.C.A., Sayekti, I., Astuti, S., & Supriyati, S.T.N. (2024). Development of an IoT-Based Egg Incubator with PID Control System and Mobile Application. International Journal on Informatics Visualization, 8(1), 465-472.

Rho, T., & Cho, B. (2024). Non-Destructive Evaluation of Physicochemical Properties for Egg Freshness: A Review. Agriculture, 14, 2049.

Vlˇcková, J., T˚umová, E., Míková, K., Englmaierová, M., Okrouhlá, M., & Chodová, D. (2019.hanges in the Quality of Eggs during Storage Depending on the Housing System and the Age of Hens. Poult. Science, 98, 6187–6193.

Wiley, V., & Lucas, T. (2018). Computer vision and image processing: A paper review. Int. J. Artif. Intell. Res. 2, 29–36.

Yang, J.R., Liu, J.H., Wang, Y.M., et al. (2023). Research progress on the effects of different treatments on the microstructure and properties of egg yolk and its components, Food Science. 44(15), 368–378. https://doi.org/10.7506/spkx1002-6630-20220613-122.

Yang, W., Yang, Y., Wang, L., Lv, X., Li, J., Cui, H., Tang, C., Zhao, Q., Jia, Y, & Qin, Y. (2023). Comparative characterization of flavor precursors and volatiles of Taihe black-boned silky fowl and Hy-line Brown yolks using multiomics and GC-O-MS-based volatilomics. Food Res. Int. 172, 113168.

Zhai, Z., Liu, Y., Li, C.,Wang, D., & Wu, H. (2024). Electronic Noses: From Gas-Sensitive Components and Practical Applications to Data Processing. Sensors 2024, 24, 4806.