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INTELLIGENT INDICATOR APPLICATION BASED ON FISH GELATIN AND POLYVINYL ALCOHOL WITH PURPLE SWEET POTATO EXTRACT AS A QUALITY INDICATOR FOR VANNAMEI SHRIMP (*Litopenaeus vannamei*)

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ABSTRACT

Rapid, real-time monitoring of Vannamei shrimp quality is essential to ensure product safety and quality during storage. Therefore, a method capable of providing direct freshness information is needed, such as through the use of an intelligent indicator. Purple sweet potato extract contains anthocyanin pigments that are sensitive to changes in pH and can produce a color-change response, making it suitable as a coloring component in an intelligent indicator. The objective of this study was to determine the optimal concentration of purple sweet potato extract and to analyze its application to Vannamei shrimp stored at cold temperatures. This study employed an experimental design with five variations of purple sweet potato extract addition: 0%, 5%, 10%, 15%, and 20%. The observed parameters included a sensitivity test for changes in Vannamei shrimp quality, changes in pH, ammonia response, total volatile basic nitrogen (TVBN) values, and the acceptability of Vannamei shrimp during storage covering appearance, aroma, and texture as assessed by 20 panelists. The results showed that the indicator color changed from pink on day 0 to light purple on day 3, light blue on day 6, and bluish-green on day 9. These color changes occurred in tandem with an increase in pH from 6.93 to 7.83, a rise in TVBN from 4.2 mg/100 g to 35.3 mg/100 g, and a gradual decline in the scores for the appearance, aroma, and texture of the Vannamei shrimp. The addition of 15% purple sweet potato dye extract was determined to be the optimal concentration as an indicator of Vannamei shrimp quality changes, based on the visualization of the most distinct color gradation changes during cold storage of the shrimp.

Keywords: Intelligent Indicator; Vannamei Shrimp; Purple Sweet Potato; Quality Changes

INTRODUCTION

According to Ramli *et al.* (2025), shrimp consist primarily of water, protein, fat, carbohydrates, minerals, vitamins, cholesterol, and other chemical compounds. This chemical composition particularly the high protein content makes shrimp susceptible to deterioration due to enzymatic activity (autolysis) and the growth of spoilage bacteria during storage (Permana *et al.,* 2023). The spoilage process generally begins after harvest or capture and is marked by the rigor mortis phase, a condition in which muscles become rigid after the organism dies. As spoilage progresses, changes in aroma, odor, and texture occur as a result of the degradation of tissue components, microbial metabolic activity, and lipid oxidation (Tavares *et al.,* 2021). This process also increases total volatile basic nitrogen (TVBN) levels volatile basic compounds formed from protein degradation by decay-causing bacteria and widely used as an indicator of the freshness of fishery products.

During the decay process, decay-causing bacteria degrade shrimp protein and produce total volatile base nitrogen (TVBN) compounds, which are basic in nature. The accumulation of these compounds causes the pH of Vannamei shrimp to increase during storage gradually. According to Le et al. (2025), the pH of shrimp increases linearly as TVBN levels rise. Therefore, pH can serve as an indicator for detecting changes in Vannamei shrimp quality during storage. However, quality monitoring using conventional methods still has limitations, necessitating a faster, more practical method capable of providing real time information such as an intelligent indicator.

Changes in the quality of Vannamei shrimp can be detected using various methods, such as organoleptic tests and laboratory tests; however, each method has its drawbacks. Organoleptic methods can be performed directly by consumers to assess appearance, texture, and aroma; however, they are subjective, and the results depend heavily on individual perception, making them less accurate in determining freshness (Kim *et al.,* 2023). Meanwhile, laboratory tests, such as the measurement of Total Volatile Base Nitrogen (TVBN), can provide accurate results but are time-consuming, costly, and cannot be performed directly by consumers (Khezerlou *et al.,* 2023). To address these issues, an indicator is needed that can provide immediate, real-time indications of quality changes and does not require specialized expertise to interpret the freshness of packaged shrimp.

Intelligent indicators are one of the innovations in the development of intelligent packaging that can be used to monitor changes in food product quality in real time. These indicators provide information about a product's freshness to consumers and distributors through color changes that occur during storage (Sahar *et al.,* 2024). The production of intelligent indicators requires a film matrix with good mechanical properties and stability. Fish gelatin was chosen because it has good film-forming ability, is biodegradable, and is safe for food

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applications. However, gelatin films have the drawbacks of being brittle and highly sensitive to moisture. Therefore, fish gelatin was combined with polyvinyl alcohol (PVA), which offers better mechanical strength, flexibility, and stability. The combination of these two materials forms hydrogen bonds between the hydroxyl groups on PVA and the amine and carbonyl groups on the gelatin, resulting in a film matrix with improved mechanical properties, greater stability, and better suitability for use as an intelligent indicator (Zeng *et al.,* 2019).

This study uses purple sweet potato extract as the coloring component in the intelligent indicator because the anthocyanins it contains have good stability and can produce a variety of color changes ranging from pink, purple, violet, blue, green, to yellow in response to changes in pH. These color changes facilitate the interpretation of food product quality conditions during storage (Alizadeh *et al.* 2020). Furthermore, purple sweet potatoes are abundantly available year-round, have a relatively short growth period, can adapt to various environmental conditions, and are inexpensive to cultivate (Chen *et al.* 2019). Numerous studies have utilized purple sweet potato anthocyanins as natural dyes in intelligent indicators. However, research combining purple sweet potato anthocyanins with a fish gelatin–polyvinyl alcohol (PVA) matrix to detect volatile compounds resulting from spoilage in Vannamei shrimp during cold storage remains limited. Therefore, this study developed a fish gelatin–PVA-based intelligent indicator with the addition of purple sweet potato extract to monitor changes in Vannamei shrimp quality in real time. This study aimed to determine the optimal concentration of purple sweet potato extract in the fish gelatin–PVA-based intelligent indicator and to analyze its performance in detecting changes in Vannamei shrimp quality during cold storage.

RESEARCH METHODS

Time and Location of the Study

The study was conducted from October to November 2025 at the Laboratory of Fishery Product Processing Technology and the Laboratory of Fish Parasites and Diseases, Faculty of Fisheries and Marine Sciences, Padjadjaran University, for the preparation and application of the indicator, pH testing, and organoleptic testing, and the Ruminant Nutrition and Food Chemistry Laboratory, Faculty of Animal Science, Padjadjaran University, for TVBN testing.

Research Design

The research method employed was an experimental design consisting of five treatment levels of purple sweet potato extract addition: 0%, 5%, 10%, 15%, and 20% (Filho *et al.,* 2024). Each treatment was replicated three times and applied to the lids of shrimp sample containers, which were stored for nine days at 4°C and observed at three-day intervals. The parameters observed in this study included a sensitivity test of purple sweet potato extract to pH changes, a sensitivity test of the intelligent indicator to ammonia vapor, a sensitivity test of the intelligent indicator to qualitative changes in Vannamei shrimp quality, a pH test of Vannamei shrimp during storage, and a quantitative test of the total volatile basic nitrogen (TVBN) content of Vannamei shrimp. The Vannamei shrimp acceptability test during storage used a scoring system that included parameters such as appearance, aroma, and texture.

Materials and Methods

The materials used in this study included 500 grams of purple sweet potatoes obtained from the Padjadjaran Center for Sweet Potato Research and Innovation Excellence (PRAISE), Faculty of Agriculture, Padjadjaran University; distilled water from the Laboratory of Chemical Applications and Services, Faculty of Mathematics and Natural Sciences, Padjadjaran University; FURO brand fish gelatin; polyvinyl alcohol powder; glycerol*,* pH 4, 7, and 9 buffers from Reys Laboratory in Bogor, fresh Vannamei shrimp weighing 20 grams each obtained from PT Superindo, trichloroacetic acid (TCA) powder, boric acid solution (H_3BO_3) 3%, potassium carbonate (K_2CO_3) 3N solution, and 0.02N HCl solution obtained from Reys Laboratory and the Laboratory of Ruminant Animal Nutrition and Food Chemistry at Padjadjaran University.

The equipment used in this study included an Ohaus analytical balance with a precision of 0.1 g, an SH-3 hot plate, a 3-cm magnetic stirrer, a mercury thermometer, *a* Faithful water bath set at 50°C, a 10-cm-diameter stainless steel sieve, *a* Centurion Scientific C2 centrifuge (5,000 rpm, 10 minutes), 150-mL amber bottles, a Sharp refrigerator, Normax 100 × 20 mm petri dishes, a Faithful vacuum oven set at 40°C and 2 bar pressure, a Rosalia digital vernier caliper, a B-One UV-Vis 100 DA-X, 5 mL glass cuvettes, 150 mL thin-wall plastic containers, ATC pH meter, Memmert IN55 incubator at 36°C, 100 mm Ningbo Conway dishes, and *a* Seward stomacher.

Research Procedure

Extraction of Anthocyanins from Purple Sweet Potatoes

Anthocyanin pigment extraction from purple sweet potatoes was performed according to a modified method by Yunilawati *et al.* (2018). A total of 200 grams of purple sweet potatoes were washed and peeled. The cleaned purple sweet potatoes were then cut into 2 x 2 cm pieces. The pieces were placed in a glass beaker*,* and distilled water was added in a 1:3 ratio. The mixture was heated to 90 ℃ for 10 minutes on *a* hotplat*e.* The extract solution was then cooled to room temperature. The solution was filtered using a stainless-steel strainer and stored in a refrigerator at 4°C for 24 hours. The extract solution was transferred to a tube and centrifuged at 4,000 rpm for 10 minutes to separate the sediment from the extract solution. The dye extract was adjusted to a pH of 2 by adding citric acid as needed until a solution with a pH of 2 was obtained. The filtrate was then concentrated using a water bath at 60°C until the volume of the filtrate was reduced to half its initial volume. The filtrate was transferred to a dark container and stored in a refrigerator at 4°C.

Preparation of the Intelligent Indicator

The intelligent indicator was prepared based on a modified version of Kwak *et al.* (2024): 0.6 grams of fish gelatin powder was weighed using a digital scale. The fish gelatin was then dissolved in 15 mL of distilled water that had been heated to a temperature of ±50°C on a hot-plate stirrer*,* while stirring until completely dissolved for 30 minutes. 3 grams of PVA powder were weighed into *a* separate glass beaker and dissolved

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in 15 mL of distilled water**.** The PVA solution was heated to a temperature of ±70–80 °C while being stirred constantly until the PVA was completely dissolved (±15–20 minutes). The two solutions (gelatin and PVA) were mixed in a 1:1 (volume) ratio in *a* clean beaker. The mixture was stirred for 1 hour until the solution appeared homogeneous. Purple sweet potato extract was added to the polymer solution according to the treatment protocol. 0.3 mL of glycerol was added as a plasticizing agent to increase the film's flexibility. A total of 20 mL of the mixture was poured evenly into a petri dish to produce a film with a thickness of ±0.1 mm. The film was placed in an oven at 40°C for ±8–12 hours until completely dry.

Application to Vannamei Shrimp

The intelligent indicator was applied to the Vannamei shrimp packaging system by placing it in the headspace of the package, specifically on the inner side of the lid. This placement was designed to prevent the intelligent indicator from coming into direct contact with the Vannamei shrimp samples; it allows the indicator to interact optimally with the volatile compounds released by the shrimp during storage without affecting the quality of the shrimp (Suratsawadee *et al.,* 2022). Whole, cleaned Vannamei shrimp samples were placed in the packaging 3 cm away from the indicator; the shrimp samples were stored in a refrigerator for different storage periods: 0 days, 3 days, 6 days, and 9 days. The shrimp samples stored for the four different periods were then removed from the refrigerator for organoleptic testing, TVBN testing, and pH measurement.

Observation Parameters

Characterization of the Indicator

Color changes were observed as follows: The workbench was prepared in a clean condition; a photo box for documenting color changes was set up with proper lighting; the shrimp samples were removed from the refrigerator; the sample lids were removed from the packaging; the lid section containing the intelligent indicator was placed in the photo box, and the color change was documented; the color change was then visually observed for descriptive analysis.

Procedure for testing the sensitivity of purple sweet potato anthocyanins to pH changes according to Amalia *et al.* (2021): The obtained anthocyanin extract was dispensed into three test tubes, each containing 10 mL. Acidic, neutral, and basic pH buffer solutions were then added to each test tube. Color changes were observed using a UV-vis spectrophotometer at wavelengths ranging from 400 nm to 800 nm.

Procedure for testing the indicator's sensitivity to ammonia vapor according to Jiang *et al.* (2020): The indicator was cut into 2 × 2 cm pieces; a 1 M (1 mol/L) NH_4OH (1 mol/L) was prepared as a source of ammonia vapor in a petri dish; the indicator was then placed on top of the petri dish to avoid direct contact with the ammonia. The film was tested for 30 minutes, with changes observed every 5 minutes, after which the color changes were analyzed.

Vannamei Shrimp Quality Test

Shrimp pH measurements were taken periodically every three days during the 9-day storage period using a digital pH meter that had been previously calibrated with buffer solutions (pH 4 and pH 7). pH measurements were conducted based on the method by Apriyantono *et al.* (1989) as follows: the pH meter was calibrated using standard buffer solutions of pH 4 and pH 7. A 5-gram sample of shrimp was weighed and then crushed using a pestle and mortar. Deionized water (45 mL) was added to the finely ground shrimp sample, and the mixture was homogenized. The homogenized sample solution was measured using the previously calibrated pH meter.

The TVB-N test was conducted in accordance with SNI 2354.8:2009 regarding the determination of Total Volatile Base Nitrogen (TVB-N) and trimethylamine nitrogen (TMA-N) in fishery products (BSN, 2009). A 10-gram sample of shrimp meat was weighed using an analytical balance and then homogenized in a blender. A total of 90 mL of a 7% trichloroacetic acid (TCA) solution was added to the sample, and the mixture was homogenized again for approximately 2 minutes. Next, the mixture was filtered using filter paper to obtain the filtrate. A total of 50 mL of the filtrate was transferred to a distillation flask, and 10 mL of a 20% NaOH solution was added. The solution was distilled using a steam distillation apparatus for 5–10 minutes. The distillate was collected in 100 mL of a 3% boric acid solution to which Tashiro indicator had been added. Next, the distillate was titrated with 0.02 N HCl solution until the color changed from purple to pink or light green. The volume of HCl solution used was recorded and then used to calculate the TVB-N value based on Equation 1.

$$TVBN = \frac{(V - V0) \times N \times 14 \times 100}{W} \quad \text{.....................(1)}$$

Notes: V = Volume of HCl for the sample (mL); V_0 = Volume of HCl for the blank (mL); N = Normality of HCl (0.02 N); W = Weight of the sample (g)

Organoleptic testing of Vannamei shrimp freshness was conducted using a scoring method in accordance with SNI 01-2346 regarding guidelines for organoleptic and/or sensory testing (BSN 2006). The scoring test was conducted by 20 semi-trained panellists to determine the freshness level of Vannamei shrimp after storage for 0 days, 3 days, 6 days, and 9 days. The scoring test used a numerical scale ranging from 1 (one) as the lowest score to 9 (nine) as the highest score.

Data Analysis

The research data were analyzed descriptively according to the characteristics of each parameter.

1. Data from the sensitivity test of purple sweet potato extract to pH changes were analyzed descriptively and quantitatively based on color changes in each pH treatment.
2. The data from the sensitivity test of the intelligent indicator to ammonia vapor were analyzed using qualitative descriptive methods based on the color change response following exposure to ammonia vapor.
3. Data from the intelligent indicator test, pH values, TVB-N values, and scoring tests during Vannamei shrimp storage were analyzed descriptively by comparing the color changes of the intelligent indicator with pH values, TVB-N values, and scoring test results to evaluate the suitability of the intelligent indicator's response in detecting changes in Vannamei shrimp quality during storage.

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4. The test results for pH and TVB-N values of the shrimp are quantitative data analyzed descriptively.
5. The organoleptic scoring test data (appearance, aroma, and texture), which are ordinal data, were analyzed using the non-parametric Kruskal-Wallis analysis of variance to determine the effect of storage duration on the sensory quality of the shrimp. If a significant effect was found ($P < 0.05$), the analysis continued with the Dunn test (*post-hoc test*) to determine significant differences among the storage duration treatments.

Conclusions were drawn based on the relationship between changes in the color of the intelligent indicator and the pH value, TVBN value, and Vannamei shrimp scoring test results.

RESULTS AND DISCUSSION

Sensitivity Test of Purple Sweet Potato Extract to pH Changes

Purple sweet potato extract exhibited different color responses at each pH condition due to changes in anthocyanin structure. These color changes were used to evaluate the sensitivity of purple sweet potato extract to pH changes as a basis for selecting natural dyes for the intelligent indicator. The results of observations of color changes in purple sweet potato extract at pH 4, pH 7, and pH 9 are presented in Figure 1.

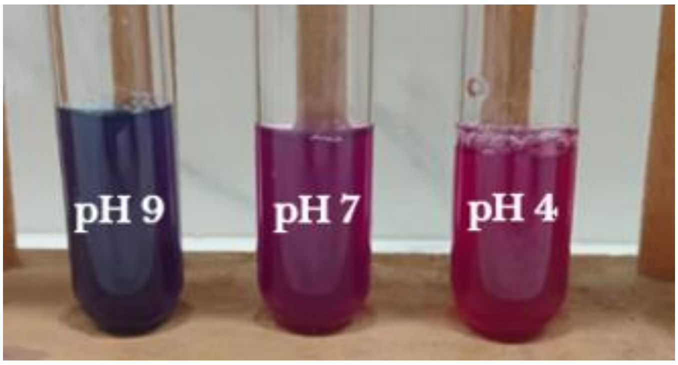

Figure 1. Purple Sweet Potato Extract at pH 4, 7, and 9

The purple sweet potato extract exhibits high sensitivity to pH changes, as indicated by distinct color shifts. At acidic pH (pH 4), the color changes to magenta due to the formation of a stable flavilium cation; at neutral pH (pH 7), it appears purple; whereas at basic pH (pH 9), it turns blue due to the formation of a quinone base and a less stable chalcone structure. This change occurs due to the structural transformation of anthocyanins, which is strongly influenced by pH conditions, resulting in a color shift from red to blue as the pH increases (Singh *et al.* 2018). The anthocyanins contained in purple sweet potato extract consist of two types, namely cyanidin and peonidin; both types of anthocyanins are the dominant pigments in purple sweet potatoes and are known to have relatively better color stability compared to several other natural sources of anthocyanins because most of them are in the acylated form (acylated anthocyanins) (Singh *et al.,* 2018).

The UV-Vis spectrum results in Figure 2 show a bathochromic shift in the maximum wavelength as pH increases. At pH 4, the absorption peak is at 520–540 nm (1.7), indicating the dominance of the flavilium cation. At pH 7, the peak shifts to 540–580 nm with lower absorbance (1.62), while at pH 9 it shifts to 580–600 nm (1.75) but decreases beyond 620 nm due to anthocyanin degradation. This confirms that changes in pH affect not only the color but also the light absorption characteristics of the purple sweet potato extract.

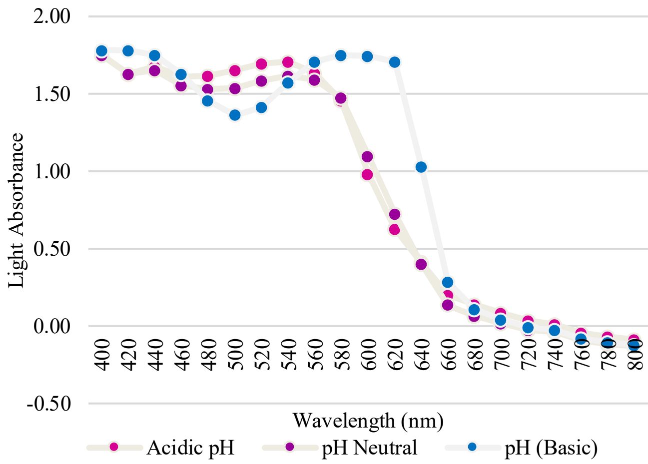

Figure 2. UV-Vis Spectra of Purple Sweet Potato Extracts in Buffer Solutions at pH 4, 7, and 9

Sensitivity Test of the Intelligent indicator to Ammonia Vapor

Sensitivity testing for ammonia vapor was conducted as an initial step to evaluate the intelligent indicator's response to volatile compounds produced during the decomposition process. The indicator's ability to detect the presence of ammonia vapor was observed through color changes at each observation time interval. The test results are presented in Table 1.

The color change of the intelligent indicator based on purple sweet potato extract indicates a relationship between the extract concentration and the response time of the color change. The observations show that the higher the concentration of purple sweet potato extract added, the stronger the initial color intensity produced, allowing the color change to be observed more clearly. Based on the observations, the initial color change began to occur at the 5th minute across all concentration treatment groups, marked by a decrease in the intensity of the pink color and the onset of purple and light blue hues. More significant color changes occurred between the 10th and 15th minutes, particularly at concentrations of 10–20%, which showed a color transition from pinkish purple to light blue.

The response time for color changes, which began at the 5th minute, indicates that the purple sweet potato extract-based indicator has sufficient sensitivity for application in smart packaging. In food packaging applications, particularly for fishery products, quality changes due to microbial activity and the formation of volatile compounds occur gradually; therefore, a response within minutes is still considered fast and effective

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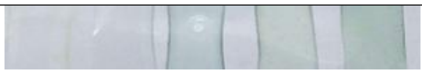
for providing an early indication of product spoilage. The increasingly distinct color changes observed by the 10th and 15th minutes demonstrate that the indicator can provide a visual representation of quality changes that consumers can easily observe directly without additional tools.

Table 1. Results of the Indicator Sensitivity Test to Ammonia Vapor

Time (minutes)	Indicator Color Change				
	0%	5%	10%	15%	20%
0					
5					
10					
15					
20					
25					
30					

Color changes in the treatments, with 15% and 20% concentrations were gradual, stable, and more visually distinct. In contrast, in the treatments with 5% and 10% concentrations, color changes occurred more rapidly, were less distinct, and quickly faded to transparency, indicating that lower concentrations exhibit high sensitivity but low color stability. These observations align with research conducted by Zhai *et al.* (2017), in which anthocyanin-based indicators exhibited rapid color-change responses to changes in pH and volatile compounds; distinct color changes occurred within a relatively short time, progressing gradually from pink to purple, then to blue, and finally to green.

According to Agunos *et al.* (2020), the color change in the intelligent indicator occurs because the ammonia vapor produced becomes trapped within the indicator matrix and reacts with the anthocyanins, thereby triggering a color change consistent with the characteristics of anthocyanins namely, from pink to green as the pH increases. In this study, the indicator matrix consisted of a composite of fish gelatin and polyvinyl alcohol (PVA), which served as a carrier matrix for the anthocyanins and as a diffusion path e for ammonia vapor. The hydrophilic nature of gelatin and PVA allows ammonia molecules to diffuse into the matrix and interact with water molecules bound to the film network. This interaction produces ammonium hydroxide (NH_4OH), which subsequently dissociates into ammonium ions (NH_4^+) and hydroxide ions (OH^-). The increase in hydroxide ion concentration causes the pH around the matrix to rise, resulting in a structural change in the anthocyanins from the flavilium cation form to the quinonoidal base form. This structural change results in a color change in the intelligent indicator that can be observed visually (Safitri *et al.,* 2022). In addition to facilitating the diffusion of ammonia vapor, the gelatin PVA composite matrix also helps maintain a homogeneous distribution of anthocyanins and improves the film's stability and mechanical properties, resulting in a clearer and more consistent color-change response.

Application of the Indicator to Vannamei Shrimp Quality

Based on the research results presented in Table 2, the intelligent indicator based on purple sweet potato extract is capable of detecting changes in Vannamei shrimp quality during storage at 4°C through changes in the indicator's color. The color changes that occur indicate the indicator's response to volatile compounds resulting from the degradation of shrimp quality, with varying levels of sensitivity at each concentration of purple sweet potato extract.

Table 2. Application of the Intelligent indicator at Concentrations of 0%, 5%, 10%, 15%, and 20% on Shrimp Quality Deterioration

Day	Application Images	Image of Shrimp Samples	Indicator Color				
			0%	5%	10%	15%	20%
0							
1							
2							
3							
4							
5							

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Day	Application Images	Image of Shrimp Samples	Indicator Color				
			0%	5%	10%	15%	20%
6							
7							
8							
9							

The color changes in the intelligent indicator during the storage of Vannamei shrimp at 4°C indicate that the concentration of purple sweet potato extract affects the clarity and speed of the indicator's response. The treatment without extract (0%) showed no color change and was therefore ineffective as an indicator. The 5% concentration exhibited a rapid change but with a faint color that was difficult to observe, while the 10% concentration showed a clearer change but was less stable. The 15% concentration provided the most optimal and gradual color change (pink–purple–blue–green) that remained consistent throughout storage, whereas the 20% concentration produced an initial color that was too intense, making the contrast of the color change less distinct. The results of a study by Yong *et al.* (2019) showed that increasing the anthocyanin concentration can enhance the indicator's sensitivity; however, concentrations that are too high can cause the initial color to be too dark, thereby reducing the effectiveness of visual observation of color changes.

The indicator's color change is influenced by a rise in pH due to the formation of basic volatile compounds, such as ammonia, resulting from protein degradation by enzymatic and microbial activity. Under initial conditions, a neutral pH maintains a pink color (flavilium cation), which then changes to purple and eventually blue as the pH rises due to the accumulation of NH_3, which forms OH^- ions. This change indicates a decline in shrimp quality. Overall, all treatments with the extract were able to respond to changes in quality; however, the 15% concentration was the most effective because it produced the clearest, most gradual, and easily observable color changes.

pH Testing of Vannamei Shrimp Samples

pH testing was conducted to monitor changes in the chemical conditions of Vannamei shrimp during storage. Changes in pH serve as an indicator of the sample's freshness level and support the interpretation of the intelligent indicator's response. The results of the pH testing during storage are presented in Figure 3.

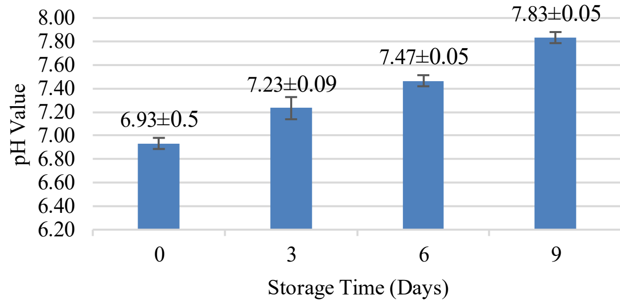

Figure 3. Graph of pH Test Results for Shrimp Samples

The low pH value of the shrimp on day 0 of storage was caused by the degradation of carbohydrates in the shrimp's body tissues, which produced lactic acid compounds, resulting in an acidic pH value (Liu *et al.,* 2024). The pH of the shrimp increased to 7.23 on the third day, 7.47 on the sixth day, and reached 7.83 on the ninth day. According to Liu *et al.* (2024), this was caused by the activity of decomposing microorganisms that break down proteins and amino acids into basic compounds such as ammonia, thereby causing an increase in pH. An increase in pH can indicate a deterioration in shrimp quality; according to He *et al.* (2022), shrimp are unfit for consumption when the pH exceeds 7.7. Based on this, the shrimp stored for nine days were no longer fit for consumption because they had exceeded the safe pH limit.

Measurement of TVBN Values in Vannamei Shrimp Samples

TVBN testing is one of the chemical parameters used to determine the freshness and degree of quality deterioration in protein-based food products, including fishery products. The test results are presented in Figure 4.

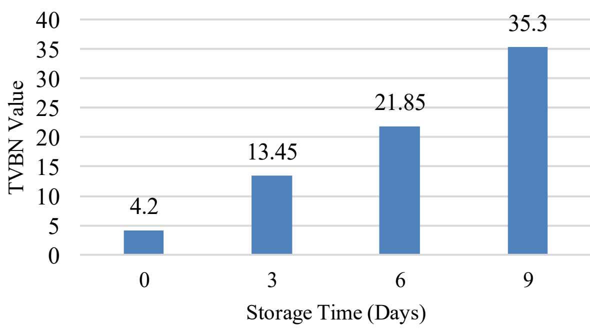

Figure 4. Graph of TVBN Test Results for Vannamei Shrimp Samples

Total Volatile Base Nitrogen (TVBN) value shows an upward trend as storage time increases, indicating a decline in the quality of Vannamei shrimp. This increase is caused by

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enzymatic activity and microorganisms that break down proteins into peptides and amino acids (Nie *et al.,* 2022), which then undergo a deamination process that produces volatile basic compounds such as ammonia and other nitrogen compounds (Altissimi *et al.,* 2015), thereby contributing to the formation of TVBN. This is consistent with Suhono *et al.* (2025), who stated that an increase in TVBN values is directly proportional to the degree of spoilage. Based on quality standards, a TVBN value of ≤10 mg N/100 g is categorized as very fresh, 10–20 mg N/100 g as fresh, 20–30 mg N/100 g still suitable for consumption, and >30 mg N/100 g as unsuitable (National Standardization Agency 2009). Furthermore, international standards state that fishery products are considered fresh if the TVBN value is <20 mg/100 g (Yun *et al.* 2024).

Test results showed that the TVB-N value increased from 4.2 mg/100 g on day 0 to 13.45 mg/100 g on day 3, which still indicated a fresh condition. On day 6, the TVB-N value rose to 21.85 mg/100 g, indicating that the quality of the shrimp had begun to decline. According to the China National Standard, this value exceeds the freshness threshold (<20 mg/100 g), but according to the National Standardization Agency (2009), the shrimp is still considered safe for consumption because it has not exceeded the maximum limit of 30 mg/100 g. Furthermore, on the 9th day, the TVB-N value reached 35.3 mg/100 g, so the shrimp were deemed unfit for consumption. The increase in TVB-N levels during storage is caused by the activity of spoilage bacteria that degrade proteins and non-protein nitrogen compounds into volatile basic compounds, such as ammonia (NH_3), trimethylamine (TMA), and dimethylamine (DMA). The accumulation of these basic compounds caused the TVB-N value to continue rising, accompanied by an increase in pH from 6.93 to 7.83. Thus, the rise in pH is not an isolated phenomenon but rather a consequence of the formation of basic compounds during the spoilage process. The higher the activity of decomposing microorganisms, the more volatile basic compounds are produced, causing both TVB-N and pH values to rise simultaneously, which ultimately accelerates the deterioration of Vannamei shrimp quality (Suhono *et al.,* 2025).

Organoleptic Test of Vannamei Shrimp Samples

Appearance

The results of the Vannamei shrimp appearance scoring test in Figure 5 show changes in the appearance of Vannamei shrimp during storage on days 0, 3, 6, and 9. Vannamei shrimp samples at the start of storage had a natural, transparent, and intact appearance, resulting in high scores as shown in Figure 6. On day 3, the shrimp began to show a duller color; by day 6, black spots appeared on the head; and by day 9, these black spots were clearly visible on both the head and body of the shrimp. The Vannamei shrimp samples on days 6 and 9 had low scores of 5.2 and 3.8, respectively, due to changes in appearance caused by melanosis, which significantly affects product acceptance (Sae-Leaw & Benjakul 2019). Black spots on the shrimp's body, or melanosis, are a discoloration process caused by the activity of the enzyme polyphenol oxidase, which catalyzes the oxidation of phenolic compounds into quinones, which then polymerize into dark pigments (Shao *et al.,* 2019). According to Tian *et al.* (2025), polyphenol oxidase enzyme activity continues even when shrimp are stored at cold temperatures; furthermore, melanosis is a characteristic sign of shrimp quality deterioration during storage.

Aroma

The decline in aroma scores of Vannamei shrimp samples during storage, as shown in Figure 7, is caused by the formation of volatile nitrogen compounds. According to Zhou *et al.* (2023), the shrimp's biological defense system ceases after the rigor mortis phase, allowing endogenous enzymes to begin breaking down proteins and non-protein nitrogen compounds a process known as autolysis. This process produces substrates utilized by spoilage microorganisms to generate pungent volatile compounds such as ammonia, trimethylamine (TMA), and dimethylamine (DMA). These compounds contribute to the emergence of fishy, indole, and other unpleasant odors, which indirectly influence the panelists' perception of the shrimp samples' aroma (Sae-Leaw & Benjakul 2019).

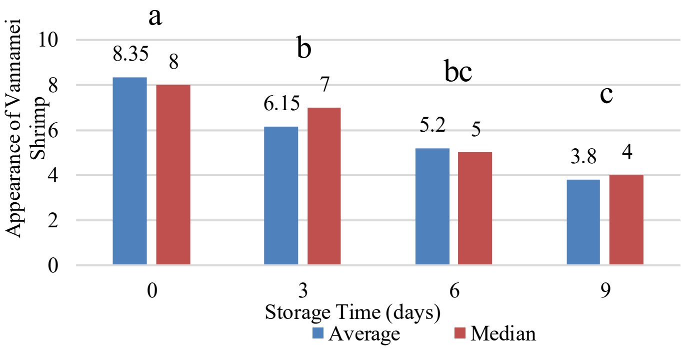

Figure 5. Appearance Score Values of Vannamei Shrimp Samples Stored at 4°C

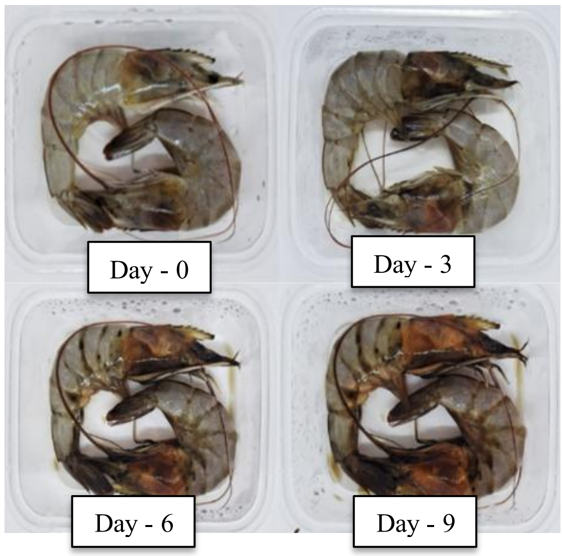

Figure 6. Changes in the Appearance of Vannamei Shrimp Samples at 4°C

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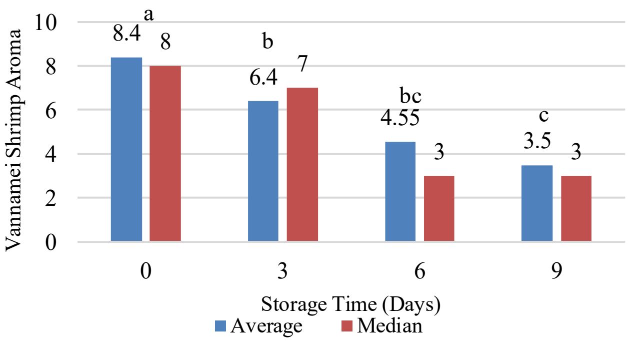

Figure 7. Aroma Scores of Vannamei Shrimp Samples Stored at 4°C

Texture

The results of the texture characteristic scoring test for Vannamei shrimp samples showed a general decline in scores, as shown in Figure 8. Based on the scoring test results, the texture of Vannamei shrimp tended to deteriorate as storage duration increased. From day 0 to day 3, the samples received high texture scores, indicating that the muscle tissue was still compact, elastic, and capable of maintaining its firmness. A decline in texture scores began to be observed from day 6 to day 9, with scores reaching 4.5. This condition was characterized by meat that became less elastic, less compact, and tended to be soft.

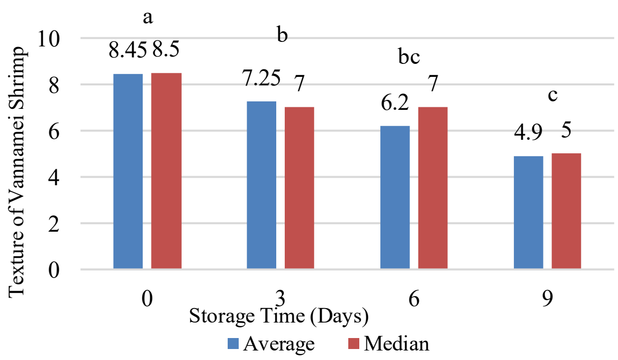

Figure 8. Texture Score Values of Vannamei Shrimp Samples Stored at 4°C

The decline in texture is initiated by the autolysis process that occurs immediately after the shrimp die. The death of the shrimp halts metabolic processes, but endogenous enzymes present in the muscle tissue such as proteases remain active and hydrolyze myofibrillar proteins as well as the proteins that make up connective tissue. This autolysis process weakens the bonds between muscle fibers, causing the tissue structure to lose its firmness and elasticity (Hafiludin & Najah 2023). As storage time increases, the activity of spoilage bacteria intensifies, accelerating the degradation of proteins into simpler compounds. The combination of endogenous enzyme activity and microbial activity causes muscle tissue damage to progress more intensively, resulting in the shrimp's texture changing from elastic, compact, and firm to soft and less compact (Sidiq *et al.,* 2021).

Protein degradation during storage is also accompanied by a decrease in the muscle tissue's ability to bind water. This condition causes intracellular fluid to leak out of the tissue (drip loss), as shown in Figure 5. The amount of fluid leaking from the shrimp's body increased from day 0 to day 3 and further from day 6 to day 9. This increase *in drip loss* causes the shrimp meat to lose its firmness and become less dense (Winarno 2016). Changes in tissue structure due to autolysis and increased drip loss also affect the appearance of the shrimp, resulting in a decline in the organoleptic scores for texture and appearance as storage time increases.

CONCLUSION

Based on the research results, it can be concluded that adding 15% purple sweet potato dye extract is the optimal concentration for indicating changes in the quality of Vannamei shrimp. A 15% concentration showed the most distinct, gradual, and consistent color changes pink on day 0, light purple on day 3, light blue on day 6, and bluish-green on day 9 which corresponded to changes in quality during cold storage. *An intelligent indicator* based on fish gelatin and *polyvinyl alcohol,* with the addition of purple sweet potato dye extract, can be used as an indicator of quality changes in Vannamei shrimp during nine days of cold storage. Analysis results showed color changes corresponding to an increase in pH from 6.93 on day 0 of storage to 7.83 on day 9 of storage, an increase in TVBN from 4.2 mg/100 g on day 0 of storage to 35.3 mg/100 g on day 9 of storage, and a gradual decrease in the appearance score from 8 to 3.8, the aroma score from 8 to 3.5, and the texture score from 8 to 4.5.

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