Effectiveness of Hibiscus Flower Extract (*Hibiscus rosa-sinensis* L.) and Red Galangal as a Freshness Indicator Label for Chicken Meat

Deli Silvia*, Muryeti, Agnes Devina Engelyca Hutauruk, Saeful Imam, and Amanda Sofidania
Department of Graphical and Publishing Engineering
Politeknik Negeri Jakarta
Depok, 16425, Indonesia
**deli.silvia@grafika.pnj.ac.id*

Date received: September 12, 2025
Revision accepted: July 23, 2025

Abstract

Chicken meat, among the most consumed animal proteins globally, is highly susceptible to spoilage due to its high moisture and nutrient content, promoting rapid microbial growth under inadequate storage. This study developed and evaluated an anthocyanin-based indicator label using hibiscus flower extract (Hibiscus rosa-sinensis L.) and red galangal (Alpinia purpurata) for freshness monitoring of raw chicken meat in intelligent packaging. Indicator films were formulated at three hibiscus extract concentrations (14%, 16%, 18%) combined with ganyong starch at 6% and 8%, and evaluated through color change (mean RGB via ImageJ, NIH, USA), pH, weight loss, and organoleptic testing at 25°C over 12 hours, with observations every 3 hours. Results showed visually distinguishable color transitions from red to dark green corresponding to meat deterioration, with the strongest response in the A1S formulation (14% hibiscus extract, 6% ganyong starch). Meat pH increased progressively from 5.64 at hour 0 to 6.67 at hour 12, consistent with volatile amine accumulation during decomposition. Organoleptic acceptability declined during storage, reaching the non-acceptable range by the later observation period. Pearson correlation analysis revealed a statistically significant but weak negative relationship between pH and mean RGB (r = -0.218; p = 0.039; r^2 = 0.047), indicating pH explained only 4.7% of color response variance. These results should be interpreted as preliminary rather than strong predictive validation. Given the absence of microbiological confirmation, TVB-N measurement, and instrumental colorimetry, the findings nonetheless suggest the potential of hibiscus-based films as freshness indicator labels for intelligent packaging.

***Keywords**:* chicken meat, freshness indicator, hibiscus flower, intelligent packaging

1. Introduction

Meat is widely recognized as a primary source of animal-based protein essential for human nutrition. Among meat types, chicken is highly perishable and poses considerable challenges for maintaining quality throughout the supply chain (Augustyńska-Prejsnar *et al.*, 2024; Kim *et al.*, 2023). Recent spoilage modeling and freshness-indicator studies on chicken breast have shown that deterioration is associated with changes in physicochemical, sensory, and microbial quality attributes, including pH, volatile basic nitrogen, and microbial growth indicators (Kim *et al.*, 2022; Kim *et al.*, 2023). The elevated moisture content and nutrient-rich composition of chicken muscle tissue create favorable conditions for rapid spoilage when handling and storage temperatures are not adequately controlled.

In response to the growing need for effective food quality monitoring, intelligent packaging technologies have emerged as a promising solution. These systems incorporate functional elements that detect and signal changes in the food matrix or surrounding environment, including fluctuations in pH, temperature, or gaseous metabolites released during spoilage (Chen *et al.*, 2023; Supardianningsih *et al.*, 2023; Zhou *et al.*, 2021). Among these, colorimetric freshness indicator labels have attracted considerable attention because they translate chemical changes into visible color signals that can be observed without opening the package or using specialized equipment. Evidence from chayote fruit further shows that passive modified atmosphere packaging can delay sprouting and reduce weight loss, although moisture retention may increase the risk of decay, emphasizing the need to optimize package permeability and the internal atmosphere (Bayogan *et al.*, 2021).

Previous studies have demonstrated the feasibility of anthocyanin-based indicator films for freshness monitoring across various food matrices. Dragon fruit peel anthocyanins incorporated into cassava starch-chitosan composite films have been reported as colorimetric indicators for protein-rich foods (Pramitasari *et al.*, 2022). Sodium alginate films containing purple sweet potato peel anthocyanins have been used to monitor dynamic changes in chicken freshness at 4°C and 25°C (Zhao *et al.*, 2022). Similarly, pH-responsive double-layer films containing anthocyanins and curcumin have been developed to monitor meat freshness through visible color changes (Zhou *et al.*, 2021). Hibiscus-derived anthocyanins have also been incorporated into pectin-based color indicator films, supporting the broader feasibility of hibiscus pigments for pH-sensitive intelligent packaging applications (Mendes *et al.*, 2022).

Beyond colorimetric sensing, biodegradable active films have also been developed from durian starch-carrageenan matrices containing carvacrol. These films reduced *Staphylococcus aureus* counts in a food model and demonstrated the potential of starch-based functional packaging (Velasco & Fundador, 2020). This emphasis on renewable materials also aligns with broader waste-valorization strategies, including anaerobic digestion of animal manure to generate biogas and reduce pollution potential (Rollo *et al*., 2017).

Hibiscus flower (*Hibiscus rosa-sinensis* L.) has been identified as a promising natural pigment source for developing pH-sensitive indicators. Recent spectrophotometric analysis confirmed anthocyanins in red hibiscus extract and demonstrated an acid-base color response, with red under acidic conditions and green under alkaline conditions (Suryani & Muna, 2024). Anthocyanins are pH-sensitive pigments that undergo structural changes as the surrounding pH shifts, and their incorporation into biopolymer films has been widely reviewed for colorimetric food freshness monitoring (Weston *et al*., 2020; Chen *et al*., 2023). These characteristics make hibiscus flower extract suitable for development as an indicator label for intelligent packaging applications.

Red galangal (*Alpinia purpurata*) was incorporated in this study as a complementary natural ingredient within the film matrix. A recent study reported that red galangal extract contains alkaloids, flavonoids, tannins, triterpenoids, and saponins, and demonstrated bacteriostatic activity against *Edwardsiella tarda*, with the highest inhibitory response observed at 500 ppm after 24 hours of incubation (Hidayati *et al*., 2023). However, because the present study did not include a comparative formulation without red galangal, its specific contribution to the indicator label performance cannot be isolated experimentally and should be treated as a supporting formulation component rather than a proven enhancement factor.

The present study aims to assess the potential of hibiscus flower extract and red galangal for developing indicator labels for intelligent packaging applications, specifically for monitoring the freshness of raw chicken meat. The performance of the films was evaluated through color change analysis, pH measurements, weight loss, and organoleptic evaluation conducted at room temperature over a 12-hour observation period.

2. Methodology

2.1 Materials and Equipment

The primary materials used in this study include hibiscus flower powder (*Hibiscus rosa-sinensis* L.), red galangal powder (*Alpinia purpurata*), ganyong starch (*Canna edulis* Ker.), 96% ethanol (analytical grade, Merck KGaA, Germany), distilled water, glycerol (analytical grade, Merck KGaA, Germany), NaOH (analytical grade, Sigma-Aldrich, USA), HCl (analytical grade, Sigma-Aldrich, USA), NH_4OH (analytical grade, Sigma-Aldrich, USA), and Whatman No. 1 filter paper (Cytiva, UK). Hibiscus flower powder and red galangal powder were procured from the online marketplaces Shopee and Tokopedia in Indonesia.

The equipment used in this study included an analytical balance (Radwag AS 220/C/2, Radwag, Poland) for mass measurements; a pH meter (Mettler Toledo S20, Mettler Toledo, Switzerland) calibrated with pH 4 and pH 7 buffer standards; a desiccator (Duran Group, Germany) for controlled drying; Pyrex glass beakers (Corning Inc., USA); a magnetic hotplate stirrer (IKA RCT Basic, IKA, Germany); Petri dishes (100 × 20 mm; Pyrex, USA); a laboratory oven (Memmert UN 30, Memmert GmbH, Germany) for film drying; a glass funnel (Pyrex, USA); a refrigerated chiller maintained at 4°C; a digital thermometer (Hanna Instruments HI98501, Hanna Instruments, USA); and ImageJ software (version 1.53, National Institutes of Health, USA) for digital image analysis of color changes.

2.2 Working Procedure

This research was conducted in two main stages: preparation of plant extracts and fabrication of indicator film labels for evaluating chicken meat freshness.

2.2.1 Preparation of Hibiscus Flower and Red Galangal Extracts

The extracts of hibiscus flowers (*Hibiscus rosa-sinensis* L.) and red galangal (*Alpinia purpurata*) were prepared through the maceration method. Dried and finely powdered plant materials were mixed with 96% ethanol (analytical grade, Merck KGaA, Germany) at a solid-to-solvent ratio of 1:5 (w/v; 1 g of powder per 5 mL of ethanol). The mixture was macerated at room temperature for 24 hours with periodic manual agitation to maximize extract yield. Following maceration, the mixture was vacuum-filtered through Whatman No. 1 filter paper (Cytiva, UK) to remove solid residues. The resulting filtrate was collected in amber reagent bottles and stored at 4°C in a dark environment to minimize anthocyanin degradation prior to use. This procedure was designed to selectively extract anthocyanins from hibiscus flowers and bioactive phenolic compounds from red galangal for incorporation into the indicator film matrix.

2.2.2 Preparation of Indicator Film Labels

Indicator film labels were prepared by dissolving ganyong starch (at concentrations of 6% and 8% w/v), 4 mL of glycerol (Merck KGaA, Germany), and 1 mL of red galangal extract in 100 mL of distilled water, then adding hibiscus flower extract at concentrations of 14%, 16%, or 18% (v/v). The mixture was heated on a magnetic hotplate stirrer (IKA RCT Basic, IKA, Germany) at 70°C and 250 rpm for 30 minutes to achieve complete gelatinization and homogeneous dispersion of the components. The resulting film-forming solution was poured into Petri dishes (100 × 20 mm) and dried in a laboratory oven (Memmert UN 30, Memmert GmbH, Germany) at 70°C for 12 hours. The selection of ganyong starch as the film-forming matrix is supported by literature describing Canna edulis starch as a promising raw material for edible coatings, bioplastics, and biodegradable packaging development due to its starch and amylose characteristics (Anggraini *et al*., 2016; Gabriel *et al*., 2021).

The six formulation codes used in this study are listed in Table 1. Code A1S denotes a formulation containing 6% ganyong starch, 14% hibiscus flower extract, 1% red galangal extract, and 4 mL of glycerol. Codes A2S and A3S follow the same composition but with hibiscus flower extract at 16% and 18%, respectively. Codes B1S, B2S, and B3S use the same formulation logic with ganyong starch at 8%.

Table 1. Sample codes and formulation composition of indicator film labels

Sample Code	Ganyong Starch (%)	Hibiscus Flower Extract (%)	Red Galangal Extract (%)	Glycerol (mL)
A1S	6	14	1	4
A2S	6	16	1	4
A3S	6	18	1	4
B1S	8	14	1	4
B2S	8	16	1	4
B3S	8	18	1	4

2.2.3 Color Change Test

Color change testing was performed by packaging fresh chicken meat on a Styrofoam trays were covered with polyethylene cling film, and indicator film labels were affixed externally. The packaged samples were stored at room temperature (25°C) for 12 hours, with photographic documentation at 0, 3, 6, 9, and 12 hours. Digital images were captured under standardized lighting conditions and analyzed using ImageJ software (version 1.53, National Institutes of Health, USA) to determine mean RGB values as a quantitative measure of color change. As chicken meat deteriorates, volatile basic nitrogen compounds and biogenic amines accumulate and interact with anthocyanin-containing indicator films, inducing visible color transitions (Zhao *et al.*, 2022; Zhou *et al.*, 2021).

2.2.4 Chicken Meat Weight Loss Test

Weight loss was calculated as the percentage change in sample mass from initial to final storage time using Equation 1:

$$Weight\ loss\ (\%) = \frac{Initial\ Weight - Final\ Weight}{Initial\ Weight} \times 100 \qquad (1)$$

2.2.5 Chicken Meat pH Test

The pH of chicken meat was measured by homogenizing 10 g of the meat sample with 100 mL of distilled water (1:10 w/v) using a laboratory blender. The pH of the homogenate was measured with a calibrated pH meter (Mettler Toledo S20, Mettler Toledo, Switzerland) standardized with pH 4 and pH 7 buffer solutions. Measurements were taken at each observation interval (0, 3, 6, 9, and 12 hours).

2.2.6 Organoleptic Test

Sensory evaluation was conducted by 30 semi-trained panelists using the hedonic scoring method with a scale of 1 to 5, referring to the sensory evaluation approach for chicken meat quality under SNI 3924:2009. Parameters assessed included appearance (color), aroma, and texture. Scores of 3 and above were considered acceptable, while scores below 3 indicated that the product had exceeded its acceptable freshness threshold. The organoleptic method was used to complement physicochemical analyses because sensory attributes reflect consumer-relevant deterioration cues, including off-odor development and textural changes.

2.3 Data Analysis

Data analysis used Pearson correlation to quantify the strength and direction of the linear relationship between mean RGB values and pH measurements at a significance level of $\alpha = 0.05$. Statistical analyses were conducted using IBM SPSS Statistics (version 26.0, IBM Corp., Armonk, NY, USA). The pooled dataset comprised 90 observations from 6 formulations (A1S, A2S, A3S, B1S, B2S, and B3S) × 5 storage times (0, 3, 6, 9, and 12 hours) × 3 measurement replicates. The pooled correlation analysis should be interpreted cautiously because observations were drawn from multiple formulations and repeated temporal measurements, which may not fully satisfy assumptions of homogeneity, independence across time, and strict linearity. The coefficient of determination (r^2) was also reported to indicate the proportion of variance in mean RGB values explained by pH.

3. Results and Discussion

3.1 Preparation of Hibiscus Flower and Red Galangal Extracts

Figure 2 presents scatter plots comparing monthly rainfall from IMERG V06B and V07B with rain gauge observations, as well as a direct comparison between V07B and V06B. The figure includes all available monthly data from 69 BMKG stations across Indonesia. The CCs between both IMERG versions and rain gauge observations are similar (0.77 for V06B and 0.78 for V07B) and consistent with previous evaluations of the IMERG Final product over the IMC (Ramadhan *et al*., 2022c). However, a notable difference is observed in RB, with IMERG V07B at 9.68%, less than half that of IMERG V06B (19.04%). These findings are consistent with earlier studies that demonstrated the greater accuracy and improved detection capabilities of IMERG V07B at the monthly scale (Wang *et al*., 2023; Li *et al*., 2025).

3.2 Preparation of Indicator Film Labels

Figure 1 presents the dried indicator film labels. The control film (without extract) exhibited a translucent, near-colorless appearance, while the hibiscus-incorporated film displayed a characteristic red-pink coloration attributable to the anthocyanin content. The film produced with 16% hibiscus flower extract, 8% ganyong starch, 4 mL glycerol, and 1% red galangal extract is shown as a representative sample. Following drying, films were trimmed to 2 × 2 cm sections, each corresponding to a specific concentration formulation, for application in chicken meat freshness testing. The uniform and flexible nature of the films indicates adequate film-forming properties conferred by ganyong starch and glycerol as plasticizer, consistent with findings by Anggraini *et al*. (2016).

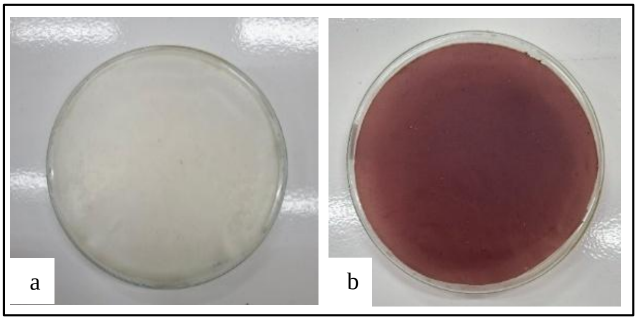

Figure 1. Edible film indicator – control (a) and with added hibiscus extract (b)

3.3 Color Testing at Room Temperature

Color change assessment was performed by calculating mean RGB values from digital images captured at 3-hour intervals over 12 hours at room temperature (25°C). The quantitative color data for all six formulations are presented as mean ± standard deviation (SD) in Table 2, with the corresponding trend graph shown in Figure 2.

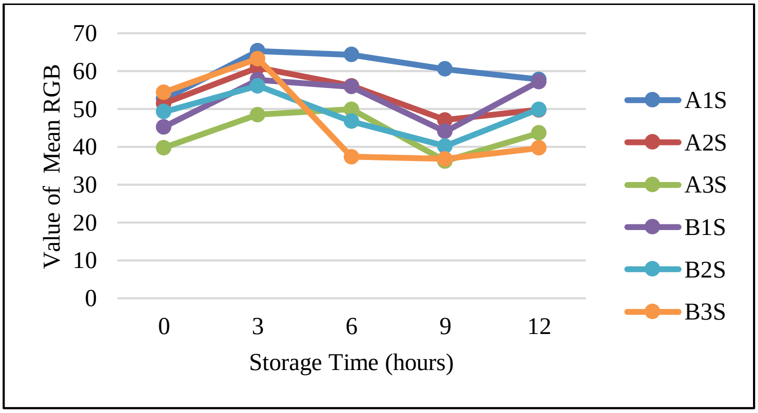

Figure 2. Mean RGB values of indicator film labels at room temperature over 12 hours

Table 2. Mean RGB values (mean ± SD) of indicator film labels at room temperature

Storage Time (hours)	A1S(mean ± SD)	A2S(mean ± SD)	A3S(mean ± SD)	B1S(mean ± SD)	B2S(mean ± SD)	B3S(mean ± SD)
0	52.677 ± 0.802	51.437 ± 1.356	39.732 ± 0.592	45.257 ± 0.180	49.291 ± 0.589	54.390 ± 1.272
3	65.304 ± 0.785	60.983 ± 3.627	48.451 ± 6.911	57.682 ± 3.495	56.088 ± 2.183	63.285 ± 8.156
6	64.339 ± 4.042	56.088 ± 2.183	49.919 ± 8.223	55.900 ± 10.369	46.690 ± 7.357	37.369 ± 3.029
9	60.516 ± 3.788	47.092 ± 3.136	36.244 ± 5.845	44.063 ± 3.391	40.175 ± 3.833	36.810 ± 6.757
12	57.776 ± 8.606	49.749 ± 1.374	43.630 ± 5.119	57.229 ± 8.867	49.902 ± 5.246	39.685 ± 3.644

Analysis of the data in Table 2 indicates that sample A1S (14% hibiscus flower extract, 6% ganyong starch) showed the most pronounced and consistent color change over the 12-hour observation period. The mean RGB value of A1S increased from 52.677 ± 0.802 at hour 0 to 65.304 ± 0.785 at hour 3, then gradually declined to 64.339 ± 4.042 at hour 6, 60.516 ± 3.788 at hour 9, and 57.776 ± 8.606 at hour 12. This pattern of an initial increase followed by a gradual decrease in RGB values may reflect pigment-matrix interactions and exposure to volatile metabolites from deteriorating chicken meat (Zhao *et al.*, 2022). The subsequent decline beyond hour 3 aligns with anthocyanin sensitivity to oxygen, moisture, and alkaline volatile compounds generated during protein decomposition (Zhao *et al.*, 2022). Anthocyanins undergo well-documented structural transformations as environmental pH rises from acidic to alkaline, shifting progressively from red flavylium cations toward quinonoidal bases and other forms, which can manifest visually as a transition from red toward darker green or blue-green coloration in the indicator film (Weston *et al.*, 2020; Zhao *et al.*, 2022).

Formulations A2S and B2S (both containing 16% hibiscus flower extract) exhibited nearly parallel fluctuation patterns, suggesting that, at this intermediate concentration, starch concentration had limited influence on color stability under the tested room-temperature condition. In contrast, the B3S formulation (18% extract, 8% starch) showed a marked decline from hour 6 onward, indicating that a higher extract concentration combined with increased starch content may influence pigment-matrix interactions in the alkaline volatile environment generated by spoiling meat. Overall, the color transition from red to dark green across the formulations indicates a qualitative response to meat quality deterioration, but this response should not be interpreted as a fully validated spoilage prediction tool without microbiological confirmation, TVB-N measurement, or instrumental colorimetry.

3.4 pH Testing of Chicken Meat at Room Temperature

Figure 3 presents the pH dynamics of chicken meat during room-temperature storage. At hour 0, the initial pH of 5.64 was consistent with the sample's relatively fresh condition before substantial storage-related deterioration. A progressive increase in pH was observed at each subsequent measurement interval: 5.76 at hour 3, 5.89 at hour 6, 6.17 at hour 9, and 6.67 at hour 12. This rising pH trend is consistent with the accumulation of alkaline volatile compounds, including ammonia and other volatile amines, which are produced during protein degradation and microbial spoilage in chicken meat (Kim *et al*., 2022; Zhao *et al*., 2022).

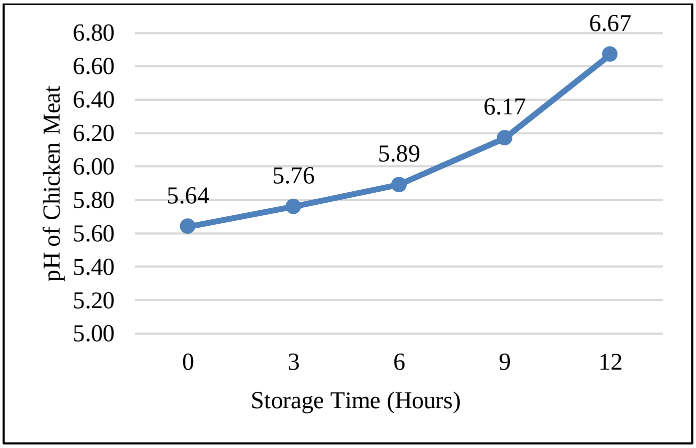

Figure 3. pH of chicken meat at room temperature over 12 hours of storage

The measured pH values align with published observations that deterioration of chicken meat during storage is accompanied by changes in pH, volatile basic nitrogen, and other quality attributes (Kim *et al*., 2022; Kim *et al*., 2023; Zhao *et al*., 2022). In the present study, the pH exceeded 6.2 between hours 9 and 12, coinciding with the decline in organoleptic acceptability. Nevertheless, pH alone is insufficient to confirm microbiological spoilage; therefore, the interpretation of freshness deterioration in this study remains based on physicochemical and sensory indicators rather than microbiological confirmation.

3.5 Organoleptic Testing of Chicken Meat at Room Temperature

Figure 4 presents the organoleptic evaluation results. At the 3rd hour of storage, the overall mean hedonic score was 3.49, indicating acceptable quality with no major deterioration in appearance, aroma, or texture. Quality scores declined progressively over time, with aroma and color scores falling to 2.0 at the 12th hour, below the minimum acceptable threshold of 3. The texture parameter reached its lowest value of 1.78 at hour 12, reflecting a softened, exudate-releasing texture characteristic of advanced quality deterioration. These observations align with the pH data, which showed marked alkalinization at hours 9 and 12, and collectively suggest that chicken meat stored at room temperature exceeded its acceptable sensory quality in the later storage period.

The deterioration of aroma during later storage is attributable to enzymatic lipid degradation and subsequent lipid oxidation. Lipolysis in meat involves the enzymatic hydrolysis of lipids, including triacylglycerols and phospholipids, generating free fatty acids and other hydrolytic products that may contribute to oxidative reactions and off-flavor development (Tatiyaborworntham *et al.*, 2022). This lipolytic and oxidative cascade is accelerated under aerobic room-temperature conditions, explaining the rapid decline in aroma acceptability beyond the 6th hour of storage.

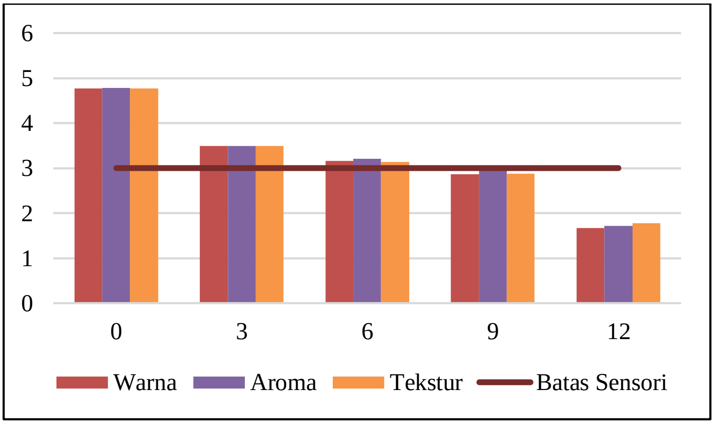

Figure 4. Organoleptic scores of chicken meat at room temperature across storage hours

3.6 Correlation between Chicken Meat pH and Color Change

Pearson product-moment correlation analysis was employed as an exploratory analysis to quantify the relationship between the pH values of chicken meat and the mean RGB color values of the indicator films over the 12-hour room temperature storage period. The dataset pooled multiple formulations, repeated time points, and replicated measurements into a single correlation analysis; therefore, the result should be interpreted cautiously because the assumptions of homogeneity, independence across time, and possible linearity may not be fully satisfied. Descriptive statistics and correlation results are presented in Table 3.

Table 3. Descriptive statistics and pooled Pearson correlation between chicken meat pH and indicator label color response

Variable pair	N	pH (mean ± SD)	Mean RGB (mean ± SD)	Pearson r (p-value)	r^2 and interpretation
pH vs. mean RGB	90	6.03 ± 0.37	50.59 ± 9.37	-0.218 (0.039)	0.047; weak negative relationship

The Pearson correlation coefficient between pH and mean RGB values was $r = -0.218$ ($p = 0.039$), indicating a statistically significant but weak negative relationship. The coefficient of determination was $r^2 = 0.047$, meaning that pH accounted for only approximately 4.7% of the variance in mean RGB values. This weak predictive relationship indicates that color response was influenced by factors beyond pH alone, such as formulation differences, pigment stability, volatile compounds, and temporal changes during storage. Therefore, the result supports only a preliminary association between pH increase and RGB decrease, rather than strong predictive validation of spoilage status.

Although the correlation strength falls within the weak range, the negative direction is chemically plausible because increasing alkalinity can shift anthocyanin pigments from red flavylium forms toward green or blue-green structural forms (Chen *et al.*, 2023; Suryani & Muna, 2024). However, the pooled correlation analysis should be interpreted cautiously because observations were derived from multiple formulations and repeated temporal measurements. In addition, the study did not include microbiological validation, TVB-N measurement, or instrumental colorimetry; therefore, the results suggest the potential of the hibiscus-based indicator label for intelligent packaging applications rather than confirming a strong predictive freshness model.

4. Conclusions and Recommendation

This study suggests that indicator film labels formulated from hibiscus flower extract (*Hibiscus rosa-sinensis* L.) combined with red galangal (*Alpinia purpurata*), ganyong starch, and glycerol have potential to provide a visual indication of raw chicken meat quality changes under room temperature storage. All six formulations exhibited observable color transitions from red to dark green, corresponding to physicochemical and sensory deterioration during storage. The most responsive formulation under room temperature conditions was A1S (14% hibiscus flower extract, 6% ganyong starch), which demonstrated the most pronounced and comparatively consistent mean RGB changes over the 12-hour observation period.

The pH of chicken meat increased steadily from 5.64 to 6.67 over 12 hours of room temperature storage, reflecting the progressive accumulation of alkaline volatile compounds associated with quality deterioration. Organoleptic assessment confirmed that chicken meat quality declined during storage and reached an unacceptable sensory range at the later observation period. Pearson correlation analysis showed a statistically significant but weak negative relationship between pH and mean RGB values ($r = -0.218$; $p = 0.039$; $r^2 = 0.047$), indicating that the color response was associated with pH changes but had limited predictive strength. The study relied on physicochemical and organoleptic indicators without microbiological confirmation of spoilage status.

Future studies are recommended to conduct comprehensive validation using microbiological analysis, total volatile basic nitrogen (TVB-N), instrumental colorimetry (e.g., L*, a*, b*, and ΔE), and material property characterization, including tensile strength, elongation at break, water vapor permeability, and transparency. Additional studies should also evaluate the indicator label under chilled storage conditions and over extended storage periods. Comparative formulations with and without red galangal are needed to determine whether red galangal contributes to antimicrobial activity, color stability, or freshness response. These additional validations are necessary before the label can be positioned as a fully integrated intelligent packaging system.

5. Acknowledgement

The authors gratefully acknowledge the financial support provided by the Politeknik Negeri Jakarta DIPA Research Grant for Indexed Publication. The authors declare no conflicts of interest.

6. References

Anggraini, D., Hidayat, N., & Mulyadi, A.F. (2016). Canna edulis starch as the raw material of edible coating and its application on the storage of Anna apples (*Malus sylvestris*): The study of canna starch and glycerol concentrations. *Industria: Jurnal Teknologi dan Manajemen Agroindustri, 5(1), 1-8.* https://doi.org/10.21776/ub.industria.2016.005.01.1

Augustyńska-Prejsnar, A., Kačániová, M., Hanus, P., Sokołowicz, Z., & Słowiński, M. (2024). Microbial and sensory quality changes in broiler chicken breast meat during refrigerated storage. *Foods, 13*(24), 4063. https://doi.org/10.3390/foods13244063

Badan Standardisasi Nasional. (2009). SNI 3924:2009: Mutu karkas dan daging ayam [Quality of chicken carcass and meat]. Badan Standardisasi Nasional.

Bayogan, E. R. V., Secretaria, L. B., Lubaton, C. D. S., & Photchanachai, S. (2021). Sprouting of chayote fruit as influenced by passive modified atmosphere packaging and different postharvest chemical treatments. *Mindanao Journal of Science and Technology, 19*(1), 14-28.

Chen, L., Wang, W., Wang, W., & Zhang, J. (2023). Effect of anthocyanins on colorimetric indicator film properties. *Coatings, 13*(10), 1682. https://doi.org/10.3390/coatings13101682

Gabriel, A.A., Solikhah, A.F., Rahmawati, A.Y., Taradipa, Y.S., & Maulida, E.T. (2021). Potentials of edible canna (*Canna edulis* Kerr) starch for bioplastic: A review. *Industria: Jurnal Teknologi dan Manajemen Agroindustri, 10*(3), 267-276. https://doi.org/10.21776/ub.industria.2021.010.03.8

Hidayati, D. A., Prajitno, A., Sulistyawati, T. D., Pratama, G., & Nilakandhi, T. (2023). Antibacterial activity of red galangal (*A. purpurata*) extract on the growth of E. tarda bacteria. *Journal of Aquaculture and Fish Health, 12*(1), 127-134. https://doi.org/10.20473/jafh.v12i1.37056

Kim, H.-J., Kim, H.-J., Kim, H. C., Lee, D., Jung, H. Y., Kang, T., & Jo, C. (2023). Mathematical modeling for freshness/spoilage of chicken breast using chemometric analysis. *Current Research in Food Science, 7,* 100586. https://doi.org/10.1016/j.crfs.2023.100586

Kim, Y.-Y., Park, S.-J., Kim, J.-S., & Shin, H.-S. (2022). Development of freshness indicator for monitoring chicken breast quality and freshness during storage. *Food Science and Biotechnology, 31,* 379-386. https://doi.org/10.1007/s10068-022-01034-x

Mendes, J.F., Norcino, L.B., Manrich, A., Oliveira, T.J.P. de, Mendes, R.F., & Mattoso, L.H.C. (2022). Pectin-based color indicator films incorporated with spray-dried Hibiscus extract microparticles. *Food Hydrocolloids, 127,* 107501. https://doi.org/10.1016/j.foodhyd.2022.107501

Pramitasari, R., Gunawicahya, L.N., & Anugrah, D.S.B. (2022). Development of an indicator film based on cassava starch-chitosan incorporated with red dragon fruit peel anthocyanin extract. Polymers, 14(19), 4142. https://doi.org/10.3390/polym14194142

Rollo, E.P.F., Pabilona, L.L., Magomnang, A.-A.S.M., Villanueva, E.P., & Magomnang, D.M.M. (2017). Analysis of biogas production from cow, chicken and swine manure. *Mindanao Journal of Science and Technology, 15*, 130-136.

Supardianningsih, Mutsla, A., Riana, M., Ardiani, S., & Amalia, B. (2023). Pengembangan label film smart packaging berbasis sensor pH dari bayam merah untuk mendeteksi kesegaran daging [Development of smart packaging film label based on red spinach pH sensor to detect meat freshness]. *Jurnal Teknologi Pangan dan Hasil Pertanian, 18(2), 111-120.* https://doi.org/10.24815/jacps.v12i3.32303

Suryani, E., & Muna, L.N. (2024). Analysis of total anthocyanin levels in hibiscus (*Hibiscus rosa-sinensis* L.) preparations by differential pH method using UV-Vis spectrophotometry. *JIPI (Jurnal IPA dan Pembelajaran IPA), 8(3), 311-320*. https://doi.org/10.24815/jipi.v8i3.40575

Tatiyaborworntham, N., Oz, F., Richards, M. P., & Wu, H. (2022). Paradoxical effects of lipolysis on the lipid oxidation in meat and meat products. *Food Chemistry: X, 14,* 100317. https://doi.org/10.1016/j.fochx.2022.100317

Velasco, E.M.Z., & Fundador, N. G.V. (2020). Development and use of antimicrobial durian starch-carrageenan/carvacrol films. *Mindanao Journal of Science and Technology, 18*(1), 118-128. https://mjst.ustp.edu.ph/index.php/mjst/article/view/378

Weston, M., Phan, M. A. T., Arcot, J., & Chandrawati, R. (2020). Anthocyanin-based sensors derived from food waste as an active use-by date indicator for milk. *Food Chemistry, 326*, 127017. https://doi.org/10.1016/j.foodchem.2020.127017

Zhao, M., Nuerjiang, M., Bai, X., Feng, J., Kong, B., Sun, F., Li, Y., & Xia, X. (2022). Monitoring dynamic changes in chicken freshness at 4°C and 25°C using pH-sensitive intelligent films based on soy protein isolate and anthocyanins. *Food Hydrocolloids, 125*, 107362. https://doi.org/10.1016/j.foodhyd.2021.107362

Zhou, X., Yu, X., Xie, F., Fan, Y., Xu, X., Qi, J., Xiong, G., Gao, X., & Zhang, F. (2021). pH-responsive double-layer indicator films based on konjac glucomannan/camellia oil and carrageenan/anthocyanin/curcumin for monitoring meat freshness. *Food Hydrocolloids, 118*, 106695. https://doi.org/10.1016/j.foodhyd.2021.106695