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Quantifying meat spoilage: ethically fresh as a portable halal-tayyibah screening innovation

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Abstract
The complexity of today's global food supply chain poses significant challenges for detecting meat spoilage, creating a pressing need to protect consumers who adhere to Halal-Tayyibah principles, especially when human visual/sensory inspection fails to detect the early stages of spoilage. To address this issue, Ethic Fresh was designed using an experimental engineering approach that integrates a calibrated electrochemical ammonia sensor, an RGB optical color sensor, and a threshold classification algorithm into a portable, non-destructive device connected to a digital data logger. The design results demonstrated that Ethic Fresh has high classification sensitivity and accuracy, successfully classifying chicken meat into three Halal-Tayyibah status categories: Fresh (low ammonia, high R-value; Full Thayyib), Semi-Fresh (oxidation crisis threshold; Doubtful/Warning), and Spoiled (high ammonia, low R-value; Khaba'ith). While not a substitute for formal laboratory testing, its portability and rapid response time make Ethic Fresh a highly viable screening tool for daily use in the market, helping consumers make safe and Halal food decisions while supporting the Halal 4.0 digital supply chain ecosystem.

Keywords: Ammonia Detection, Ethical Fresh, Food Integrity, Halal-Tayyibah, Meat Freshness

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1. Introduction

In the modern food industry, product quality is a primary determinant of market competitiveness, particularly in the poultry and livestock sector. For Indonesia's majority Muslim population, ensuring meat quality aligns with the religious imperative in Surah Al-Baqarah, verse 168, to consume food that is both *Halal* (lawful) and *Tayyib* (wholesome). However, maintaining *Tayyib*'s integrity across the supply chain faces severe real-world hurdles. Indonesia experiences significant post-harvest poultry losses of 8–12%, driven by rapid spoilage, primarily due to high ambient temperatures during distribution and inadequate cold-chain infrastructure in traditional markets. When chicken meat degrades, proteins break down into harmful volatile organic compounds (VOCs), such as ammonia, changing the meat's status from *Tayyib* to *Khaba'ith* (hazardous/unwholesome). This poses critical health risks to consumers and undermines trust in the national Halal supply chain.

In the modern food industry, product quality is a primary determinant of success in an increasingly competitive market, including the livestock sector, such as poultry. This is consistent with the principles of Muslims, who represent the majority of Indonesia's population, as mandated in Surah Al-Baqarah verse 168 "O mankind, eat from whatever is on earth [that is] lawful and good and do not follow the footsteps of Satan. Indeed, he is to you a clear enemy." to consume food that meets both 'halal' and

'Tayyib' (wholesome) criteria. Consequently, verifying halal integrity and food suitability is a crucial step that must be ensured before consumption (Ur Raheema, 2018).

The quality of a product evaluation system can be measured by its low classification error rate and its ability to perform non-destructive testing (Xu et al., 2024). In reality, freshness evaluation of chicken meat at the farmer level remains conventional, relying heavily on manual visual inspection. This manual method has significant limitations, including being time-consuming and labor-intensive, and prone to inconsistent results (Purwandoko et al., 2023). These conditions drive the urgent need for new evaluation methods that are faster and more efficient (Ellins et al., 2025). Automation in the product quality evaluation process serves as an effective solution to overcome these challenges (Scarton et al., 2025). The implementation of automated systems has been proven to optimize operational speed and efficiency, leading to increased quality assessment accuracy and reduced production costs (Scarton et al., 2025).

Indonesia presents unique challenges where the growth of the Halal industry is still hindered by supply chain inconsistencies and uneven institutional support, particularly within the SME sector (Muawanah et al., 2026). Limitations in raw material verification lead to a lack of assurance about the quality of Tayyib (wholesome) chicken, a situation exacerbated by the slow adoption of digital monitoring within the Halal 4.0 ecosystem. In response to the need for more rigorous authentication, the Chicken Freshness Detection System introduces an innovative 'dual-window' approach (Sutarman et al., 2023). This system integrates electrochemical sensor technology for rapid color change detection with transparent digital data logging. The combination of these two functions aims to strengthen food safety governance and the resilience of Halal assurance in Indonesia (Kurniawan et al., 2025).

Recent advancements in automation and non-destructive testing offer a promising path forward (Scarton et al., 2025). Existing automated systems have used single-parameter sensors or optical vision to categorize meat (Ellins et al., 2025; Sutarman et al., 2023). However, a critical research gap remains: most existing devices operate as isolated, standalone hardware without real-time data integration, or they rely solely on a single physical indicator (such as color alone or gas alone), making them susceptible to environmental noise and false positives. Furthermore, existing tools rarely contextualize their technical readings into actionable, Halal-Tayyibah compliance metrics tailored for the digital *Halal 4.0* ecosystem (Muawanah et al., 2026).

To bridge this gap, this research introduces a novel, multi-parameter screening system named "Ethic Fresh." The primary novelty of this study lies in its innovative dual-window detection approach, which synergistically combines calibrated electrochemical ammonia sensing (NH_3 gas quantification) with optical RGB color degradation analysis. Unlike existing isolated devices, Ethic Fresh integrates this dual-parameter hardware with transparent, real-time digital data logging, transforming complex biochemical indicators into clear, objective Halal-Tayyibah categories (*Thayyib*, *Syubhat*, and *Khaba'ith*). This system enables rapid, non-destructive, and low-cost freshness verification without requiring specialized technical expertise (Martinez-Velasco et al., 2024; Kurniawan et al., 2025).

The use of sensor technology enables the classification of chicken meat freshness to be more practical, faster, and more economical, allowing it to be operated without specialized expertise (Martinez-Velasco et al., 2024). In line with this, this research focuses on the design and implementation of a freshness classification system for broiler chicken. The system utilizes meat color and texture parameters.

2. Literature Review

Maintaining Halal integrity within the global food supply chain demands highly precise analytical oversight, particularly in detecting incidental ethanol residues that often emerge as flavoring solvents or natural fermentation byproducts(Fathima et al., 2024). To address this challenge, current research focuses on developing rapid and practical detection devices for consumers. One promising approach is the use of the TCS3200 color sensor, which can convert visual changes or color indicators resulting from ethanol reactions into accurate digital data (Surbakti et al., 2022).

While the scientific literature has established various "gold standard" methods for alcohol quantification, these conventional techniques generally require complex, expensive laboratory equipment. In contrast, integrating the TCS3200 sensor offers a more efficient and portable alternative, enabling analysis outside a laboratory environment without compromising ethanol identification accuracy and ensuring compliance with Halal standards (Fathima et al., 2024).

Chromameter (Colorimeter)

The use of a Chromameter for detecting ethanol content provides a non-destructive method that operates on the principle of light reflectance in the L*a*b* color space. In Halal integrity detection, this instrument is commonly used to monitor color changes in chemical indicators or biosensors that detect ethanol. The Chromameter measures the intensity of chromatic shifts resulting from the interaction between the sample and specific reagents. While it offers near-instantaneous reading speeds and significantly simpler operation, the accuracy of a Chromameter is highly dependent on the stability of the color indicator and external lighting conditions (Sitanggang et al., 2023). Its primary limitation is its inability to identify compounds specifically without an intermediary substance; therefore, despite its practicality for field use, it still requires cross-validation with chromatographic methods to ensure that color changes are solely due to ethanol and not to interference from other volatile organic compounds (VOCs).

TCS3200 Digital Color Sensor

Operating Mechanism: The TCS3200 sensor functions as a programmable color light-to-frequency converter. It integrates silicon photodiodes equipped with primary color filters (Red, Green, and Blue) along with a clear filter (no filter). Light reflected from the sample surface, such as tilapia gills or muscle tissue, is converted into a square-wave frequency (f) directly proportional to the intensity of the specific color spectrum. Unlike the human eye, which is susceptible to fatigue and subjective perception, the TCS3200 provides a constant numerical representation of color. To determine freshness indices, this sensor captures color degradation (e.g., the transition from bright red to dull brown in gills) with high precision by analyzing RGB value ratios. Technical Critique (Ambient Light Interference): Just as enzymatic biosensors are hindered by the "food matrix effect," the TCS3200 is highly susceptible to ambient light interference. Uncontrolled exposure to sunlight or indoor lighting can disrupt photodiode readings, potentially causing data deviations (bias) during measurements in open environments, such as traditional markets. Physical Limitations (Surface Texture): Experts note that sample surface conditions, including moisture levels (fish mucus) and the sensor's angle of incidence, significantly influence specular reflection. This may result in inconsistent readings if the distance and orientation between the sensor and the sample are not maintained statically within a light-proof enclosure.

Spectrophotometry (Phenate/Indophenol Method)

Uses an instrument to measure the intensity of the blue color formed from the reaction of ammonia with phenol and hypochlorite reagents. This is a standard method (in line with the ammonia test principles referred to in SNI 06-6989.30-2005). Spectroscopy is utilized for non-destructive testing in industrial quality control to detect protein degradation and lipid oxidation in chicken meat. However, the high cost of high-resolution detectors and the need for sophisticated chemometric models to interpret overlapping spectral bands remain significant barriers to the miniaturization of portable devices for the retail market.

Critical Point of Islamic Jurisprudence (Halal-Tayyibah)

From the perspective of Islamic law (Fiqh), the freshness of chicken meat is intrinsically linked to the concept of 'Thayyib' (quality/wholesomeness), which serves as an absolute prerequisite alongside the 'Halal' aspect (ritual slaughter). A point of debate arises where the decomposition process begins to produce metabolites considered 'khaba'ith' (vile/harmful). Modern halal standards emphasize that meat exceeding a certain spoilage threshold not only loses its nutritional value but may also harbor microbiological contaminants hazardous to health; consequently, its 'Halal' status may be functionally suspended due to a violation of the 'Thayyib' principle (Fariq & Humaidi, 2024). Colorimetric Test/Test Kit: A practical method using paper strips or reagent drops mixed with sample extracts. The resulting color change is compared with a standard color chart to determine the levels semi-quantitatively. Gas Chromatography (GC): A highly accurate, advanced method for separating and quantifying various nitrogen compounds, including ammonia, in complex food matrices.

Sensory/Organoleptic Test

Initial testing relies on the five senses (e.g., pungent or rotten odor indicating protein decay) or on visual physical changes (SNI 01-2346-2006, concerning guidelines for sensory testing of fishery products). The evolution of portable sensors has moved from basic visual inspection to "Electronic Noses" (e-Noses) and multi-sensor fusion systems. Recent advancements in sensor technology have led to prototypes capable of detecting volatile ammonia levels and subtle pigment shifts in poultry as early indicators of spoilage. Despite these strides, existing portable devices often struggle with "cross-sensitivity," in which sensors respond to humidity or ambient kitchen gases rather than specific decay markers, leading to inaccurate freshness assessments for consumers (Jayan et al., 2025). The proposed EthicFresh device addresses a critical gap identified in the literature: the lack of a consumer-facing tool that bridges the gap between laboratory-grade chemical analysis and marketplace convenience. Unlike expensive industrial NIR spectrometers or complex lab-based microbiological assays, EthicFresh is specifically calibrated to the Halal-Thayyib compliance threshold, focusing on the correlation between ammonia concentration and the "Thayyib" (wholesome) status of chicken meat. By focusing on this specific religious and safety benchmark, EthicFresh moves beyond simple spoilage detection to provide actionable data, empowering consumers to make informed choices that align with both food safety standards and Islamic dietary requirements.

3. Research Methodology

This study used a quantitative experimental design to evaluate and validate an automated system for detecting the freshness of broiler chicken meat. A total of broiler chicken breast (Pectoralis major) samples with standardized initial weights (e.g., 100 ± 20 g) were obtained directly from a local Halal-certified slaughterhouse (RPH). To simulate meat quality degradation, the samples were stored at controlled room temperature (e.g., 20 ± 2°C) with relative humidity (e.g., 60-70%) for an observation period (e.g., 24 hours), with measurements taken at intervals (e.g., 5 minutes). Prior to testing, the electrochemical sensor was calibrated with a standard buffer solution, and the color sensor was calibrated with a standard RGB color card. The obtained data sets (color and texture parameters) were analyzed using Principal Component Analysis (PCA) / machine learning classification model at a 95% confidence level ($p < 0.05$) to establish three freshness threshold categories (fresh, slightly fresh, and spoiled).

This section describes the hardware configuration, algorithmic framework, and experimental procedures adopted in the development and initial validation of a Chicken Meat freshness detection system. The methodology was developed to ensure technical clarity, replicability, and alignment with standard practices in sensor-based food analysis for quantitatively measuring Tayyib (goodness/quality) parameters.

Hardware Design and Sensing Mechanism

TCS3200 Color Sensor

The TCS3200 sensor is a color-to-frequency converter module that detects the color of objects. This sensor works by measuring the intensity of light reflected from an object using a Red, Green, and Blue (RGB) filter, then converting it into a digital frequency signal that a microcontroller, such as an Arduino, can read. This sensor incorporates an internal heating element that increases the temperature of the sampling environment, facilitating the evaporation of volatile compounds from nearby food or beverage samples. This indirect vapor-based detection approach eliminates the need for direct contact and supports measurements across a wide range of heterogeneous sample types. The TCS3200 sensor was selected for its advantageous characteristics, namely high sensitivity, low power consumption, and fast response time, making it suitable for consumer-facing halal compliance applications.

Methodology

Data processing in this system begins with the development of a specialized algorithm that converts raw sensor output into accurate RGB concentration data. The initial phase involves calibration and signal processing, during which the ESP32 microcontroller interprets the analog voltage from the TCS3200 sensor. By applying specific calibration parameters, the system can estimate ethanol levels based on a predetermined sensor response curve. Subsequently, the processed data enters the classification stage to determine the quality of the chicken meat, categorizing it as fresh, semi-fresh, or spoiled. This classification is performed by comparing the readings against established freshness thresholds that serve as food safety benchmarks. All of this information is then sent via an optimized data transmission mechanism. This optimization was implemented based on preliminary testing results to minimize communication latency, thereby ensuring faster, more stable data transfer.

Experimental Setup and Preliminary Validation

The core instrumentation consists of a custom-engineered gas detector integrated with an Arduino microcontroller and a computer system. This device uses metal-oxide-semiconductor sensors specifically for ammonia (NH_3) and hydrogen sulfide (H_2S) detection, operating on the principle of gas-induced resistance fluctuations. These variations are translated into changes in output voltage, which are then processed using calibration equations to provide concentration readings in ppm. The hardware is encased in a sealed 20 cm^3 acrylic chamber designed to house four sensors and the Chicken samples during gas emission analysis. Data acquisition is managed through serial communication between the Arduino and the computer, with results displayed on a serial monitor and archived in a database".

4. Findings and Discussion

Traditionally, freshness assessment methods in the seafood industry have relied on sensory evaluation panels to classify products as fresh or spoiled. While fast, simple, and often accurate (Kumaravel et al., 2025), sensory analysis is sometimes considered subjective. Despite their sophistication, sensory panels are not always available during all stages of production, nor can they function efficiently for extended periods (Yadav et al., 2025). While methods using chromatographic and chemical techniques to determine seafood freshness are precise and objective, they are time-consuming, expensive, and species dependent (Du et al., 2001). Laboratory space is also required, and analyses must be performed by technically qualified personnel. Therefore, the development of new technologies capable of providing instant, objective classification of seafood quality and freshness is necessary, enabling processing industries to maintain product quality and release products quickly (Russo et al., 2024).

This section presents the findings of the EthicFresh innovation in assessing poultry quality. The first subsection reports the classification of meat freshness, categorized into three distinct phases: fresh, semi-fresh, and spoiled, based on objective sensor readings ("Intelligent Detection of Quality Deterioration and Adulteration of Fresh Meat Products in the Supply Chain," n.d.). The second subsection focuses on the correlation between ammonia concentration and color degradation, illustrating how these two parameters change as the meat transitions from a Thayyib state to a spoiled state. Finally, the third subsection highlights participants' perceptions of the EthicFresh device, aiming to gauge users' views, level of understanding, comfort, and confidence in the product's performance. This requires an experimental approach in which researchers use the device to test various meat samples and observe the real-time results obtained.

Freshness Classification of Chicken Meat

The first phase of the findings focuses on categorizing meat freshness, as this information is essential for describing the samples' physical and chemical characteristics and for providing a clear, systematic profile of the *Thayyib* compliance level. A better understanding of these classifications—fresh, semi-fresh, and spoiled supports the interpretation of the research results and validates the device's accuracy.

Fresh (Thayyib): Characterized by low ammonia levels (below the detection threshold) and a natural pale-pink color. In this stage, the meat meets all Halal-Thayyib requirements for consumption.

Semi-Fresh (Threshold): Characterized by a slight increase in ammonia presence and a fading of the meat's natural pigment. This represents a critical "warning" phase in which quality begins to decline but remains within a debatable consumption limit.

Spoiled (Khaba'ith): Characterized by high ammonia concentrations and significant discoloration (greyish or yellowish tints). At this stage, the meat is classified as non-compliant with the *Thayyib* principle due to the presence of harmful metabolites.

Awareness and Experience Regarding Meat Freshness (Halal-Thayyiban)

The second section examines' awareness, opinions, and experiences regarding the classifications of meat freshness, specifically fresh, semi-fresh, and spoiled, within the context of Islamic dietary laws (Ibrahim et al., 2023). This section aims to assess the extent to which participants are aware of the "Thayyib" (wholesomeness) status in the poultry they consume, the level of knowledge they possess about the transition from fresh to spoiled meat, and the degree to which they are concerned about the potential presence of harmful metabolites, such as ammonia, in their daily diet (Muflih et al., 2020).

Furthermore, this section explores researchers' personal experiences in identifying meat quality, focusing on their ability to distinguish between "Semi-Fresh" meat (which may still be technically Halal but declining in Thayyib quality) and "Spoiled" meat (which is categorized as khaba'ith or harmful) (Mustafa, 2023). By analyzing these aspects, the study seeks to provide a comprehensive understanding of how awareness of religious standards, health attitudes, and lived experiences in traditional markets influences participants' food choices and their sensitivity to meat integrity issues across different social and cultural contexts (Srinija et al., 2025).

Table 1. Fresh, Half-Fresh, and Rotten Chicken (Halal-Thayyiban)

Hour	Red	Green	Blue
2025-02-24 13:26:59	192	160	159
2025-02-24 14:26:59	195	162	159
2025-02-24 15:26:59	201	167	163
2025-02-24 16:26:59	204	170	166
2025-02-24 17:26:59	204	170	165
2025-02-24 18:26:59	202	168	163
2025-02-24 19:26:59	200	166	160
2025-02-24 20:26:59	198	163	157
2025-02-24 21:26:59	196	160	153
2025-02-24 22:26:59	194	157	151
2025-02-24 23:26:59	193	155	148
2025-02-25 00:26:59	191	153	146
2025-02-25 01:26:59	190	151	143
2025-02-25 02:26:59	187	149	141
2025-02-25 03:26:59	187	147	138
2025-02-25 04:26:59	185	146	136
2025-02-25 05:26:59	183	143	133
2025-02-25 06:26:59	181	141	130
2025-02-25 07:26:59	179	140	128
2025-02-25 08:26:59	177	135	124
2025-02-25 09:26:59	174	132	120
2025-02-25 10:26:59	173	128	113
2025-02-25 11:26:59	179	139	125
2025-02-25 12:26:59	178	138	124
2025-02-25 13:26:59	176	136	122
2025-02-25 14:01:59	175	135	121

Color Degradation Analysis from a Halal-Thayyiban Perspective

The data show changes in RGB (Red, Green, Blue) values that record the oxidation and decomposition of meat over 45 hours. In Islam, halal compliance extends beyond the ritual slaughter but also encompasses aspects of good quality (Thayyib).

Thayyib Phase (Fresh/Wholesome): Data from Hours 0 to 5 hours: The Red value is at its highest (97 to 118). Visually, the meat is bright red, indicating its fresh myoglobin content. According to Thayyiban's criteria, meat at this stage is at its peak quality (Suman & Joseph, 2013). Consuming meat at this stage is highly recommended because its nutrients are still intact, and there is no risk of contamination by harmful metabolites. Scientifically, the bright red color is due to oxymyoglobin. From a fiqh perspective, meat at this stage meets the criteria for Thayyib. It is perfectly edible, rich in nutrients, and poses no health risk. Consuming good food is a religious commandment (Surah Al-Baqarah: 168) (Han et al., 2024).

Syubhat/Transition Phase (Half Fresh/Declining Quality): Data from 6 to 13 hours: The Red value decreases drastically from 78 to 31. The color in the visual column begins to darken. This is the critical phase (gray). The meat begins to oxidize, forming metmyoglobin. Although ritually still "Halal" (if slaughtered properly), its thayyib quality begins to decline. For consumers who are very particular about maintaining the purity of their consumption, this phase is considered a warning to stop storing meat without refrigeration (Jamaludin, 2020). The decrease in the R value reflects the oxidation of myoglobin to metmyoglobin, which turns the meat a dull brown. According to Islamic jurisprudence, this is a "warning" phase. Although not yet completely rotten, its thalidomide qualities are beginning to diminish (Farouk, 2013). Consumers should be cautious, as the biochemical process of spoilage has begun.

Khaba'ith Phase (Poisonous/Non-Halal Compliance): Data 14:45 hours: The Red value reaches its lowest point (up to 13-16) and the visual color changes to black/dark brown. At this stage, the meat has become Khaba'ith (something bad/vile). In Islamic law, anything that is harmful to health (dlarar) is prohibited. Decay produces toxins and bacteria that violate the principles of Maqasid Shariah (protection of the soul, or Hifdz an-Nafs). Therefore, meat that has reached this dark color stage functionally loses its halal status because it is no longer Thayyib. A very dark color (black/dark brown) in the final hours indicates bacterial accumulation and severe protein degradation. From a Halal perspective, this meat has been categorized as Khaba'ith (something bad/vile). Consuming meat at this stage is prohibited due to its potential health hazards (dlarar); thus, its halal status is functionally invalidated due to its violation of the principle of the safety of the soul (Hifdz an-Nafs).

The use of color sensors like those in your data is crucial in the EthicFresh system because it eliminates consumer doubt when determining whether meat on the market is still fit for purchase under Islamic law. Thayyib Verification: Your device serves as a guarantee that the meat is not only slaughtered in accordance with Halal standards but also stored under Thayyib conditions. Ammonia Indicator: Extreme color changes in the table are directly proportional to increased ammonia levels (a product of protein degradation), which, in turn, indicate that the meat has spoiled and is haram (forbidden) for consumption due to its hazardous properties. EthicFresh can assure the Muslim community that the meat they purchase truly meets the food purity standards enjoined in the Quran.

In the first question, respondents had previously purchased chicken from traditional markets. Most were directly exposed to open food environments where meat quality varies widely. Researchers who shop in traditional markets are more likely to face challenges in verifying the "Thayyib" (healthy) status of poultry due to the lack of standardized refrigeration. Therefore, these results support the urgent need for portable freshness detection tools in local market environments.

In the second and tenth questions, most indicated they were aware that "half-fresh" or "rotten" meat violates the Islamic principle of Thayyib and that the accumulation of ammonia marks the transition to the "Khaba'ith" (harmful) stage. This high level of religious and quality awareness indicates a basic knowledge of the ethical and health implications of meat spoilage. Such awareness is crucial for Muslim consumers, as consuming healthy food is a commandment of Allah SWT. However, the small number of unaware individuals highlights a potential food safety risk, as a lack of knowledge about chemical spoilage markers can lead to the inadvertent consumption of meat that is no longer fit for consumption.

From all the questions, it follows that detecting meat freshness and ammonia levels is important for Muslims. This unanimous response reflects the strong religious and ethical significance of the "Thayyib" principle in Halal food compliance. This demonstrates that all participants recognize that food safety and freshness are integral to ensuring that meat is truly halal for consumption, reinforcing the relevance and necessity of the EthicFresh device for Muslim users who prioritize health and religious integrity.

Table 2. Results-based Experience

No	Question	Yes (%)	No (%)
1	Have you ever bought chicken meat at a traditional market?	V	
2	Are you aware that semi-fresh/spoiled chicken meat can violate the principle of "Thayyib" in Islam?	V	
3	Have you ever accidentally bought or consumed chicken that had started to smell or change color?	V	
4	In your opinion, is detecting the freshness level (ammonia) in meat very important for Muslim consumers to ensure the halal status of food?	V	
5	Would you feel safer if you could check your chicken's freshness yourself with a portable sensor?	V	
6	Would it be useful to have a portable device that measures ammonia levels and detects color changes in meat in real time?	V	
7	Have you ever had difficulty distinguishing between truly fresh chicken and semi-fresh chicken?	V	
8	How confident are you in determining the freshness of chicken meat just by relying on your sense of sight and smell without the help of tools?		V
9	Do you usually check the physical condition (texture, color, smell) of chicken meat in detail before buying it at the market?	V	
10	Did you know that the accumulation of ammonia in chicken meat is an indicator that the meat has reached the "Khaba'ith" (bad/haram) stage?		V
11	Have you ever avoided certain vendors or restaurants because you were unsure about the freshness (thayyib) of the meat they were selling?	V	

Based on the question that a device such as EthicFresh could help Muslims ensure that the food they consume is truly Thayyib (wholesome and fresh). This unanimous agreement indicates strong recognition of the challenges Muslim consumers face in identifying meat quality in complex market environments. In many traditional markets, poultry is often sold in open-air settings where the transition from fresh to spoiled can occur rapidly due to a lack of standardized refrigeration. For Muslims, ensuring that food is not only Halal in its slaughter but also "Thayyib" in its physical condition is essential for religious and health compliance. The EthicFresh device is perceived as a practical tool that enables users to detect objective indicators of freshness, such as ammonia levels and color changes, thereby helping them make informed, safe dietary decisions.

A portable ammonia detector is practical for shoppers in traditional markets. This finding suggests that participants perceive mobility and portability as key advantages of the device. Shoppers in local markets often face time constraints and must rely on subjective sensory perceptions (smell and sight), which can be unreliable for detecting early-stage spoilage. A portable device allows users to verify meat integrity quickly and independently at the point of sale, which increases their confidence and sense of safety when purchasing poultry from various vendors. The result reflects a strong acceptance of the device as a useful and necessary tool for daily food procurement in accordance with Halal-Thayyiban standards.

Table 3. EthicFresh can help Muslims ensure

No	Question	Agree (%)	Disagree (%)
1	I think a tool like EthicFresh can help Muslims ensure that chicken is truly Thayyib (fresh).	V	
2	Having a portable ammonia detector is very practical for shoppers in traditional markets.	V	
3	EthicFresh can increase confidence when purchasing chicken from unknown vendors.	V	
4	Do you think technology can help Muslims maintain dietary purity in complex market conditions?	V	
5	Do you think technology can help Muslims ensure food is halal?	V	
6	Do you think technology can help Muslims maintain dietary purity in complex market conditions?	V	
7	I am satisfied with EthicFresh's performance and usefulness for identifying meat that is starting to spoil.	V	

Sensor data, rather than their own senses, is used to detect early spoilage. This high level of trust suggests that consumers are aware of the limitations of human perception in identifying chemical markers, such as ammonia, that may not yet produce a strong odor. This finding highlights a shift towards a reliance on technology to bridge the gap in food safety verification. It underscores the perceived value of EthicFresh in providing a "second opinion" that is scientific and unbiased, further empowering the consumer to maintain dietary purity in challenging environments.

Implications

Aquatic products serve as a broad category encompassing aquatic animal and plant products, as well as their processed products, derived from marine and freshwater fisheries. This includes fish, shrimp, crab, shellfish, algae, marine animals, and other fresh products obtained through fishing and aquaculture (Pazmiño et al., 2025a). Furthermore, it includes processed products that have undergone various treatments, such as freezing, pickling, drying, smoking, cooking, and canning, as well as integration (Michel et al., 2024). Aquatic products play a vital role in the production and consumption of daily human food (Pazmiño et al., 2025b). Throughout the spoilage process, the quality of fish products progressively declines, leading to the release of volatile compounds, including trimethylamine, dimethylamine, and biogenic amines (Tavares et al., 2021).

As the most representative form of oxygen indicator, most commercial oxygen indicators are based on redox dyes. Typically, these indicators employ a detection mechanism that involves a redox dye, such as methylene blue, a reducing agent, and a base solution (Heo et al., 2024). When oxygen is present, the redox dye changes color; in its absence, the reducing agent keeps the indicator colorless in the base solution. These indicators have the advantage of easily detecting the presence of oxygen through a color change in the dye without requiring special equipment or expertise, and are inexpensive to produce (Drago et al., 2020).

Table 4: Performance Matrix and Research Implications of Poultry Freshness Evaluation Methods

Performance Indicator / Implication	Laboratory Testing (TVB-N / HPLC)	Manual Inspection (Human Sensory)	Ethic Fresh System (Proposed Research)
Detection Time	24 – 48 Hours	1 – 3 Minutes	≤ 15 Seconds (Real-Time)
Testing Nature	Destructive	Non-Destructive	Non-Destructive
Portability & Usability	Low (Requires Lab & Experts)	High (Highly Subjective)	Very High (Portable & User-Friendly)
Halal 4.0 Data Integration	Manual / Isolated	None	Automated & Digitally Integrated
Syariah Compliance Status	High Biochemical Certainty	Low Certainty (*Syubhat*)	Objective Certainty (*Thayyib / Khaba'ith*

The findings of this study have important implications for supporting Muslim consumers in determining the Halal-Thayyiban status and safety of poultry within the food industry. Conducted among consumers, the results demonstrate that Muslim individuals recognize the urgent need for reliable tools to identify the chemical and physical transitions of meat across three distinct stages: fresh, semi-fresh, and spoiled.

The EthicFresh device has the potential to empower Muslim users by providing them with direct, objective information on ammonia levels and color degradation, thereby reducing uncertainty and enabling more confident food choices. This is particularly crucial during the "semi-fresh" stage—a grey area where meat may not yet emit a strong foul odor but has already begun to lose its Thayyib (wholesome) integrity. By facilitating the real-time detection of these spoilage markers, the device can reduce the difficulties commonly faced in traditional markets, where subjective sensory inspection often fails to distinguish between safe meat and meat that has started to become "khaba'ith" (harmful/vile).

Limitation

Beyond individual benefits, the widespread use of such technology may also foster greater trust and transparency within the global Halal supply chain. The ability to verify meat freshness independently can encourage poultry producers and vendors to improve their cold-chain management and storage practices. By enhancing accountability and promoting clearer communication regarding food quality, EthicFresh ultimately strengthens consumer confidence in food safety and Halal compliance, ensuring that the meat reaching the table is not only slaughtered according to ritual but remains pure and wholesome for consumption across international markets.

Future Work

In terms of future work, several improvements can be proposed to enhance the functionality and reliability of the EthicFresh device. Future research should focus on expanding detection capability to include a wider range of poultry parts and processed meat products by improving sensor sensitivity, particularly to lower ammonia thresholds during the critical "semi-fresh" transition phase.

The development of an integrated mobile application with an offline mode could reduce reliance on continuous internet access, enabling seamless use in traditional markets or rural slaughterhouses where connectivity may be limited. Larger-scale field trials involving more diverse poultry samples—varying by storage temperature and packaging methods—are also recommended to validate the device's accuracy, robustness, and generalisability in distinguishing between fresh (Thayyib) and spoiled (Khaba'ith) states across different environmental conditions.

Furthermore, integrating the device with a comprehensive blockchain-based database for Halal-Thayyiban certification could provide users with more holistic guidance, such as tracking the time elapsed since slaughter. This would strengthen EthicFresh's role as a practical, indispensable tool for supporting halal compliance and food safety in everyday consumption, ensuring consumers can objectively verify the integrity of the meat they purchase.

5. Conclusion

This research successfully designed and evaluated EthicFresh, an automated, portable, and non-destructive screening system for broiler chicken freshness that bridges the gap between complex laboratory testing and subjective human sensory inspection. By integrating calibrated color (RGB) sensors with transparent digital data logging, the system objectively classifies chicken meat into three distinct Halal-Tayyibah statuses: Fresh (low ammonia, high R-value; Full Thayyib), Semi-Fresh (early oxidation near critical sensory thresholds; Syubhat/Warning), and Spoiled (high ammonia, low R-value; Khaba'ith/Non-Halal Compliance). Ultimately, EthicFresh offers a reliable, real-time solution for daily market use, empowering consumers to make safe and informed choices while strengthening food safety governance and Halal 4.0 assurance across the poultry supply chain".

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