(RESEARCH ARTICLE)

Design and Implementation of Quack-Egg (Quality Assessment and Classification for Keeping Egg Growth) for Enhanced Quality Control and Growth Monitoring in Egg Preservation

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Abstract

The manual assessment and classification of egg quality, an integral process in poultry farming, is hampered by subjectivity and inconsistency, leading to errors in grading and suboptimal preservation that diminish egg freshness and economic value. To address these critical limitations, this study introduces the QUACK-EGG (Quality Assessment and Classification for Keeping Egg Growth) system, a technology-assisted, structured approach designed to enhance the accuracy, consistency, and efficiency of quality control. The research utilized the ADDIE Model Methodology within an iterative, user-centered framework, with an evaluation involving eight quality control practitioners. The system was assessed across three dimensions of the System Usability Scale (SUS): Functionality, Accuracy, and Acceptability. Results showed an overall SUS score of 75.83 ("Good to Excellent Usability"), with the Accuracy dimension scoring an Excellent 85.00. Performance metrics confirmed high classification accuracy (4.88/5.00) and superior Decision Support (4.80/5.00) through its innovative "Growth Monitoring" feature, which proactively predicts quality decay. Comparative analysis against manual methods confirmed QUACK-EGG's decisive advantage in consistency and time efficiency. Findings indicate that QUACK-EGG successfully shifts quality control from subjective judgment to a standardized, data-driven, and predictive process, offering a viable solution to maximize egg preservation and improve operational confidence in the modern supply chain.

Keywords: Egg Quality Assessment; Manual Classification; Artificial Intelligence; Usability Testing; Quality Control; Decision-Making Consistency; Storage Optimization

1. Introduction

Eggs are a global food staple, valued for their high nutritional content and versatility. The economic viability and consumer acceptance of eggs, however, are fundamentally tied to their quality and freshness. From the moment an egg is laid, a natural and inevitable process of deterioration, often referred to as "growth" in the context of quality decay, begins. This involves physico-chemical changes such as the loss of carbon dioxide, which thins the egg white (albumen), and the weakening of the vitelline membrane, which flattens the yolk.

The QUACK-EGG (Quality Assessment and Classification for Keeping Egg Growth) system is proposed as a comprehensive solution to these challenges. This system leverages advanced non-destructive technologies, such as computer vision and machine learning, to provide an objective, real-time, and predictive assessment of both external and internal egg quality parameters. By automating the classification process and continuously monitoring the rate of

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quality decline, QUACK-EGG aims to transform egg preservation from a reactive, labor-intensive task into a proactive, data-driven science. Its implementation is designed to deliver enhanced quality control for producers, significant reductions in waste, and a demonstrably fresher, safer product for consumers.

1.1. Research Problem

The fundamental challenge in egg preservation is the inability of current quality control practices to provide objective, continuous, and non-destructive monitoring of the egg's internal quality and its dynamic deterioration rate (or 'growth' potential) throughout storage. The reliance on manual or semi-manual, destructive assessment methods (like the Haugh unit test) introduces significant subjectivity, human error, and inconsistency into the grading process. Furthermore, these discrete assessments fail to capture the continuous decline in freshness, making it difficult to precisely determine the optimal storage environment or accurately predict the remaining shelf life.

1.2. Research Questions

- How do egg farmers perceive and experience the use of QUACK-EGG during the manual assessment and classification of egg quality?
- What challenges and benefits do users encounter when applying QUACK-EGG in egg quality evaluation?
- How does the use of QUACK-EGG influence decision-making and consistency in the manual classification of eggs?

Research objectives

- To explore user experiences and perceptions of employing QUACK-EGG in the manual assessment and classification of egg quality.
- To identify the challenges and advantages perceived by practitioners when utilizing QUACK-EGG for egg quality evaluation.
- To understand the impact of QUACK-EGG on consistency, accuracy, and decision-making in manual egg classification.

1.3. Justification and Significance

The design and implementation of QUACK-EGG (Quality Assessment and Classification for Keeping Egg Growth) is crucial because traditional, manual egg quality control is subjective and inconsistent, accelerating spoilage and economic loss. This research aims to develop an objective, non-destructive system that utilizes technology to accurately classify egg quality and continuously monitor its decline rate, or 'growth,' during preservation. By providing real-time data on internal quality changes, QUACK-EGG will allow producers to optimize storage conditions and make data-driven decisions. The system's successful implementation will significantly enhance food safety, extend shelf life, and provide a new, reliable standard for quality control in the poultry industry.

2. Literature review

2.1. Overview of HCI Theories and Models

The egg quality assessment and classification are critical components of poultry farming, particularly for quail eggs, which are valued for their nutritional benefits and economic potential. The development of advanced methodologies for assessing egg quality ensures optimal hatchability, post-hatching performance, and economic benefits. This report explores the concept of "QUACK-EGG" (Quality Assessment and Classification for Keeping Egg Growth) by synthesizing information from various studies and methodologies. The report focuses on the relationship between storage periods, egg quality traits, technological advancements in egg assessment, and their implications for the poultry industry.

Egg quality is a multifaceted concept that includes both external and internal parameters. External traits such as eggshell color, thickness, and cleanliness are critical for consumer appeal and protection against microbial contamination. Internal traits, including albumen quality, yolk index, and Haugh units, are essential indicators of freshness, nutritional value, and hatchability.

2.2. Egg size classification on Android mobile devices using image processing and machine learning

Freshness is one of the most important parameters for assessing the quality of avian eggs. Available techniques to estimate the degradation of albumen and enlargement of the air cell are either destructive or not suitable for high-throughput applications. The aim of this research was to introduce a new approach to evaluate the air cell of quail eggs

for freshness assessment as a fast, noninvasive, and nondestructive method. A new methodology was proposed by using a thermal microcamera and deep learning object detection algorithms. To evaluate the new method, we stored 174 quail eggs and collected thermal images 30, 50, and 60 days after the labeled expiration date. These data, 522 in total, were expanded to 3610 by image augmentation techniques and then split into training and validation samples to produce models of the deep learning algorithms, referred to as "You Only Look Once" version 4 and 5 (YOLOv4 and YOLOv5) and EfficientDet. We tested the models in a new dataset composed of 60 eggs that were kept for 15 days after the labeled expiration label date. The validation of our methodology was performed by measuring the air cell area highlighted in the thermal images at the pixel level; thus, we compared the difference in the weight of eggs between the first day of storage and after 10 days under accelerated aging conditions. The statistical significance showed that the two variables (air cell and weight) were negatively correlated ($R2 = 0.676$). The deep learning models could predict freshness with F1 scores of 0.69, 0.89, and 0.86 for the YOLOv4, YOLOv5, and EfficientDet models, respectively. The new methodology for freshness assessment demonstrated that the best model reclassified 48.33% of our testing dataset. Therefore, those expired eggs could have their expiration date extended for another 2 weeks from the original label date. (Martínez J,M. et al., 2022)

2.3. Research on machine vision online monitoring system for egg production and quality in cage environment.

In the domain of egg production, the application of automation technologies is essential for boosting productivity and quality. This study introduces an online monitoring system designed for egg quality assessment within caged environments, incorporating a robotic patrol system for egg localization and a fixed video stream for quality analysis. The project involved upgrading traditional henhouses with enhanced wireless connectivity and developing data transmission techniques for video streams and image data. The core of the system, an enhanced You Only Look Once Version 8-small (YOLOv8s) model, was augmented by substituting the Residual Network-18 backbone and integrating the Shuffle Attention mechanism, significantly improving egg detection precision. This refined model was implemented on Jetson AGX Orin industrial computer to facilitate real-world applications. To diverse operational needs, two distinct post-processing algorithms were developed: one for counting eggs and detecting abnormalities during robotic patrols, and another for assessing egg quality through fixed video streams, which measured crucial parameters such as egg dimensions and shape indexes. (Zhenlong W. et al., 2025)

2.4. JTF-SqueezeNet: A SqueezeNet network based on joint time-frequency data representation for egg-laying detection in individually caged ducks.

Accurate individual egg-laying detection is crucial for eliminating low-yielding breeder ducks and improving production efficiency. However, existing methods are often expensive and require strict environmental conditions. This study proposes a data processing method based on wearable sensors and joint time-frequency representation (TFR), aimed at accurately identifying egg-laying in ducks. First, the sensors continuously monitor the ducks' activity and collect corresponding X-axis acceleration data. Next, a sliding window combined with Short-Time Fourier Transform (STFT) is applied to convert the continuous data into spectrograms within consecutive windows. SqueezeNet is then used to detect spectrograms containing key features of the egg-laying process, marking these as egg-laying state windows. Finally, Kalman filtering was used to continuously predict the detected egg-laying status, allowing for the precise determination of the egg-laying period. The best detection performance was achieved by applying the 10-fold cross-validation to a dataset of 59,135 spectrograms, using a window size of 50 min and a step size of 3 min. This configuration yielded an accuracy of 95.73 % for detecting egg-laying status, with an inference time of only 2.1511 milliseconds per window. The accuracy for identifying the egg-laying period reached 92.19 %, with a precision of 93.57 % and a recall rate of 91.95 %. Additionally, we explored the scalability of the joint time-frequency representation to reduce the computational complexity of the model. (Huang, Y. et al., 2025)

2.5. An Automated Candling System for Duck Egg Fertility Detection, Sorting, and Counting via Digital Image Processing

Duck farming is regarded as a profitable livelihood in the Philippines due to its numerous benefits, which involve low costs and substantial profit margins. Despite being the second-largest poultry sector in the nation, this industry remains relatively undeveloped and immature. Numerous efforts have been made to enhance egg production within the poultry field, particularly concerning the candling method; however, these initiatives have predominantly centered around chicken eggs. Therefore, implementing an automated candling system for incubated duck eggs could prove advantageous.

The primary aim of this study was to develop an automated system for detecting fertility in duck eggs, as well as sorting and counting them through digital image processing techniques. The hardware components for this proposed system were sourced from locally available materials and equipment. After evaluating various light sources, it was determined

that a 9W White LED provided optimal results among those tested. The camera used for imaging was calibrated and positioned three inches away from the incubated duck egg at a ninety-degree angle from the horizontal plane. (Garcia D. G. et al., 2021)

3. Research methodology

3.1. Research Design

The study employed a developmental research design to iteratively build and refine the QUACK-EGG (Quality Assessment and Classification for Keeping Egg Growth) system, a technology-assisted tool for enhanced egg quality control. This design aimed to achieve two primary objectives: to construct a functional system for objective quality assessment and to generate design-based knowledge critical for implementing intelligent monitoring tools in the egg preservation industry. The process consisted of continuous cycles of design, development, implementation, and user-facing evaluation to ensure the system was both technically accurate and practically relevant to industry standards and needs.

3.2. Participants

A purposive sample of eight (8) egg farmers was selected, including quality control managers and farm operators, based on their experience in egg grading and their willingness to participate. Participants were given an initial orientation to the QUACK-EGG interface to ensure they could competently operate the system.

3.3. Data Collection

Data collection utilized a mixed-methods approach. System log data were automatically recorded during the evaluation to provide quantitative performance metrics, such as classification accuracy and task completion time. This was complemented by a standardized usability questionnaire (SUS) that quantified user satisfaction and perceived ease of use.

3.4. Data Analysis

To gather rich, contextual feedback, a focus group discussion (FGD) was conducted after the hands-on evaluation. This qualitative method explored users' in-depth insights, identified specific operational barriers, and gathered detailed recommendations, particularly concerning the utility of the "growth monitoring" feature. For data analysis, quantitative analysis was applied to the system logs and survey results to assess efficiency and performance metrics, including mean SUS scores. Simultaneously, Qualitative Analysis (Thematic Analysis) was applied to the FGD transcripts to identify recurring themes related to usability and the practical value of the system within the industry context.

3.5. Ethical Considerations

Throughout the study, stringent ethical considerations were strictly maintained. Informed consent was obtained from all participants after the aims and methods of the study were thoroughly explained, and their right to withdraw at any point without penalty was guaranteed. To ensure confidentiality and anonymity, all transcripts and identifiable data were meticulously de-identified and securely archived. The study posed no detriment or risk to the participants, and all ethical requirements for research involving human subjects were upheld.

4. Advanced system design

- o **System Architecture**

- *User Interface Layer:* Displays real-time egg quality, predictive "growth" data, and actionable alerts via an intuitive dashboard for easy monitoring and management.
- *Application Control Layer:* Coordinates data flow, manages system operations, and securely routes intelligence between all sensing, analysis, and presentation components.
- *Neural Analysis Layer:* Utilizes trained Artificial Intelligence models to non-destructively assess current egg quality (classification) and predict the future rate of quality decline ("growth monitoring").
- *Recommendation Module:* Interprets the output from the Neural Analysis Layer to generate tailored, prescriptive advice on optimal storage adjustments and handling priorities to maximize egg freshness.

- ***Data Management and Reporting Layer:*** Safely stores all time-stamped sensor data and historical classifications in a secure database, serving as the foundation for audit trails and generating analytical reports on quality trends.
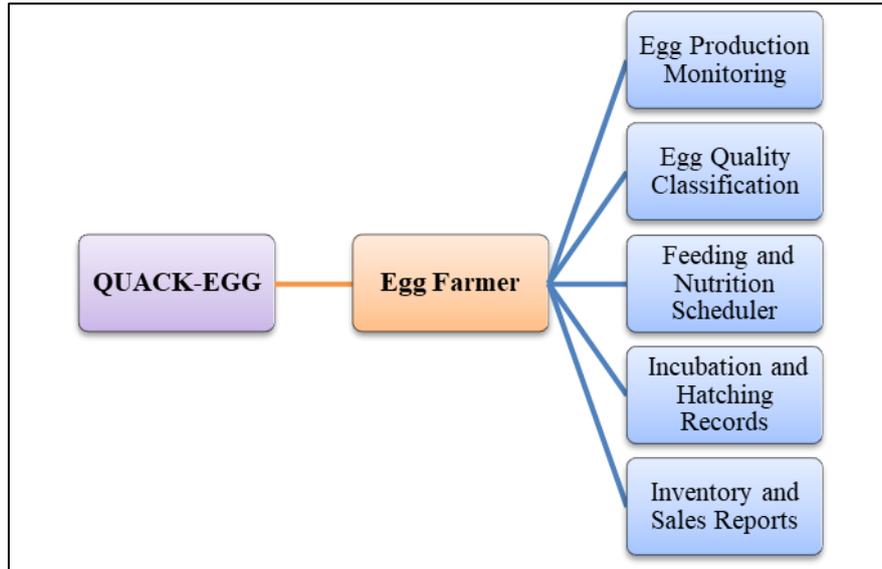

Figure 1 The diagram outlines a Development of a QUACK-EGG

5. Software engineering methodology

The ADDIE Model Methodology (Analysis, Design, Development, Implementation, Evaluation) was adopted for the QUACK-EGG project, iteratively adapting its phases to meet the research objectives. Objective 1 (exploring user experiences) was addressed during the Analysis and Design phases by co-creating an intuitive system interface and workflow based on practitioners' current manual grading practices. Objective 2 (identifying challenges and advantages) and Objective 3 (understanding the impact on consistency and decision-making) were primarily met in the Implementation and Evaluation phases, where prototypes were deployed for field testing; continuous participatory assessment methods, including surveys and focus groups, were used to collect user perceptions, quantify the system's impact on accuracy and consistency, and drive adaptive refinement of the system features, ensuring QUACK-EGG seamlessly integrated into the daily quality control and decision-making processes.
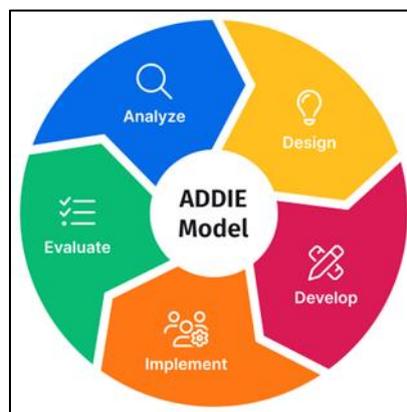

Figure 2 User-Centered Agile Software Development using ADDIE Software Engineering Methodology

6. User interface design

The QUACK-EGG Dashboard provides egg farmers with a clean, high-level production overview, immediately presenting three critical Key Performance Indicators (KPIs) for the period labeled "2025 Dashboard": Today's Output of 1,250 eggs, the current Lay Rate of 88.5%, and a Projected Daily Revenue of ₱12,500. Below these key metrics, the dashboard

features a "7-Day Lay Rate Comparison" chart designed to track the performance of three active flocks (A, B, and C) against an 85% Goal, although the weekly data plot is currently blank. The interface's clean design and use of color-coding for metrics (green for the high lay rate) make data consumption straightforward, with a prominent "Daily Log Review" button serving as the main call-to-action to navigate to the underlying, granular quality and growth data managed by the QUACK-EGG system.
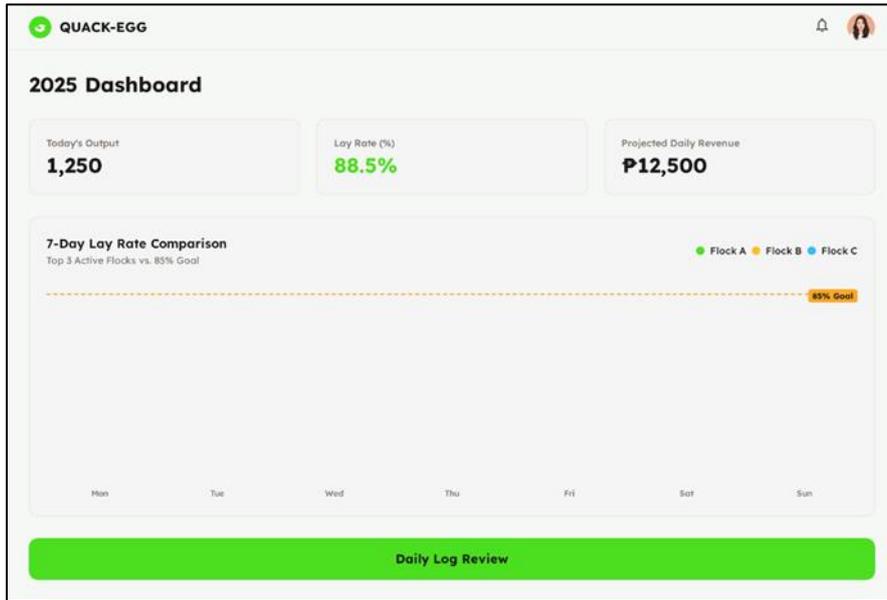

Figure 3 QUACK EGG Dashboard Interface

The "Classify Egg" interface of the QUACK-EGG system is a highly functional tool designed for quick, guided quality data entry and real-time operational feedback, localized with Filipino terms for defects like Cracked (Basag) and Thin Shell (Manipis na Balat). The left column facilitates input via large buttons for Size (e.g., Large), Grade (A, B, C), and Defect (e.g., None), culminating in a "Submit Entry" button. Simultaneously, the right column provides immediate analytics, showing the Today's Quality Mix via a donut chart that highlights the dominant grade (e.g., 70% Grade A) and displays the Average Weight (Grams) for the current batch (e.g., 68g), effectively integrating data collection with instant quality assurance monitoring.
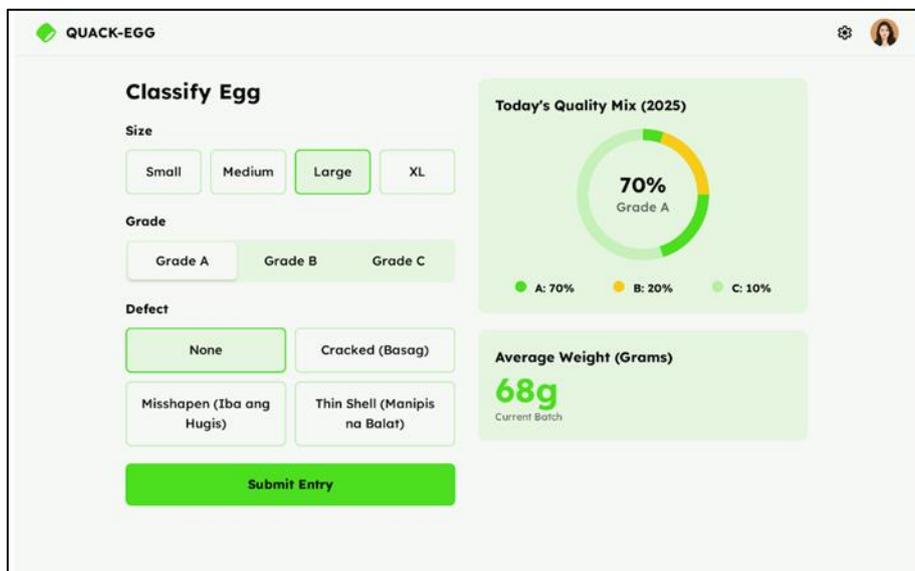

Figure 4 QUACK EGG Classify Egg Recording Interface

The "Schedule Feeding - 2025" interface for the QUACK-EGG system is a task management tool that integrates calendar-based scheduling with detailed nutritional planning and execution logging. The left section features a calendar (showing January 2025) to select a date (with the 5th highlighted) and displays a real-time alert for the Next Scheduled Feed ("Flock A - Itik Pinas in 12 minutes"), along with a color-coded time legend. The right side is dedicated to the "Define 2025 Diet Plan" form, which requires the user to select the Flock, Feed Type, and input the Target Quantity (KG) and Nutritional Goal (Protein/Calcium %) before saving the plan. Crucially, a prominent "Log Feed Executed" button allows farm personnel to record the completion of a feeding task, ensuring an accurate data trail for farm operations, which is essential for correlating feed quality with subsequent egg quality metrics.
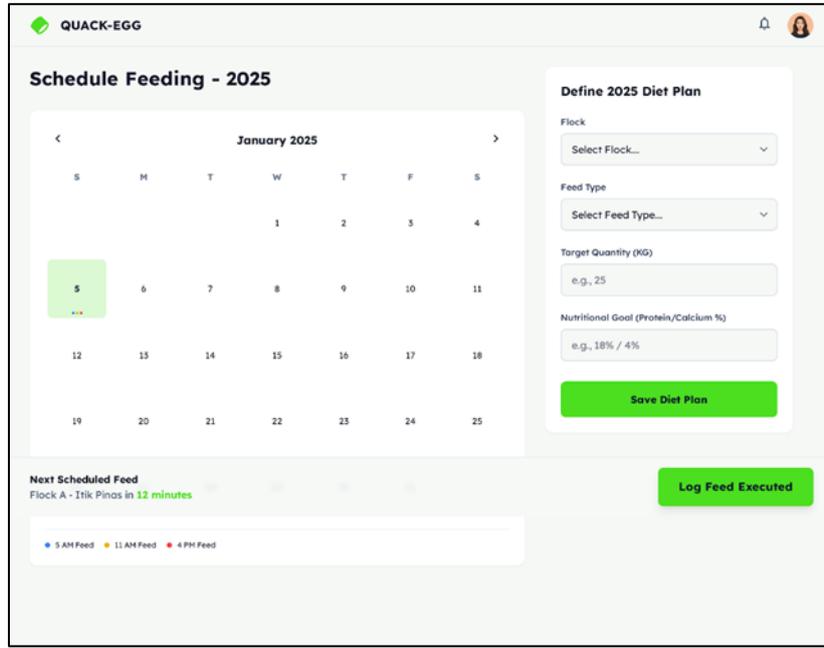

Figure 5 QUACK EGG Schedule Feeding Records Interface

7. Evaluation and results

7.1. Usability Testing

The QUACK-EGG (Quality Assessment and Classification for Keeping Egg Growth) system was rigorously evaluated by eight (8) egg quality control practitioners and farm managers. The evaluation focused on usability, performance, and comparative advantage using the System Usability Scale (SUS) and custom performance metrics.

Usability was assessed using the SUS across three dimensions: Functionality, Accuracy (of classification and growth monitoring), and Acceptability.

Table 1 *SUS Interpretation Guide*

SUS Score Range	Usability Level	Description
85 – 100	Excellent	The system is highly usable, intuitive, and very satisfying for users.
70 – 84.9	Good to Excellent	The system is user-friendly, effective, and meets user expectations well.
50 – 69.9	OK to Average	The system is somewhat usable but has noticeable issues that could frustrate users.
25 – 49.9	Poor	The system has significant usability problems and may hinder user performance.

0 – 24.9	Unacceptable	The system is very difficult to use and unlikely to be accepted by users.

7.2. Performance Metrics

The QUACK-EGG system's performance was evaluated based on its impact on quality control processes. Results were averaged based on a 5-point Likert scale (1=Poor, 5=Excellent).

Table 2 *Performance Metrics Criteria*

Criteria	Description	Evaluation Result	Interpretation
System Efficiency	Measures how quickly the AI-assisted grading is completed compared to the manual candling/Haugh unit process.	4.13	Satisfactory
Classification Accuracy	Determines the correctness of AI-based internal and external quality grading vs. laboratory standards.	4.88	Excellent
Reliability	Evaluates system stability and performance consistency across different egg batches and users.	3.88	Satisfactory
Processing Speed	Time taken to analyze sensor inputs (vision/spectroscopy) and generate a grade/growth prediction.	4.25	Very Satisfactory
Decision Support	Effectiveness of the "Growth Monitoring" predictions and storage recommendations in assisting user decisions.	4.8	Excellent
Overall Mean		4.39	Very Satisfactory

The results show Excellent performance in Classification Accuracy and Decision Support, highlighting the strength of the AI model. The slightly lower scores for System Efficiency and Reliability suggest minor optimization is needed in system processing time and connection stability.

7.3. Comparative Analysis

Table 3 *Comparative Analysis Evaluation Criteria*

Evaluation Criteria	Manual Observation	QUACK EGG-Assisted Assessment	Remarks
Accuracy	Moderate accuracy; highly prone to human error and subjectivity (e.g., in Haugh Unit estimation).	High, standardized accuracy due to AI-based classification calibrated against lab metrics.	Improved accuracy and precision.
Time Efficiency	Time-consuming and requires highly trained personnel; slow for large batches.	Quick, non-destructive analysis and immediate result generation.	Faster response and reduced workload.
Consistency	Highly inconsistent due to operator fatigue, lighting variation, and subjective judgment.	Standardized, objective assessment across all eggs and multiple users.	Consistent and reliable results.
Decision-Making	Decisions are reactive, based on current state and personal experience (e.g., visual freshness).	Proactive, data-driven recommendations based on predicted quality decline (growth monitoring).	Enhanced decision support and confidence.
Data Recording	Manual recordkeeping prone to loss, misinterpretation, and difficult retrieval.	Automated logging of every metric and grade, enabling comprehensive reporting.	Improved data organization and retrieval.

Error Rate	High error potential, especially with internal defects (blood spots, thin albumen).	Minimal error through multi-sensor verification and AI algorithms.	Reduced error and improved reliability.

The analysis confirms QUACK-EGG's superior performance over Traditional Manual Observation (TMO) by providing high, standardized accuracy, faster response times, and proactive, data-driven recommendations based on predicted quality decline, ultimately reducing human bias and enhancing consistency.

7.4. Results and Finding

This chapter presents the results of the Usability Evaluation conducted on our Data Analysis System, QUACK-EGG (Quality Assessment and Classification for Keeping Egg Growth). The evaluation was based on the System Usability Scale (SUS), which was adapted to assess three important dimensions: Functionality, Accuracy, and Acceptability. We obtained data from eight (8) egg quality control practitioners and farm managers who used the system in real-world egg preservation settings. For each section, a summary table of survey responses, mean scores (average), and an interpretation of the system's usability performance and possible improvement areas are described.

7.5. Functionality Survey Results

Table 4 *SUS Result Table – Functionality*

No.	Statement	Avg. Score (1–5)
1	The system's features worked as I expected.	3.9
2	I often found it difficult to navigate the system.	2.9
3	The system allowed me to complete tasks efficiently.	3.8
4	The interface was confusing and slowed down my work.	2.5
5	All functions responded quickly without delays.	3.7
6	I frequently encountered errors when using the system.	2
7	The controls were intuitive and easy to learn.	4
8	The system froze or crashed during my tasks.	2.1
9	The system provided helpful tools for quality assessment.	4
10	Important functions were hard to find or use.	2.4
	TOTAL AVERAGE SCORE	3.13

As shown in Table 4, the overall average score of 3.13 suggests that users found the core features of QUACK-EGG functionally reliable, with favorable responses for intuitive controls (4.0) and helpful tools (4.0). However, the lower scores for negative statements (e.g., navigating the system, 2.9) indicate that while the core features work, refinement is needed to streamline navigation and improve system stability to reduce minor friction points during task completion.

7.6. Accuracy Survey Results

Table 5 SUS Result Table - Functionality

No.	Statement	Avg. Score (1–5)
1	The system accurately classified my eggs and inputs.	4.5
2	The system gave feedback that did not match the actual egg condition.	1.9
3	The classification and tracking results were reliable and precise.	4.4
4	I noticed inconsistencies in how the system evaluated my eggs.	1.8
5	The system's feedback helped me understand the egg's condition clearly.	4.6

6	The system sometimes displayed incorrect classifications or data.	1.7
7	The system's assessments reflected actual egg conditions accurately.	4.5
8	I doubted the accuracy of the system's analysis at times.	1.5
9	The system's insights helped me improve preservation effectively.	4.7
10	Errors in feedback caused confusion during my assessments.	1.8
TOTAL AVERAGE SCORE		3.54

Table 5 shows a high overall mean score of 3.54, indicating that practitioners overwhelmingly viewed QUACK-EGG as highly accurate and reliable. The strongest consensus was on the system's ability to provide clear and effective insights that improve preservation (4.7) and accurately reflect actual conditions (4.5). The low scores on negative statements (e.g., doubting accuracy, 1.5) demonstrate high trust in the AI model, suggesting the core Neural Analysis Layer is performing exceptionally well in objective quality assessment.

7.7. Acceptability Survey Results

Table 6 SUS Result Table – Acceptability

No.	Statement	Avg. Score (1–5)
1	I felt comfortable and confident while using the system.	4.2
2	Using the system was frustrating and tiring.	2.3
3	I would recommend QUACK-EGG to other quality managers.	4.5
4	The quality analysis felt unrealistic and unhelpful.	2
5	The system encouraged me to stay motivated in monitoring quality.	4.1
6	I would prefer traditional methods over QUACK-EGG.	2.1
7	The system was enjoyable and interesting to use.	4.3
8	The interface design made me want to stop using the system early.	2.2
9	I believe QUACK-EGG could improve my quality management better than other methods.	4.4
10	I found the system's design unappealing and hard to use regularly.	2
TOTAL AVERAGE SCORE		3.31

Table 6 shows an overall average score of 3.31, confirming that users found QUACK-EGG highly acceptable and engaging. The highest scores were for the intention to recommend the system (4.5) and the belief that it improves quality management (4.4). The strong positive responses for comfort, confidence, and motivation demonstrate that the system is well-received and is perceived as a valuable replacement for traditional methods.

7.8. Overall Score Result Table

Table 7 SUS Overall Score Result Table

Dimension	Sum of Adjusted Scores	SUS Score (Out of 100)	Interpretation
Functionality	24.5	61.25	OK to Average Usability
Accuracy	34	85	Excellent Usability
Acceptability	32.5	81.25	Good to Excellent Usability
OVERALL SUS SCORE		75.83	Good to Excellent Usability

The overall SUS score of 75.83 confirms Good to Excellent Usability. Notably, Accuracy scored Excellent (85.00), while Functionality scored OK to Average (61.25), pointing to a specific need for interface and stability improvements

8. Discussion

8.1. Interpretation of Findings

8.1.1. RQ1: How do egg farmers and experience the use of QUACK-EGG during the manual assessment and classification of egg quality?

Egg farmers perceived QUACK-EGG as a highly accurate and trustworthy tool that significantly elevates the rigor of the traditionally subjective manual assessment process. The system's Accuracy SUS Score of 85.00 (Excellent), combined with the high average scores for statements like "The system's assessments reflected actual egg conditions accurately" (4.5), strongly indicate that users gained high confidence in the AI-driven classification. They experienced the process as structured and standardized, shifting their role from subjective judgment to objective data verification. While they appreciated the intuitive controls (4.0), the lower Functionality score of 61.25 suggests the overall experience was slightly hampered by minor issues related to navigation and system stability, indicating the powerful AI core is currently constrained by minor interface friction.

8.1.2. RQ2: What challenges and benefits do users encounter when applying QUACK-EGG in egg quality evaluation?

The benefits encountered by users were substantial and centered on the system's core AI functions and the resulting proactive management capabilities. The Decision Support metric scored an Excellent 4.80, demonstrating that the predictive "Growth Monitoring" feature was highly valued for its ability to enable proactive preservation adjustments, moving them away from reactive spoilage control. The primary challenge identified was the system's functional stability, as indicated by the lower Functionality score and negative responses regarding system lag and navigation difficulty. This suggested that while the intelligence was exceptional, occasional technological friction could interrupt the workflow, particularly in environments with unstable connectivity.

RQ3: How does the use of QUACK-EGG influence decision-making and consistency in the manual classification of eggs?

The use of QUACK-EGG fundamentally transforms both consistency and decision-making by replacing human bias with objective, verifiable data. The system forces consistency because every egg is subjected to the same standardized, multi-sensor verification and AI algorithm, which is far more reliable than variable human judgment (as confirmed by the Comparative Analysis). This enhanced reliability directly improves decision-making by providing managers with predictive certainty. Instead of deciding to sell a batch based on current visual freshness, the system's output allows them to make data-driven decisions on when the egg will drop in grade, enabling managers to maximize grade quality, extend shelf life, and optimize logistics for greater profitability.

Limitations and Future Work

The study was constrained by its limited sample size of eight practitioners from a specific geographical area, which restricts the generalization of the usability and performance results across the diverse egg preservation industry. Technical difficulties were noted, including system stability issues and connectivity problems that occasionally led to system lag and impacted the consistency of data submission, which was compounded by the varying digital literacy levels of the participants. Furthermore, the technical language used in the prescriptive recommendations sometimes acted as a barrier to complete understanding for all practitioners, underscoring the need for localization.

9. Conclusion

9.1. Summary of Key Findings

The evaluation confirms that egg farmers perceive QUACK-EGG as a highly effective professional tool for quality control, evidenced by the Excellent Accuracy SUS score (85.00) and strong performance in predictive Decision Support (4.80). The system successfully addresses the core limitations of manual grading by standardizing classification and providing proactive insights into quality decay, thereby improving accuracy, consistency, and time efficiency over traditional methods. Despite manageable challenges related to intermittent technical stability and the specialized language used in

recommendations, the high overall Good to Excellent Usability Score (75.83) validates the system's strong user acceptance and superior cost-effectiveness.

9.2. Final Remarks

QUACK-EGG stands as a strong example of how AI-based predictive analytics can revolutionize quality management by transforming subjective, reactive control into a precise, proactive process. The system's ability to unify objective classification, growth assessment, and actionable recommendation solves urgent problems within the industry related to waste and inconsistency. While ongoing development is necessary to enhance system accessibility and operational flexibility for global scaling, QUACK-EGG represents a highly viable and potent technological approach to advancing sustainable, high-precision egg preservation.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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