Red Dragon Fruit Peel Extract as Fish Shelf-Life Detector Bioactive Agent for A Chitosan-Based Smart Packaging



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ABSTRACT: Red dragon fruit contains betalain pigment that is responsible for its deep red-purple deep colour. Betalain is known as a bioactive agent in smart packaging to sense pH change and ammonia. In this research, dragon fruit peel extract, as a betalain source, was formulated with a chitosan/polyvinyl alcohol (chitosan/PVA) mixture for developing a smart biodegradable packaging film for tilapia fish. The film was prepared by blending chitosan solution in acetic acid and PVA solution at 80ºC followed by the addition of the red dragon fruit peel extract at various quantities. The mixture was then cast into a thin layer and dried at ambient room temperature for 5 d. The developed films were then tested to monitor the freshness of tilapia fish fillet after 16 h at room temperature and chiller temperature. The film incorporating red dragon fruit peel extract, attached to the packaging container's headspace containing the fish samples, shows the increase of colour intensity with time. In a separate measurement, the pH of fish fillet tends to increase, as measured every 4 h for 16 h. The increase of fillet fish pH may correlate with the emerging of ammonia from decayed fish. The independent tests of the developed films toward ammonia also show a notable response. This result implies that dragon fruit peel extract response to the pH change as well as the emerging ammonia from the fish sample. The developed chitosan/PVA enriched with red dragon fruit peel extract also shows some accepted mechanical properties such as 6.4 MPa of tensile strength and 36.37% of elongation.

KEYWORDS: Betalain; colourimetric indicators; fish spoilage; pH; smart film

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I. INTRODUCTION

Smart packaging technologies have greatly transformed the food industry, especially by improving food safety and quality through the mechanisms that accurately monitor the alterations occurring inside the food products. These technologies, categorized into active packaging, which interacts with food to prolong shelf life, and intelligent packaging, which monitors food quality, have gained significant attention for their ability to deliver real-time information about the food condition without opening the package (Thirupathi Vasuki et al., 2023; Akhila et al., 2024). Important components that play a role in this packaging system are indicators and sensors that detect various conditions in the packaged product's head space such as pH, oxygen, carbon dioxide, temperature, and other compounds (Akhila et al., 2024).

Despite advancements in smart packaging, significant challenges persist in creating cost-effective, biodegradable, and efficient materials capable of accurately detecting food spoilage. Many current solutions depend on synthetic indicators and non-biodegradable films, raising environmental concerns and failing to meet the growing demand for eco-friendly alternatives (Chen et al., 2020). Moreover, numerous existing packaging systems lack the sensitivity required to address specific spoilage mechanisms for different food types, particularly in detecting volatile compounds like ammonia, a critical indicator of protein decomposition in fish and meat products (Mohebi & Marquez, 2015). A potential solution to these challenges is the development of biodegradable films combined with natural freshness indicators that show visible changes due to the presence of certain materials or the formation of volatiles from the food matrix.

Among the diverse smart packaging preparation methods, colourimetric indicators are frequently utilized as pH sensors, using both natural and synthetic dyes (Kuswandi et al., 2022; Guo et al., 2024). Nevertheless, synthetic dyes pose health hazards because of their carcinogenic, mutagenic, and teratogenic effects (Wu et al., 2021). On the contrary, natural

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pH-sensitive dyes in smart packaging systems have shown more promising potential, as they are typically simple to produce, safe, and environmentally friendly (Kanha et al., 2022). Integrating natural colourants into smart packaging systems can be an effective approach for monitoring food freshness and spoilage, aligning with consumer preferences for safer and more sustainable food products (Young et al., 2020).

Recent developments in pH-sensitive smart packaging, designed to shift colour in response to food spoilage, involve the incorporation of pigments obtained from natural sources such as betalain, alizarin, anthocyanin, shikonin, and curcumin (Guo et al., 2024). Due to their chemical structure, these bioactive molecules not only possess colour-inducing properties but also exhibit antimicrobial and antioxidant activities, offering substantial potential for extending food shelf-life (N et al., 2024). In addition, these natural indicators can improve the visual appeal of packaging while supporting sustainability efforts by minimizing dependence on synthetic additives (Roy & Rhim, 2021; Fadhallah et al., 2023).

Betalains, which are natural water-soluble nitrogen pigments found in species belonging to the order Caryophillales and in fungi, have many functions due to their bioactivity like anticancer, antioxidant, anti-inflammatory, and antimicrobial (de Oliveira Filho et al., 2022). Studies have shown that betalains function effectively as pH indicators, shifting colour in response to spoilage-related environmental changes, such as ammonia emissions from decomposing fish and meat products (Fadhallah et al., 2023; Abedi-Firoozjah et al., 2025). Betalains obtained from different plant sources like beetroot, red pitaya, and amaranth, have been extensively applied to prepare smart films capable of indicating the freshness and spoilage of various foods (Qin et al., 2020; Hu et al., 2020; Surendhiran et al., 2023).

Some fruit peels, including those of red dragon fruit (*Hylocereus polyrhizus)* and prickly pear (*Opuntia spp*.) have been declared as excellent sources of betalains (Calva-Estrada et al., 2022). In fact, betalain extracted from red dragon fruit peel has gained recognition as a valuable natural additive for smart packaging due to their antioxidant, antimicrobial, and colourimetric properties. Renowned for their vibrant hues and bioactive advantages, these pigments enhance packaging functionality by offering visual spoilage indicators and safeguarding food against oxidative damage (de Oliveira Filho et al., 2022; Qin et al., 2020). Research indicates that red dragon fruit peel extract exhibits greater antioxidant activity than the fruit itself, making them an excellent choice for naturally extending the shelf life of perishable foods (Kusumasari et al., 2024).

Freshness indications are available in two main forms: labels and films, usually preferably made from biocompatible and renewable polymers or biopolymers and natural colouring agents as they are biodegradable thus addressing safety and environmental concerns (Abedi-Firoozjah et al., 2025). Integrating betalain pigments derived from red dragon fruit peel into polyvinyl alcohol (PVA) and chitosan-based films presents a sustainable option. Chitosan is a biodegradable polymer recognized for its film-forming and antimicrobial properties. The combination of chitosan's ability to inhibit microbial growth with the antioxidant effects of betalains creates a multifunctional packaging solution that addresses the dual challenges of food safety and environmental sustainability (Pal et al., 2021; de Oliveira Filho et al., 2022). However, chitosan has several limitations including low mechanical strength, high cost, limited flexibility, poor thermal stability, and rapid dissolution in acidic conditions. Combining chitosan with other polymers, such as PVA, presents an optimal solution to address these issues, as PVA offers excellent biocompatibility, high hydrophilicity, enhanced mechanical properties, solvent resistance, superior film-forming capabilities, and strong chemical stability (Haghighi et al., 2020).

Recently, natural dyes have been reported to interact with chitosan/PVA films through hydrogen bonding, which strengthens their mechanical resistance, boosts antiradical and antimicrobial activities, and enhances the halochromic properties of the films. Consequently, these interactions significantly improve the functional performance of chitosan/PVA films (Yao et al., 2022). Incorporation betalains into chitosan/PVA films enhances the visual appeal of packaging while also improving food safety by inhibiting the growth of spoilage-causing microorganisms (Qin et al., 2020). This approach not only serves as a visual indicator of spoilage but also improves the packaging's mechanical and antimicrobial characteristics (Qin et al., 2020; Abedi-Firoozjah et al., 2025). By optimizing the composition of these biodegradable films, it is possible to design smart packaging systems that are responsive to changes in food quality and align with environmental sustainability.

While substantial progress has been made in developing smart packaging systems incorporating natural extracts, several research gaps remain unresolved. A major challenge lies in optimizing the composition of biopolymers like PVA and chitosan combined with natural extracts such as betalains to achieve the desired mechanical properties and sensitivity to spoilage indicators. Many existing studies focus on the antimicrobial and antioxidant properties of these films, but limited research has examined their combined effects within a fully integrated smart packaging system (Yao et al., 2020; Yao et al., 2022).

Another key gap involves the application of betalain-based packaging such as that from red dragon fruit peel extract specifically designed for monitoring protein degradation, like detecting ammonia levels in fish products. Current research predominantly explores betalains general colourimetric properties but lacks emphasis on their specificity and accuracy in signaling spoilage in high-protein foods like fish and meat (Du et al., 2024). To address these challenges, further studies are needed to refine the formulation of betalain-incorporated films, focusing on enhancing mechanical strength, spoilage sensitivity, and environmental compatibility.

The main objective of this study is to develop a biodegradable chitosan/PVA film infused with betalain extract from red dragon fruit peel, functioning as a smart packaging label capable of detecting food quality deterioration, particularly through ammonia and pH sensitivity. This research aims to determine the optimal composition chitosan/PVA and red dragon fruit peel extract to improve the film's mechanical properties and spoilage detection capabilities, specifically for

applications in fish products like tilapia fillets. The novelty of this study lies in the targeted use of betalain pigments as natural spoilage indicators, combined with the antimicrobial and antioxidant properties of chitosan, to create an eco-friendly and effective packaging solution. To achieve the best performance, a systematic approach involving empirical testing across a range of extract concentrations is essential. By evaluating the tensile strength, elongation, and WVP at different levels, an optimal concentration can be determined that enhances tensile strength while minimizing the reduction in elongation and moisture barrier properties. This balance is crucial for developing functional and reliable active packaging materials.

II. MATERIALS AND METHODS

A. Materials

Several key materials used to facilitate this research process are detailed as follows: food grade chitosan (deacetylation degree of 85%, PT Biotech Surindo, Cirebon, Indonesia), red dragon fruit from one of traditional markets in Serang City (Indonesia), acetic acid (glacial) (100%, Merck) for dissolving chitosan, polyvinyl alcohol (PVA) (fully hydrolized, Merck) as a blending agent to improve the thermal and mechanical stability of the chitosan matrix, and distilled water.

B. Methods

1) Red Dragon Fruit Peel Extraction

The extraction and preparation of betalain from red dragon fruit peel (*Hylocereus polyrhizus*) were carried out by specific stages involving drying, grinding, and pH adjustments to enhance yield and stability. Fresh and ripe red dragon fruit peel was washed, and the green parts were removed before separating the peel from the flesh. The peel was then cut into small pieces, dried in a vacuum oven at temperature of 60°C for 24 h, and crushed into powder (approximately 40 mesh). The red dragon fruit peel powder was then stored in a closed container equipped with silica gel inside for further use. Testing the sensitivity of red dragon fruit peel extract to acidic and basic pH conditions was carried out using distilled water as a solvent due to the high solubility of betalain in water (Namazzadeh et al., 2022).

Figure 1 illustrates the preparation stages, showing the peel before and after vacuum-oven drying and grinding. The drying process is critical for removing moisture, which facilitates efficient grinding and extraction of the betalains, as reflected in the appearance change from a hydrated peel to a dry, pulverized form. This pre-processing step is essential in maximizing the surface area for solvent interaction, ultimately leading to higher extraction yields (Ramli et al., 2014).



Figure 1. Preparation stage for extracting red dragon fruit peel: (a) before vacuum-oven, (b) after vacuum-oven, (c) after mashed

2) Label Film Preparation

The method used to prepare chitosan-based colourimetric film in this study was a modification of previous reports (Pramitasari et al., 2022; Barleany et al., 2024). Chitosan (3.4 g) was dissolved in 80 ml of 10% acetic acid solution and stirred magnetically for 12 h at room temperature. Separately, PVA (1.7 g) was dissolved in 40 ml of distilled water at 100°C with constant stirring for 2 h, then cooled to room temperature. The PVA solution was mixed with the chitosan solution at a ratio of 3:1 (v/v). The red dragon fruit peel extract was then added in varying amounts to the chitosan/PVA mixture. The resulting mixture was poured into molds, cast into thin layers, and dried at room temperature for 5 d. The chitosan/PVA film label was then stored in glass jars with silica gel. Figure 2 shows the visual appearance of chitosan solution, PVA solution, and a mixture of chitosan and PVA solution during the film solution preparation stage.

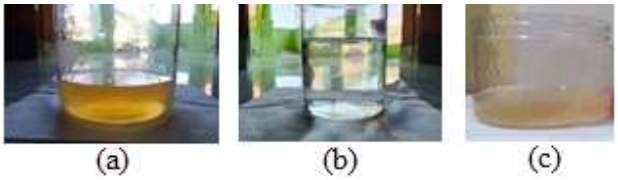


Figure 2. Film label preparation (a) Chitosan solution, (b) PVA solution, (c) chitosan + PVA

3) Film Characterization

Thickness, Tensile Strength, and Elongation

The thickness of the films was measured using a digital micrometer (Mitutoyo No. 293 – 766, Tester Sangyo Co., Ltd., Tokyo, Japan) with an accuracy of 0.001 mm. Measurements were taken at five random points across the film, and the average value was recorded. Tensile strength and elongation at break were determined using a Universal Testing Machine (UTM) following ASTM D882-12 standards. Film samples (100 mm x 10 mm) were clamped and stretched at a crosshead speed of 50 mm/min. Tensile strength (TS) was calculated using equation (1) as follows:

$$TS\ (MPa) = \frac{F}{A} \quad (1)$$

where F is the maximum force applied (N), and A is the cross-sectional area of the film (mm²). Elongation at break (E) was determined by measuring the percentage increase in length before the film ruptured, using equation (2):

$$E(\%) = \frac{L_f - L_i}{L_i} \text{ x } 100 \quad (2)$$

where Lf is the final length at break, and Li is the initial length of the film.

Water Vapor Transmission Rate (WVTR)

The water vapor transmission rate (WVTR) of the films was measured following the ASTM E96 standard method, as adapted by a previous study (Rachtanapun et al., 2021). Circular film samples were sealed over the mouths of aluminum cups with a diameter of 6 cm, each containing silica gel. The cups were placed in an environmental chamber set at 25°C and 50% relative humidity. The weight loss of the cups was monitored every 24 h for 6 d. WVTR was calculated using equation (3):

$$WVTR = \frac{\Delta w}{A \, x \, \Delta t} \quad (3)$$

where ΔW is the weight loss (g), A is the surface area of the film (cm^2), and Δt is the time (d).

Sensitivity Testing of the Film

The sensitivity of the chitosan smart film was tested for ammonia and pH, both of which are important indicators in monitoring fish freshness. The procedure for testing the film response to ammonia was carried out based on the report of previous research (Mohseni-Shahri & Moeinpour, 2023), with modifications. The film sample (2 cm x 1.5 cm) was attached to the headspace of a petri dish containing 15 ml of ammonia solution (2 mol/L). Film colour changes were observed at intervals of 0, 10, 20, 30, 40, 50 and 60 min.

The film's sensitivity to pH was tested during the storage of tilapia fillets. Fillets were placed in two separate closed containers, with one stored at room temperature (30°C) and the other in a refrigerator (4°C). Films with different compositions were attached to the packaging container's headspace, and measurements were taken every 4 h for 16 h. Changes in pH and film colour were recorded, with the pH measured using a pH meter following standard protocols (Kim et al., 2023).

III. RESULTS AND DISCUSSION

A. Yield of The Dried Red Dragon Fruit Peel

The yield efficiency of the extraction process reached 18.39%, indicating a significant presence of bioactive components in the peel (Table 1). This high yield is a result of optimal drying and grinding conditions, which ensure that the cellular structures of the peel are adequately ruptured, allowing for maximum diffusion of betalains into the solvent. The use of a vacuum-oven also minimizes thermal degradation of these heat-sensitive pigments, preserving their bioactivity and colour intensity, which is crucial for subsequent applications in food and packaging (da Silva et al., 2018).

Table 1. Yield of the dried red dragon fruit peel

Raw dragon fruit peel (g)	Dry powder of dragon fruit peel (g)	Yield (%)
500	91.96	18.39

The observed extraction efficiency of betalains from red dragon fruit peel aligns well with other studies utilizing similar techniques, including conventional, ultrasound-assisted (UAE), and microwave-assisted extractions (MAE) (Ramli et al., 2014; Thirugnanasambandham & Sivakumar, 2017; Phan Van et al., 2020). It has been reported that the yield of dragon fruit peel extract using the conventional extraction method is higher than the UAE method (Ramli et al., 2014). The yield efficiency recorded in the extraction of betalains from red dragon fruit peels in this study is comparable to those reported in similar studies particularly (Rodriguez et al., 2016), thereby, emphasize the role of advanced extraction techniques in enhancing pigment stability and yield.

Figure 3 shows the impact of pH alterations on betalain stability, highlighting significant colour changes under acidic and alkaline conditions. The betalain extract, initially vibrant in colour, showed distinct shifts when adjusted with hydrochloric acid (HCl) and sodium hydroxide (NaOH). In acidic conditions (pH<4), the betalains maintained a stable red hue, which is desirable for food and packaging applications as it indicates pigment integrity. Conversely, under alkaline conditions (pH>7), the betalains exhibited colour degradation, shifting toward purple shade, which signifies structural breakdown of the pigments (Meléndez-Pizarro et al., 2020).

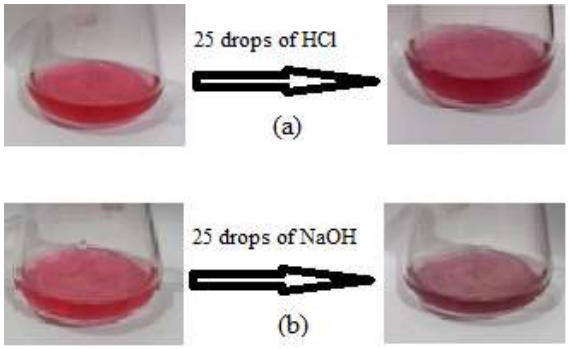


Figure 3. Colour transition of red dragon peel extract with the addition of different solutions: (a) HCl solution, (b) NaOH solution

Maintaining an optimal pH during extraction is crucial for preserving betalain quality. Betalains are most stable within a pH range of 4.0 to 7.0, with peak stability around pH 5.5, where the pigments exhibit maximum colour retention and bioactivity (Li et al., 2019). Deviations from this pH range can lead to protonation or deprotonation of betalain molecules, affecting their structural integrity and leading to a decline in colour intensity. This phenomenon emphasizes the importance of precise pH control during the extraction and processing stages to maintain pigment stability, especially when preparing betalains for sensitive applications like biopolymer films (Popescu et al., 2021).

B. Effect of Red Dragon Fruit Peel Extract on Visual Color of Film Solution

The incorporation of dragon fruit peel extract, as shown in Figure 4, imparted distinct colours and textures to the films, with higher extract concentrations resulting in deeper pigmentation. This variation in concentration significantly affected the physical and functional properties of the films, influencing their mechanical strength, water vapor permeability, and overall appearance.

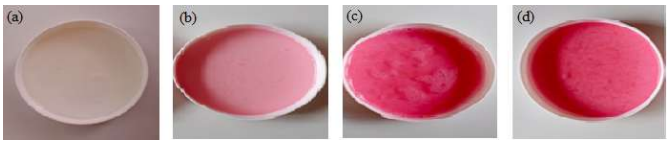


Figure 4. Film solution with various amount of red dragon fruit peel extract (a) 0 g (without extract), (b) 0.2 g, (c) 0.3 g, (d) 0.5 g

Figure 5 depicts the dried films with varying extract concentrations, demonstrating differences in colour intensity that correlate with the amount of extract added. The presence of betalains in the dragon fruit peel extract not only enhanced the visual appeal of the films but also contributed to the modification of their properties.

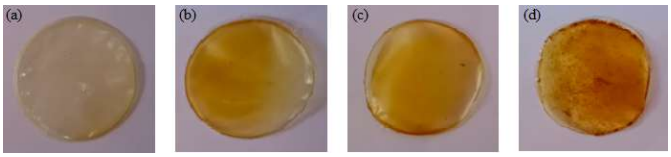


Figure 5. Dry label film with variations of red dragon fruit peel extract (a) 0 g (without extract), (b) 0.2 g, (c) 0.3 g, (d) 0.5 g

As indicated in Table 2, the addition of dragon fruit peel extract influenced the thickness, tensile strength, and elongation of the films, with higher concentrations generally leading to thicker films and alterations in mechanical performance. These results underscore the impact of extract concentration on film characteristics, highlighting the importance of optimizing the formulation to achieve the desired mechanical and barrier properties.

Table 2 Film thickness, Tensile Strength (TS), and Elongation (E)

Amount of extract (g)	Thickness (mm)	TS (MPa)	E (%)
0 (without extract)	0.27	6.12	55.39
0.2	0.17	6.40	36.37

The mechanical properties of the films, including tensile strength and elongation, were influenced by the ratios of chitosan and PVA as well as the concentration of dragon fruit peel extract. As shown in Table 2, films with higher concentrations of dragon fruit peel extract showed an increase in tensile strength but a reduction in elongation, suggesting that the extract enhancing strength while slightly compromising flexibility. The tensile strength improves with higher extract concentrations due to the formation of cross-links between the phenolic compounds in the extract and the chitosan matrix, as noted by Kumar et al. (2021). However, the data also indicate a decrease in elongation, which is attributed to the increased rigidity of the film structure. The introduction of solid particles from the extract reduces flexibility, a trade-off seen in Augusto et al. (2018) involving natural extracts.

Water vapor permeability (WVP) and water vapor transmission rate (WVTR) are both key indicators of a film's moisture barrier properties. WVP assesses how easily water vapor can penetrate through the film, while WVTR measures the speed at which the vapor moves through the material. These factors are closely connected, with variations in WVTR directly influencing WVP, thereby impacting the film's overall effectiveness as a moisture barrier (Tang et al., 2011; Nasution et al., 2024). Films with high WVP will accelerate the spoilage process and shorten the shelf life of food products, so this characteristic is not desired in packaging films (Nasution et al., 2024). In addition, the WVP value directly affects the quality and colour expression of the indicator film. A lower WVP value indicates better properties for the indicator film, because a high WVP value can allow water molecules to move more easily through the film, causing it to react with betalains to cause colour shifting without any food quality changes occurring inside (Kanha et al., 2024).

In this current study, the WVP of the films was also affected by the presence of dragon fruit peel extract. Table 3 shows that the WVTR values increase with higher concentrations of dragon fruit peel extract. This trend aligns with findings from the literatures, where the addition of plant extracts introduces hydrophilic components that enhance moisture transmission. For instance, Yan et al. (2013) demonstrated that rosemary extract increased WVP in starch-alginate films due to the introduction of hydrophilic groups, similar to the betalain extract used in this study. Additionally, Roy et al. (2021) found that cellulose nanocrystals in CMC films slightly raised WVP, attributed to the formation of permeate paths and reduced intermolecular interactions effects likely paralleled here by the structural modifications induced by the extract. Hu et al. (2019) also reported that phenolic compounds in *Ginkgo biloba* extract altered the film structure and increased WVP, reinforcing the idea that higher extract concentrations in this study affect the film's moisture barrier properties.

Table 3 Water Vapor Transmission Rate (WVTR) values of different film compositions

No	Sample	Extract (g)	WVTR ($g.cm^{-2}.d^{-1}$)
1	Chitosan + PVA	0 (without extract)	6.02×10^{-7}
2	Chitosan + PVA + Extract	0.2	8.80×10^{-7}
3	Chitosan + PVA + Extract	0.3	1.20×10^{-6}
4	Chitosan + PVA + Extract	0.5	1.48×10^{-6}

Choosing the optimal concentration of red dragon fruit peel extract for incorporation into chitosan-based active films is crucial for balancing mechanical and barrier properties. The addition of plant extracts, such as those derived from red dragon fruit peel, can enhance the tensile strength of the films, but beyond a certain threshold can negatively impact other key properties, such as elongation and moisture barrier performance. Previous similar studies found that higher extract concentrations did not consistently lead to improved film tensile strength, greater elongation, or decreased WVP (Nasution et al., 2024). This suggests the need for a balance

concentration that strengthens the film without compromising its flexibility or moisture barrier properties.

C. Ammonia Sensitivity and Spoilage Detection

Spoilage of beef, fish, and shrimp is usually followed by a change in the environment inside the packaging towards alkaline conditions. This change is caused by the presence of total volatile basic nitrogen compounds (TVB-N) derived from ammonia, dimethylamine, and triethylamine produced by the decomposition of proteins in meat (Sutthasupa et al., 2021). Figure 6 shows the ammonia sensitivity of the chitosan/PVA film, highlighting its effectiveness in detecting spoilage through visual colour changes. The film was tested under conditions simulating the spoilage of fish fillets, with ammonia released as a by-product of protein degradation. The indicator label sensitivity test to ammonia were conducted over a 60-minute contact period, with measurements taken every ten minutes. After 10 minutes, the colour of the indicator label (inside the container) showed a slight but insignificant change, and this change could be visually compared with the adjacent label, which was not exposed to ammonia. This observation is in line with the finding by Li et al. (2023), that the colour change in the indicator label was caused by gaseous alkaline chemicals released as a result of the meat foods deterioration.

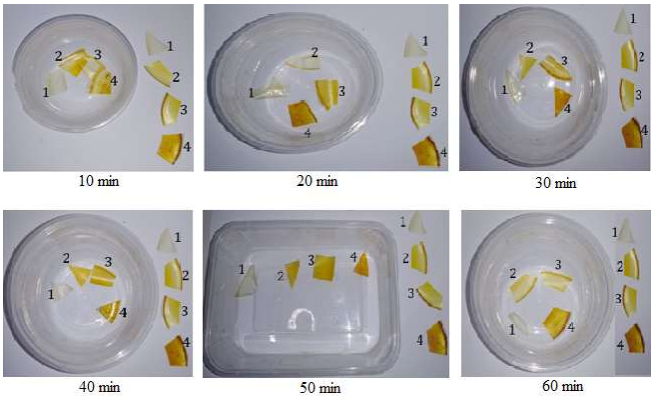


Figure 6. Analysis of film sensitivity to ammonia with various amount of extract: (1) 0 g (without extract), (2) 0.2 g, (3) 0.3 g, (4) 0.5 g

Figure 7 illustrates the distinct colour transitions observed in films with various concentrations of dragon fruit peel extract during storage of tilapia at different temperatures. Figure 7 (a) and (f) are the initial conditions of observation, where the fish are still fresh, then observations at room temperature are shown in Figure 7 (b) to (e) and the chiller temperature is shown in Figure 7 (g) to (j). Each at room temperature and chiller temperature, the indicator labels were analyzed every 4 h for 16 h. The film without the extract remained relatively unchanged, showing minimal response to ammonia. In contrast, films with 0.2 g, 0.3 g, and 0.5 g of extract displayed pronounced colour changes, transitioning from pink to green as the ammonia concentration increased. This response is attributed to the pH-sensitive properties of betalains in the dragon fruit peel extract, which alter their colour in response to ammonia exposure, effectively signaling the onset of spoilage (Calva-Estrada et al., 2022).

The effectiveness of the films in detecting spoilage is closely linked to the concentration of the dragon fruit peel extract. Films with higher extract concentrations (0.3 g and 0.5 g) exhibited faster and more distinct colour changes compared to those with lower concentrations, demonstrating greater sensitivity to ammonia. This indicates that increasing the amount of betalain-rich extract enhances the film's ability to detect spoilage early. The strong correlation between film colour change and the onset of spoilage confirms the utility of these films as practical tools for real-time monitoring of food freshness, particularly in fish fillets, where ammonia production is a critical spoilage marker (de Oliveira Filho et al., 2022; Li et al., 2023).

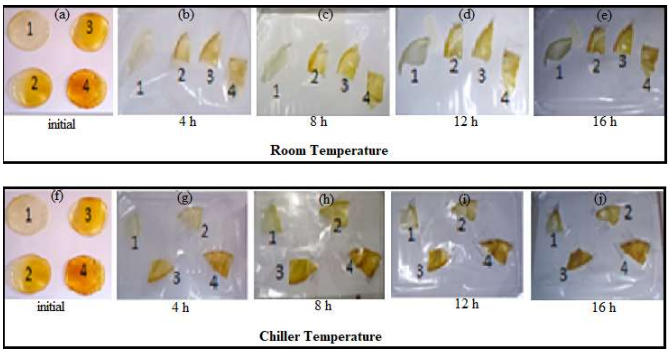


Figure 7. Colour Change of Film During Fish Storage

The addition of dragon fruit peel extract significantly enhances the sensitivity of the chitosan/PVA films to ammonia, as evidenced by the results depicted in Figure 7. Films without the extract exhibited limited responsiveness, highlighting the critical role of natural pigments like betalains in improving ammonia detection. Betalains, particularly betacyanins, undergo structural changes when exposed to varying pH levels, which occur during food spoilage due to ammonia release. This pH-induced structural shift triggers the observed colour change, providing a clear, visible indication of spoilage 14. In comparison, synthetic ammonia indicators, although highly sensitive, often involve environmentally unfriendly materials and lack the appeal of natural, biodegradable solutions (Chia et al., 2022).

Films with 0.3 g of dragon fruit peel extract demonstrated the best balance of sensitivity and stability, showing a rapid and distinct colour change without being overly affected by external factors like light or temperature. The inclusion of betalains also aligns with consumer preferences for non-toxic, natural indicators that do not pose health risks (de Oliveira Filho et al., 2022). Moreover, the dragon fruit peel extract not only provides sensitivity to ammonia but also enhances the visual appeal of the films, making them attractive for consumer use in food packaging applications where both aesthetics and functionality are critical (Kanha et al., 2022). The use of these films can significantly reduce food waste by providing immediate feedback on the freshness of the product, thereby improving food safety and extending shelf life.

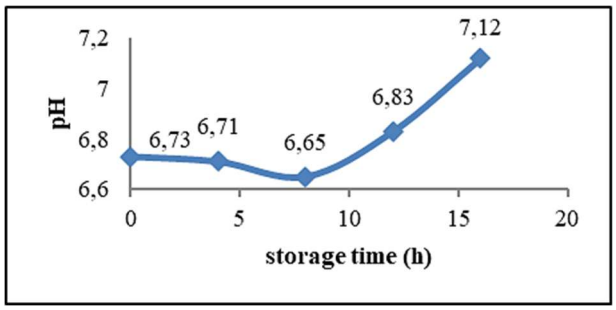
The findings from the ammonia sensitivity tests highlight the potential of chitosan/PVA films with dragon fruit peel extract as a practical solution for intelligent food packaging. The distinct colour changes observed upon ammonia exposure

provide an immediate, visual indication of spoilage, making these films particularly valuable in the packaging of perishable items such as fish fillets. The strong correlation between film response and spoilage onset allows consumers and food handlers to make informed decisions about the freshness and safety of their food, reducing the risk of consuming spoiled products (Calva-Estrada et al., 2022).

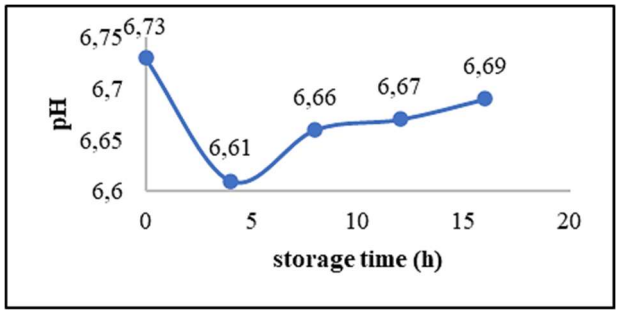
The incorporation of natural pigments like betalains into the film matrix not only enhances their functional properties but also supports sustainable packaging practices by utilizing biodegradable materials. This approach aligns with the growing demand for eco-friendly packaging solutions that contribute to reducing plastic waste and environmental impact (Guo et al., 2024). Additionally, the films offer a safer alternative to synthetic indicators, addressing consumer concerns about the potential health risks associated with synthetic chemicals used in traditional packaging.

D. pH and Organoleptic Analysis of Tilapia Fillets

Figure 8 (a) and 8 (b) illustrate the pH changes of tilapia fillets stored at room and chiller temperatures, respectively, demonstrating how storage conditions affect the freshness of fish. At room temperature, the pH of the fillets increased significantly, rising from an initial value of approximately 6.4 to over 7.0 within 16 h, indicating rapid spoilage due to accelerated microbial activity. In contrast, fillets stored at chiller temperature exhibited a slower pH increase, maintaining values below 7.0 over the same period. This slower pH rise suggests that cooler temperatures effectively delay spoilage, thereby extending the shelf life of the fish (Dulal et al., 2023).



(a)



(b)

Figure 8. Changes in pH Value of Tilapia Fish Fillets at (a) Room Temperature Storage, (b) Chiller Temperature Storage

The visual appearance of tilapia fillets, as shown in Figure 9, further supports the pH findings. Fillets stored at room temperature rapidly developed a dull, discoloured surface with evident signs of spoilage, such as slime formation and discolouration. In contrast, fillets kept at chiller temperature maintained a relatively fresh appearance for a longer time, with fewer visible spoilage signs. Figure 10, which displays organoleptic scores (sensory attributes such as appearance, smell, and texture), reveals a clear decline in sensory attributes over time at both storage conditions. At room temperature, fillets quickly lost their fresh smell, firm texture, and vibrant colour, scoring poorly on sensory evaluations after just 16 h. Meanwhile, the fillets stored in the chiller maintained acceptable sensory qualities for a longer period, aligning with the slower pH increase observed under these conditions.

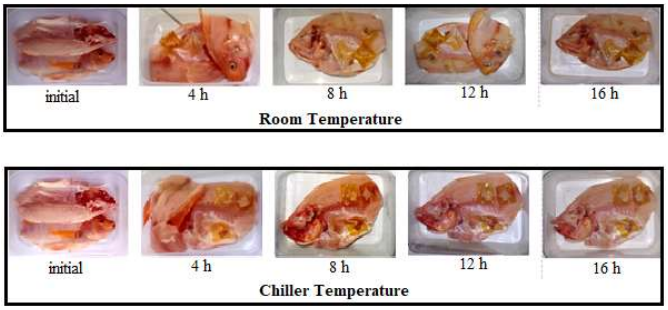


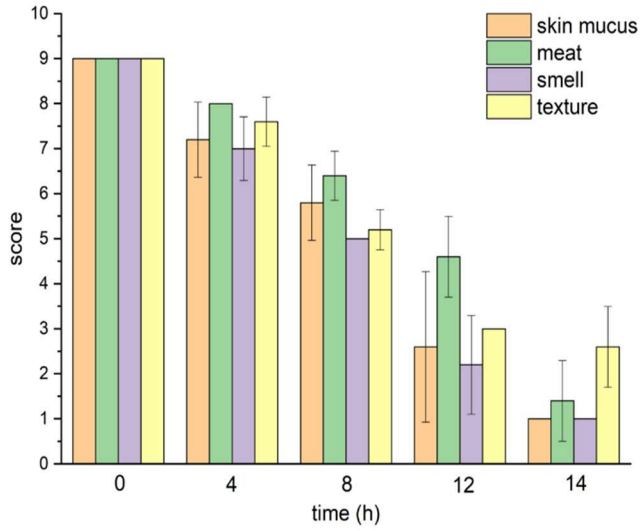
Figure 9. Appearance of Tilapia Fish Fillets After Storage Under Different Conditions

The observed pH changes in tilapia fillets are consistent with the biochemical processes associated with fish spoilage, where microbial metabolism and enzymatic degradation of proteins produce alkaline byproducts, such as ammonia and trimethylamine. These volatile compounds elevate the pH, serving as indicators of advanced spoilage stages (Kuswandi et al., 2022; Dulal et al., 2023). The rapid pH increase in room temperature-stored fillets highlights the accelerated spoilage rate under warmer conditions, emphasizing the importance of low-temperature storage to inhibit microbial growth and delay fish deterioration (Junianto et al., 2020).

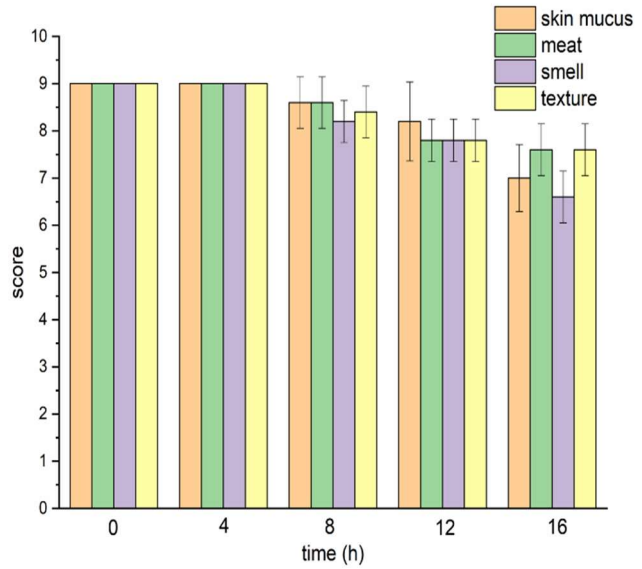
Sensory evaluations provide complementary insights into the quality changes occurring during storage. Fresh fish is characterized by a mild aroma, firm texture, and bright appearance, all of which degrade as spoilage progresses. The strong correlation between pH levels and sensory scores underscores the utility of these measurements in assessing fish freshness. At room temperature, the sensory scores for smell, appearance, and texture dropped sharply, reflecting the rapid spoilage observed visually and through pH changes. Conversely, fish stored at refrigeration temperature experienced a slower decline in organoleptic quality, maintaining higher scores for a longer period. This difference highlights the practical benefits of refrigeration in preserving the sensory qualities of fish fillets and prolonging their marketability.

The alignment of pH changes with sensory evaluations supports the use of pH as a reliable, objective measure of fish freshness. While sensory evaluations provide valuable, immediate feedback on product quality, pH measurements

offer a quantifiable metric that can be used alongside sensory assessments to confirm spoilage stages. This dual approach enhances the accuracy of freshness evaluations, providing a comprehensive assessment of fish quality that can be easily implemented in both commercial and domestic settings (Wu et al., 2022).



(a)



(b)

Figure 10. Results of The Organoleptic Test on Tilapia Fillet (a) Room Temperature Storage, (b) Chiller Temperature Storage

The findings from the pH and organoleptic analyses underscore the importance of temperature control in maintaining fish quality during storage. Refrigeration slows the biochemical processes that lead to spoilage, as evidenced by the slower pH increase and higher sensory scores of fillets stored under cold conditions. This reinforces the need for proper cold chain management from harvesting to consumer purchase to preserve the sensory and nutritional qualities of fish fillets (Dulal et al., 2023).

The practical applications of these findings are significant for the seafood industry, where maintaining fish freshness is crucial for consumer safety and satisfaction. By regularly monitoring pH and conducting sensory evaluations, producers and retailers can make informed decisions about the shelf life and marketability of their products. Additionally, the integration of pH-sensitive indicators, such as films that change colour in response to pH alterations, could provide a simple, cost-effective tool for real-time monitoring of fish quality, enhancing food safety protocols and reducing the risk of selling spoiled products (Zhai et al., 2017; Shi et al., 2021).

IV. CONCLUSION

The study successfully developed a biodegradable chitosan/PVA film incorporating red dragon fruit peel extract, demonstrating its potential as a smart packaging solution for monitoring fish freshness. The film responded to changes in pH and ammonia levels, indicating spoilage through colour change, aligning with the rise in pH during fish decay. Mechanical tests showed adequate tensile strength, elongation, and water vapor permeability, making the film suitable for packaging applications. Incorporating red dragon fruit peel extract into the chitosan/PVA film resulted in an increase in tensile strength, a reduction in elongation, and an elevation in WVTR. The use of 0.2 g of red dragon fruit peel extract was the best composition obtained in this study, with tensile strength, elongation, and WVTR values of 6.4 MPa, 36.37%, and 8.80 x 10^{-7} g.cm^{-2}.d^{-1}, respectively. This innovative approach highlights the potential of natural extracts in enhancing food safety and sustainability, addressing the need for eco-friendly spoilage indicators in smart packaging systems. In future research, other extraction methods need to be applied to obtain red dragon fruit peel extract with higher betalain content such as ultrasound-assisted (UAE) and microwave-assisted extractions (MAE), so that the color changes of the film at various pH conditions can be more clearly seen by the naked eye.

AUTHOR CONTRIBUTIONS

D. R. Barleany: Conceptualization, Methodology, Writing – original draft. **M. Yulvianti**: Writing-review & editing, Project administration. **R. P. Efendy**: Data curation, Supervision. **R. Y. Fajar**: Resources, Formal Analysis**. A. Gunawan**: Visualization, Software. **W. E. Kosimaningrum**: Investigation, Formal, Validation.

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REFERENCES

Abedi-Firoozjah, R., Azimi-Salim, S., Afrah, A., Moradiyan, M. H., Assadpour, E., Sarlak, Z., Azizi-Lalabadi, M., Dehnad, D., & S. M. Jafari (2025). Comparison of the pH- and NH3-sensitivity of chitosan/polyvinyl alcohol smart films containing anthocyanins or betacyanins for monitoring fish freshness. Carbohydrate Polymer Technologies and Applications, 9, 100639.

Akhila, K., Ramakanth, D., Lakshman Rao, L., Singh, S., & K. K. Gaikwad (2024). Plant phytochemicals as bio-responsive compounds in smart packaging for food spoilage detection: a comprehensive review. Sustainable Food Technology, 2(4), 860-875.

Augusto, A., Dias, J. R., Campos, M. J., Alves, N. M., Pedrosa, R., & S. F. J. Silva (2018). Influence of Codium tomentosum extract in the properties of alginate and chitosan edible films. Foods, 7(4), 53.

Barleany, D. R., Sari, D. K., Lestari, R. S., Raharja, Y., & A. Gunawan (2024). Biopolymer-Based Film Preparation for Potential Smart Food Packaging Material Application. International Journal of Innovation in Mechanical Engineering and Advanced Materials, 5(3), 109-117.

Calva-Estrada, S. J., Jiménez-Fernández, M., & E. Lugo-Cervantes (2022). Betalains and their applications in food: The current state of processing, stability and future opportunities in the industry. Food Chemistry: Molecular Sciences, 4, 100089.

Chen, S., Brahma, S., Mackay, J., Cao, C., & B. Aliakbarian (2020). The role of smart packaging system in food supply chain. Journal of Food Science, 85(3), 517-525.

Chia, M. R., Ahmad, I., & S. W. Phang (2022). Starch/Polyaniline Biopolymer Film as Potential Intelligent Food Packaging with Colourimetric Ammonia Sensor. Polymers, 14(6), 1122.

de Oliveira Filho, J. G., Bertolo, M. R. V., Rodrigues, M. Á. V., Silva, G. da C., de Mendonça, G. M. N., Bogusz Junior, S., Ferreira, M. D., & M. B. Egea (2022). Recent advances in the development of smart, active, and bioactive biodegradable biopolymer-based films containing betalains. Food Chemistry, 390, 133149.

Du, H., Said, N. S., & W.-Y. Lee (2024). Development of pH-Sensitive intelligent films incorporating betacyanin from dragon fruit peel and TiO2 nanoparticles for monitoring fish fillet freshness. Sustainable Chemistry and Pharmacy, 42, 101839.

Dulal, M. A., Jahan, I., Rasul, M. G., Islam, M. R., Khan, M., & A. K. M. A. Shah (2023). Antioxidant and antimicrobial potential of water lily extracts and their effects on the quality of frozen Nile tilapia (Oreochromis niloticus) fillets. Food Science and Nutrition, 11(1). 535-544.

Fadhallah, E. G., Rinjani, S. E. R., Anantasya, A. K. S., Pranata, A., Triharto, R., & A. H. Dameswary (2023). Potency of betacyanin from beetroot (Beta vulgaris) peel waste as chicken meat freshness indicator in sago starch-based biodegradable smart packaging. MOJ Ecology & Environmental Sciences, 8(5), 186-190.

Guo, C., Li, Y., Zhang, H., Zhang, Q., Wu, X., Wang, Y., Sun, F., Shi, S., & X. Xia (2024). A review on improving the sensitivity and color stability of naturally sourced pH-sensitive indicator films. Comprehensive Reviews in Food Science and Food Safety, 23(4), e13390.

Haghighi, H., Licciardello, F., Fava, P., Siesler, H. W., & A. Pulvirenti (2020). Recent advances on chitosan-based films for sustainable food packaging applications. Food Packaging and Shelf Life, 26, 100551.

Hu, H., Yao, X., Qin, Y., Yong, H., & J. Liu (2020). Development of multifunctional food packaging by incorporating betalains from vegetable amaranth (Amaranthus tricolor L.) into quaternary ammonium chitosan/fish gelatin blend films. International Journal of Biological Macromolecules, 159, 675-684.

Hu, X., Yuan, L., Han, L., Li, S., & L. Song (2019). Characterization of antioxidant and antibacterial gelatin films incorporated with: Ginkgo biloba extract. RSC Advances, 9(47), 27449-27454.

Junianto, Shofiani, S., Rostini, I., & E. Afrianto (2020). The Effect of Concentrations of Basil Leaves Extract as Natural Preservatives in Mullet Fillet. Asian Journal of Fisheries and Aquatic Research, 9(3), 41–51.

Kanha, N., Jaimun, R., Rattanamato, B., & T. Laokuldilok (2024). Novel indicator film incorporating Dendrobium orchid extract and TiO_2 nanoparticles for seafood freshness monitoring. Future Foods, 10, 100512.

Kanha, N., Osiriphun, S., Rakariyatham, K., Klangpetch, W., & T. Laokuldilok (2022). On-package indicator films based on natural pigments and polysaccharides for monitoring food quality: a review. Journal of the Science of Food and Agriculture 102(15), 6804-6823.

Kim, D., Park, S. W., & H. Shin (2023). Fish Freshness Indicator for Sensing Fish Quality During Storage. Foods, 12(9), 1801.

Kumar, N., Pratibha, Trajkovska Petkoska, A., Khojah, E., Sami, R., & A. A. M. Al-Mushhin (2021). Chitosan edible films enhanced with pomegranate peel extract: Study on physical, biological, thermal, and barrier properties. Materials, 14(12), 3305. https://doi.org/10.3390/ma14123305

Kusumasari, S., Syabana, M. A., Pamela, V. Y., & B. Meindrawan (2024). Potential use of food waste in food processing to add nutritional value. E3S Web of Conferences, 483, 02006

Kuswandi, B., Hasanah, F., Pratoko, D. K., & N. Kristiningrum (2022). Colorimetric Paper-Based Dual Indicator Label for Real-Time Monitoring of Fish Freshness. Food Technology and Biotechnology, 60(4), 499-508.

Li, G., Meng, X., Zhu, M., & Z. Li (2019). Research progress of betalain in response to adverse stresses and evolutionary relationship compared with anthocyanin. Molecules, 24(17), 3078.

Li, S., Wu, J., Tang, Q., He, D., Li, H., Peng, D., & Z. Zou (2023). Construction of novel ammonia-sensitive polyvinyl alcohol-based films containing nano Co-ATMP for smart packaging application. LWT, 186, 115222.

Meléndez-Pizarro, C. O., Calva-Quintana, A., Espinoza-Hicks, J. C., Sánchez-Madrigal, M., & A. Quintero-Ramos (2020). Continuous flow UV-C irradiation

effects on the physicochemical properties of aloe vera gel and pitaya (stenocereus spp.) blend. Foods, 9(8), 1068.

Mohebi, E., & L. Marquez (2015). Intelligent packaging in meat industry: An overview of existing solutions. Journal of Food Science and Technology, 52(7), 3947-64.

Mohseni-Shahri, F. S., & F. Moeinpour (2023). Development of a pH-sensing indicator for shrimp freshness monitoring: Curcumin and anthocyanin-loaded gelatin films. Food Science and Nutrition, 11(7), 3898–3910.

N, S. K., Dar, A. H., Srivastava, S., Dash, K. K., & V. K. Pandey (2024). Carotenoids based smart packaging: A comprehensive review. Measurement: Food, 15, 100190.

Namazzadeh, G., Ehsani, A., & Z. Ghasempour (2022). Microencapsulation of red beet extract using chitosan-Persian gum complex coacervates. Journal of Food Processing and Preservation, 46(12).

Nasution, H., Harahap, H., Iriany, Yustira, A., Julianti, E., & M. Jaafar (2024). Innovative edible food wraps from tilapia fish bone gelatin and passion fruit peel extract. Case Studies in Chemical and Environmental Engineering, 10, 100990.

Pal, K., Bharti, D., Sarkar, P., Anis, A., Kim, D., Chałas, R., Maksymiuk, P., Stachurski, P., & M. Jarzębski (2021). Selected applications of chitosan composites. International Journal of Molecular Sciences, 22(20), 10968.

Phan Van, M., Tran Duc, D., Thi Thanh, H. D., & H. T. Chi (2020). Comparison of ultrasound assisted extraction and enzyme assisted extraction of betacyanin from red dragon fruit peel. E3S Web of Conferences, 187, 04004.

Popescu, V., Blaga, A. C., Pruneanu, M., Cristian, I. N., Pîslaru, M., Popescu, A., Rotaru, V., Crețescu, I., & D. Cașcaval (2021). Green chemistry in the extraction of natural dyes from colored food waste, for dyeing protein textile materials. Polymers, 13(22), 3867.

Pramitasari, R., Gunawicahya, L. N., & D. S. B. Anugrah (2022). Development of an Indicator Film Based on Cassava Starch–Chitosan Incorporated with Red Dragon Fruit Peel Anthocyanin Extract. Polymers, 14(19), 4142.

Qin, Y., Liu, Y., Zhang, X., & J. Liu (2020). Development of active and intelligent packaging by incorporating betalains from red pitaya (Hylocereus polyrhizus) peel into starch/polyvinyl alcohol films. Food Hydrocolloids, 100, 105410.

Rachtanapun, P., Klunklin, W., Jantrawut, P., Jantanasakulwong, K., Phimolsiripol, Y., Seesuriyachan, P., Leksawasdi, N., Chaiyaso, T., Ruksiriwanich, W., Phongthai, S., Sommano, S. R., Punyodom, W., Reungsang, A., & T. M. P. Ngo (2021). Characterization of chitosan film incorporated with curcumin extract. Polymers, 13(6), 963.

Ramli, N. S., Ismail, P., & A. Rahmat (2014). Influence of conventional and ultrasonic-assisted extraction on phenolic contents, betacyanin contents, and antioxidant capacity of red dragon fruit (Hylocereus polyrhizus). Scientific World Journal, 2014, 964731.

da Silva, H. R. P., da Silva, C., & B. C. Bolanho (2018). Ultrasonic-assisted extraction of betalains from red beet (Beta vulgaris L.). Journal of Food Process Engineering, 41(6), e14762.

Rodriguez, E. B., Vidallon, M. L. P., Mendoza, D. J. R., & C. T. Reyes (2016). Health-promoting bioactivities of betalains from red dragon fruit (Hylocereus polyrhizus (Weber) Britton and Rose) peels as affected by carbohydrate encapsulation. Journal of the Science of Food and Agriculture, 96(14), 4679-4689.

Roy, S., Kim, H. J., & J. W. Rhim (2021). Synthesis of Carboxymethyl Cellulose and Agar-Based Multifunctional Films Reinforced with Cellulose Nanocrystals and Shikonin. ACS Applied Polymer Materials, 3(2), 1060–1069.

Roy, S., & J. W. Rhim (2021). Preparation of Gelatin/Carrageenan-Based Color-Indicator Film Integrated with Shikonin and Propolis for Smart Food Packaging Applications. ACS Applied Bio Materials, 4(1), 770-779.

Shi, C., Zhang, J., Jia, Z., Yang, X., & Z. Zhou (2021). Intelligent pH indicator films containing anthocyanins extracted from blueberry peel for monitoring tilapia fillet freshness. Journal of the Science of Food and Agriculture, 101(5), 1800-1811.

Surendhiran, D., Roy, V. C., Ho, T. C., Park, J. S., Lee, S. C., & B. S. Chun (2023). Smart packaging film prepared from subcritical water-modified oat starch and betalain of beetroot extract reinforced with cellulose nanofibrils. Sustainable Chemistry and Pharmacy, 36, 101349.

Sutthasupa, S., Padungkit, C., & S. Suriyong (2021). Colorimetric ammonia (NH_3) sensor based on an alginate-methylcellulose blend hydrogel and the potential opportunity for the development of a minced pork spoilage indicator. Food Chemistry, 362, 130151.

Tang, C. H., Xiao, M. L., Chen, Z., & X. Q. Yang (2011). Influence of succinylation on the properties of cast films from red bean protein isolate at various plasticizer levels. Journal of Applied Polymer Science, 120(4), 1934-1941.

Thirugnanasambandham, K., & V. Sivakumar (2017). Microwave assisted extraction process of betalain from dragon fruit and its antioxidant activities. Journal of the Saudi Society of Agricultural Sciences, 16(1), 41-48.

Vasuki, M. T., Kadirvel, V., & G. Pejavara Narayana (2023). Smart packaging-An overview of concepts and applications in various food industries. Food Bioengineering, 2(1), 25-41.

Wu, H., Jiao, C., Li, S., Li, Q., Zhang, Z., Zhou, M., & X. Yuan (2022). A Facile Strategy for Development of pH-Sensing Indicator Films Based on Red Cabbage Puree and Polyvinyl Alcohol for Monitoring Fish Freshness. Foods, 11(21), 3371

Wu, Y., Tang, P., Quan, S., Zhang, H., Wang, K., & J. Liu (2021). Preparation, characterization and application of smart packaging films based on locust bean gum/polyvinyl alcohol blend and betacyanins from cockscomb (Celosia cristata L.) flower. International Journal of Biological Macromolecules, 191, 679-688.

Yan, Q., Zhang, J., Dong, H., Hou, H., & P. Guo (2013). Properties and antimicrobial activities of starch-sodium alginate composite films incorporated with sodium dehydroacetate or rosemary extract. Journal of Applied Polymer Science, 127(3), 1951-1958.

Yao, X., Hu, H., Qin, Y., & J. Liu (2020). Development of antioxidant, antimicrobial and ammonia-sensitive films

based on quaternary ammonium chitosan, polyvinyl alcohol and betalains-rich cactus pears (Opuntia ficus-indica) extract. Food Hydrocolloids, 106, 105896.

Yao, X., Liu, J., Hu, H., Yun, D., & J. Liu (2022). Development and comparison of different polysaccharide/PVA-based active/intelligent packaging films containing red pitaya betacyanins. Food Hydrocolloids, 124(B), 107305.

Young, E., Mirosa, M., & P. Bremer (2020). A systematic review of consumer perceptions of smart packaging technologies for food. Frontiers in Sustainable Food Systems, 4, 63.

Zhai, X., Shi, J., Zou, X., Wang, S., Jiang, C., Zhang, J., Huang, X., Zhang, W., & M. Holmes (2017). Novel colorimetric films based on starch/polyvinyl alcohol incorporated with roselle anthocyanins for fish freshness monitoring. Food Hydrocolloids, 69, 308-317. h