Jurnal Perikanan
Fisheries Journal, 15 (1), 256-268 (2025)
http://doi.org/10.29303/jp.v15i1.1342

FISHERIES PRODUCT SPOILED MONITORING USING SMART PACKAGING CONTAIN ANTHOCYANIN: A REVIEW

Pemantauan kerusakan produk perikanan menggunakan kemasan pintar mengandung antosianin: Sebuah *review*

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(Received December 31th 2024; Accepted January 20th 2025)

ABSTRACT

Smart packaging is currently demanded to monitor the spoilage level of packaged products, for instance fishery products, characterized as perishable food. Smart packaging requires a halochromic substance, for instance, natural pigments extracted from fruits or flower. The natural pigment extracted from the plant should have a halochromic ability for example anthocyanins compound. Anthocyanin compounds are incorporated to edible film to produce smart film. The smart film has the ability to screen the quality and to monitor freshness of fishery products by demonstrating color changes from purple or blue to green and then yellow color after being exposed to spoiled conditions. The color changes are induced by changes of pH and TVB-N production in deteriorated of packaged fishery products. Moreover, smart packaging is able to provide real-time information to consumers regarding product freshness, thus enhancing the safety and maintaining the quality of food products. In addition, the advantages of a smart packaging system include simple and inexpensive production, providing "best before" information, and potentially reducing unnecessary food waste.

Keywords: Agriculture innovation, Anthocyanin, Fisheries Products, Smart Packaging, Plastic debris.

ABSTRAK

Pengemasan cerdas saat ini dituntut untuk memantau kesegaran produk yang dikemas seperti produk perikanan yang bercirikan sebagai pangan yang mudah rusak. Kemasan cerdas memerlukan zat halokromik, misalnya pigmen alami yang diekstraksi dari buah atau bunga. Pigmen alami yang diekstrak dari tumbuhan harus mempunyai kemampuan halokromik misalnya senyawa antosianin. Senyawa antosianin ditambahkan ke dalam film yang dapat dimakan (*edible film*) untuk menghasilkan film pintar (*smart film*). Smart film ini mempunyai kemampuan untuk memantau kualitas dan kesegaran produk perikanan dengan menunjukkan perubahan warna dari ungu atau biru menjadi hijau dan kemudian menjadi kuning setelah terkena kondisi pangan yg rusak. Perubahan warna tersebut disebabkan oleh perubahan pH dan produksi TVB-N pada produk perikanan kemasan yang telah rusak. Selain itu, *smart packaging* mampu memberikan informasi real-time kepada konsumen mengenai kesegaran produk, sehingga meningkatkan keamanan dan kualitas produk pangan. Selain itu, keunggulan sistem pengemasan cerdas antara lain produksi yang sederhana dan murah, memberikan informasi "baik sebelum", dan berpotensi mengurangi limbah makanan yang tidak diperlukan.

Kata Kunci: Inovasi Pertanian, Antosianin, Produk Hasil Perikanan, *Smart Packaging*, Sampah Plastik.

INTRODUCTION

Fishery products such as fresh fish is perishable due to unfavorable environmental conditions. An analysis using the Kjeldahl method is required to determine the condition of the fish. The Kjeldahl method is used to analyze the Total Volatile Base Nitrogen (TVB-N) to indicate fish spoilage (Chen *et al*., 2020), but the method cannot be applied easily and show in the real time. The awareness of food quality and safety, encouraged researchers to develop packaging that could present the quality status of a packaged product. Moreover, the quality of a product not only be showed from the materials source, but could also from the form and type of packaging technology that minimized or prevented product damage. One of the packaging innovations that continues to be developed today is smart packaging, whose role differs greatly from conventional packaging. Therefore, a solution to easier for consumers determine the level of freshness of a fishery product is smart packaging

Conventional packaging only acts as a passive barrier to protect food from environmental impacts. In contrast, smart packaging not only interacts passively but also evolves with active protection aimed at increasing the durability of food during the distribution process. The smart packaging was actively exposed to its environment to maintain the quality and safety of food. Nevertheless, smart packaging focuses on monitoring and providing information about the condition of the food (Drago *et al*., 2020). One of the natural ingredients that can be used in smart packaging is anthocyanin. Anthocyanin has ability as antioxidant and antimicrobial showed sensitivity to pH change, thus could be applied as active and intelligent packaging to extend the shelf-life and monitoring the spoiled status during storage.

Anthocyanin is a type of natural water-soluble pigment that demonstrated different chemical form depending on the pH condition. Anthocyanin is suggested as an excellent choice for pH-sensitive indicators due to significant color and different structures changes (Bao *et al*., 2022). Anthocyanins derived from fruits and flowers have been shown to affect intelligent packaging products. The previous studies suggested that anthocyanins extracted from various plan or fruits sources could be used as a pH-sensitive natural colorant in food freshness monitoring, for example grape skin (Abdillah *et al*., 2022) (Kafashan *et al*., 2023), red poppy (Tavassoli *et al*., 2024), red cabbage (Nadi *et al*., 2023) (Zhan *et al*., 2024), barberry and saffron (Khezerlou, Alizadeh Sani, *et al*., 2023), dried hibiscus (*Hibiscus sabdariffa*) (Khezerlou, Tavassoli, *et al*., 2023), red beetroot (Ranjbar *et al*., 2023), pistachio peel (Taheri-Yeganeh *et al*., 2024), and *Clitoria ternatea* flower (Kim *et al*., 2022). Therefore, the review aims to summarize several previous studies focused to anthocyanins as colorant in smart packaging, applied as spoiled monitoring in packaged fisheries products.

METHOD

The research method for literature review is the systematic literature review method. Systematic Literature Review (SLR) method, aims to identify, examine, and interpret previous research (Triandini *et al*., 2019). The use of the SLR method could avoid subjective identification of a study. The references were collected from July to December 2025 by focused to selected the research and review articles published between 2019 to 2024 in the reputed international journal. The keywords for example: smart films, smart packaging, and anthocyanin source were used to screen the article from the database.

RESULTS

Anthocyanin

Anthocyanin names from Greek, namely "Anthos" which means flower and "Kyanos" which means dark blue. Based on many studies, anthocyanin is not only found in flowers, but also in fruit skin, fruit flesh, tubers, seeds, leaves and so on. There are 275 types of anthocyanins and 18 aglycones found in nature. The six aglycones that are important in the food sector include pelargonidin, cyanidin, delphinidin, peonidin, petunidin, and malvidin (Lestario, 2018).

Anthocyanins are found in various chemical structures and several colors depending on the different pH values. In general, anthocyanins displayed red color in acidic environment, pink color in neutral pH, and blue color in alkaline environment (Zhao *et al*., 2022). Accordingly, if the color of the anthocyanin extract tends to be blue, it contains many hydroxyl groups, while if the color tends to be red, there are many methoxy groups (Lestario., 2018). The color change ability of anthocyanins is most widely incorporated in the production of smart films to monitor food freshness related on different pH environment. In addition, anthocyanins improve the mechanical properties and show the thermal stability of smart films due to good intermolecular cross-links, for instance, hydrogen bond interaction (Zhang *et al*., 2020). The anthocyanin structure are showed in **Figure 1**.

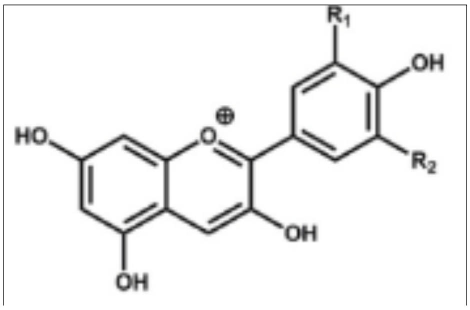


Figure 1. Basic structure of anthocyanin (Neves *et al*., 2022)

Anthocyanins reported good as antibacterial, antioxidant, and presented excellence water-solubility. Based on the pH sensitivities, anthocyanin structures are grouped into six common forms on the benzene ring such as pelargonidin, cyanidin, peonidin, delphinidin, petunidin, and malvidin. Anthocyanins in strongly acidic conditions form the flavylium that presented a reddish color and demonstrated relatively high stability. When the pH increases, flavylium form changes into quinoidal bases with a light blue color and shows lower stability. In alkaline conditions, quinoidal bases are shifted to chalcones with a yellow color appearance (Zheng *et al*., 2022). The various color changes of anthocyanin in different pH conditions are shown in **Figure 2**.

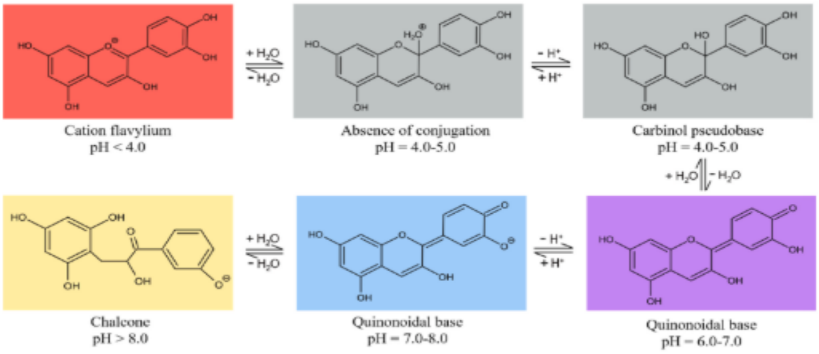


Figure 2. Chemical structure of anthocyanins at different pH (Zhao *et al*., 2022)

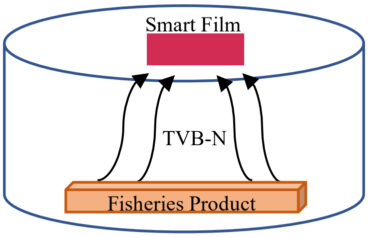


Figure 3. Smart packaging

Smart Packaging

Smart packaging, a packaging technology, function to show the shelf life of the product during storage. Smart packaging also implements a communication system and improves product identification and tracking the expiration date of product. Smart packaging could improve food security, ensure food quality, and provide information and a warning of deteriorates by monitoring the condition changes in the internal and external packaging environment (Drago *et al*., 2020). The package is grouped as smart packaging if it contains a smart system in the packaging, formed as a label, printed, or inserted into the food packaging matrix. The smart system functions as an oxygen and carbon dioxide detector, pH change indicator, and time-temperature sensor due to the use of natural dyes (Santos *et al*., 2022). The smart packaging system presents the quality of a product's freshness in real-time through a pH sensor indicator. Detection could be observed from the color formed on the film based on changes in the pH of the product. The smart film innovation presented a low cost, real-time monitoring capabilities, and biodegradability advantages.

In previous studies, smart packaging was developed by incorporating synthetic dyes into the polymer matrix. The incorporation of synthetic dyes causes the release of chemical components that meet food safety issues. Accordingly, synthetic dyes are replaced by natural colorants extracted from fruits or flowers from plants as pH-sensitive color indicators due to food safety and environmental friendliness. Smart packaging could maintain food safety and extend shelf life by incorporating active substances such as antibacterial and antioxidant substances to inhibit microbial growth and nutrient oxidation. In addition, smart packaging provides real-time information of food freshness to consumers related to pH changes (Li *et al*., 2024).

Smart Packaging to Monitoring Freshness

In general, to determine the freshness of a food product, the consumer visually observed the visual change and smell unpleasant aroma. The aroma produced due to the process of food ingredients degradation, for instance protein, which produces volatile base nitrogen such as dimethylamine, trimethylamine, and ammonia. The volatile base nitrogen compounds have correlation with changes in pH values. Nevertheless, the olfactory method in detecting the quality of the freshness of a food product is inefficient to applied if the product is packaged. Therefore, the packaging innovation plays a role to easier for consumers access the quality of a food product in the real time. The concept of an innovative packaging system is needed to maintain the safety and quality of the product until it reaches the consumer (Drago *et al*., 2020).

Moreover, anthocyanin is a natural pigment used as smart packaging dyes that show the color change ability after expose with the pH change environment. Anthocyanin reported as an ideal choice of indicator due to the sensitivities to pH that effected color changes and different structures change (Bao *et al*., 2022). During the shrimp decomposition process, Total Volatile Basic Nitrogen (TVB-N) consisting of Trimethylamine (TMA), Dimethylamine (DMA), and ammonia (NH_3) are released in the closed packaging. Accordingly, increasing the storage period causes the released base compounds to become denser at the environment of the packaging. The TVB-N compounds will expose with the smart film that acts as an indicator for the packaging and the presence of TVB-N compounds cause an increase in hydroxyl ions in the film. Deproteination of the hydroxyl group changes the anthocyanin structure into anionic quinoid bases, shifting the color from light purple to blue (Zhang *et al*., 2020). Smart packaging function as monitoring and informing consumers directly about the condition of packaged products such as freshness or spoiled status. The smart packaging incorporated with natural indicators could detect and/or measure product parameters in packaging such as pH, temperature, and spoiled compound produced after nutrient degradation by bacteria (Neves *et al*., 2022). Smart packaging provided real-time information of the food freshness to consumers regarding with a pH level change as indicator (Li *et al*., 2024).

DISCUSSION

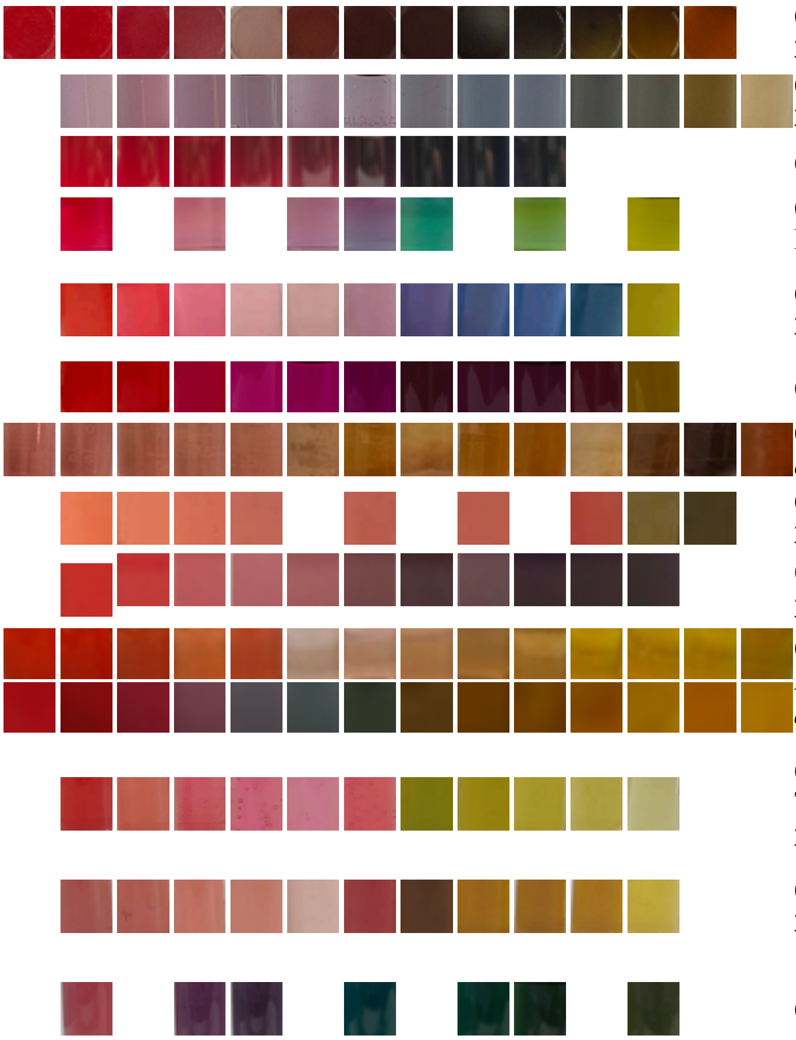
Anthocyanin in nature could be a smart system for fishery product freshness indicators based on pH changes in packaging. In general, the smart film demonstrated various color changes in the pH range between 1 to 14 with high pH response sensitivity (Table 1). In an alkaline environment, the green and yellow colors are presented as dominant colors due to the formation of chalcone structures. Furthermore, the pH value range around 6 to 8 is shown during protein spoilage and degradation in most fishery products (**Table 4**) and could be observed from the color changes on the smart film (**Table 2**).

The color variance presented in the smart film exposed to alkaline conditioning is very obvious because the film is directly exposed to an alkaline environment during the pH response test (**Table 2**), whereas in practical application studies, the film will not directly contact with the fish product in the packaging (**Table 3**). Accordingly, the color appearance observed in alkaline solutions fails to be expected and to be reproduced when evaluating the film in real food packaging applications. The selection of anthocyanin extract source is a concerning issue, as how the anthocyanin could inhibit significant color to facilitate consumers' access to the freshness of fishery products in real-time.

Protein-rich food products, for instance, fisheries products, can generally deteriorate during storage at ambient conditions or a refrigerated temperature that is caused by spoiled bacteria, oxidation of lipids, protein denaturation, and biochemical changes of product. Protein degradation resulted in ammonia and amines compounds accumulating and leading to increased pH levels in a packed environment (Tavassoli *et al*., 2024). The TVB-N is a parameter compound that is produced related to spoilage bacteria and intestinal enzyme activities during spoiled time, while the TVB- N concentration in fresh fish products should not exceed more than 20 mg/100 g (Nadi *et al*., 2023). The pH and TVB-N levels are critical indicators of fish freshness that continuously increase as the storage time. An increase in pH and TVBN values accompanied by color changes in the smart film described in **Table 4**. Moreover, Tavasoli *et al.,* (2024) suggested that the initial pH and TVB-N values were 6.5 and 6.48 mg/100 g. After 72 h of storage at room temperature, the pH increased to 6.5, and TVB-

N values were significantly higher to 58.3 mg/100 g. Similarly, Khezerlou *et al*., (2023) reported that the pH of packed product was higher from 6.8 to 8.4, and the TVB-N concentration was significantly higher from 6.7 to 53.3 mg/100 g in 72 h of storage. The results suggested that the fish product is inappropriate to consume after three days of storage due to the safe consumption issues.

Table 1. Color changes of anthocyanin extract based on pH conditions



Source of anthocyanin	pH 1	2	3	4	5	6	7	8	9	10	11	12	13	14	References
Kyoho grape skin															(Abdillah *et al*., 2022)
Grape skin															(Kafashan *et al*., 2023)
Red cabbage															(Zhan *et al*., 2024)
															(Sadi & Ferfera-Harrar, 2023)
Purple chinese cabbage															(Hashim *et al*., 2023)
Red radish															(Yi *et al*., 2023)
Pistachio peel															(Taheri-Yeganeh *et al*., 2024)
Blackberry															(Sganzerla *et al*., 2021)
Bilberry															(R. Li *et al*., 2024)
Barberry															(Khezerlou, Alizadeh Sani, *et al*., 2023)
Saffron															
Dried Hibiscus (*Hibiscus sabdariffa*)															(Khezerlou, Tavassoli, *et al*., 2023)
Red poppy															(Tavassoli *et al*., 2024)
Butterfly pea (*Clitoria ternatea*) flower															(Kim *et al*., 2022)

Table 2. Color changes of smart film based on pH conditions

Smart Film Material			pH														References
Polymer basis	Anthocyanin extract	Extract concentration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Arrowroot starch/ iota-carrageenan	Kyoho grape skin	50%															(Abdillah *et al*., 2022)
		30%															
		10%															
Alginate/chitosan	Red beetroot	5mL															(Ranjbar *et al*., 2023)
Gellan gum	Red cabbage	0,1 g															(Zhan *et al*., 2024)
		0,2 g															
		0,3 g															
		0,4 g															
Chitosan/zein	Red radish																(Yi *et al*., 2023)
Gelatin/pectin	Pistachio peel	9%															(Yi *et al*., 2023) (Taheri-Yeganeh *et al*., 2024)
		6%															
		3%															
Gelatin/chitin nanofiber	Barberry	3%															(Khezerlou, Alizadeh Sani, *et al*., 2023)
	Saffron	3%															

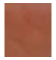
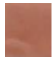
Chitosan	Dried Hibiscus (*Hibiscus sabdariffa*)	3%						(Khezerlou, Tavassoli, *et al*., 2023)
Whey protein isolate (WPI)/ chitin nanofiber (CNF)	Red poppy							(Tavassoli *et al*., 2024)

Table 3. Application of smart packaging on fisheries product

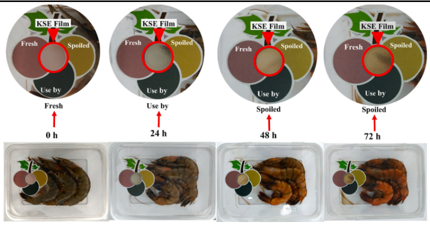
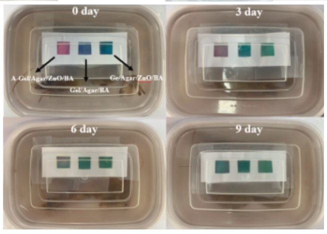
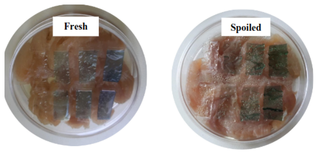
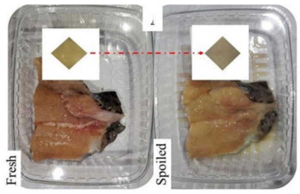
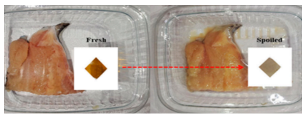
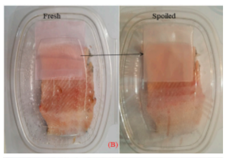
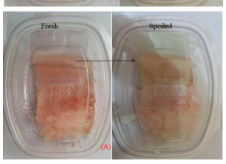
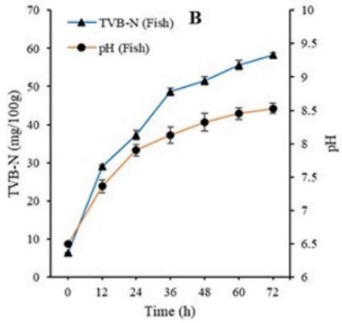
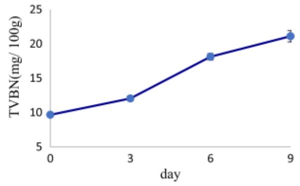
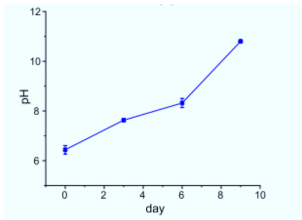
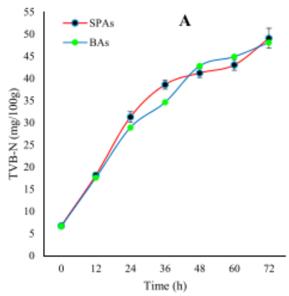
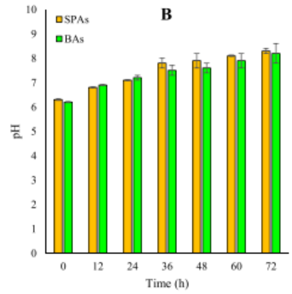
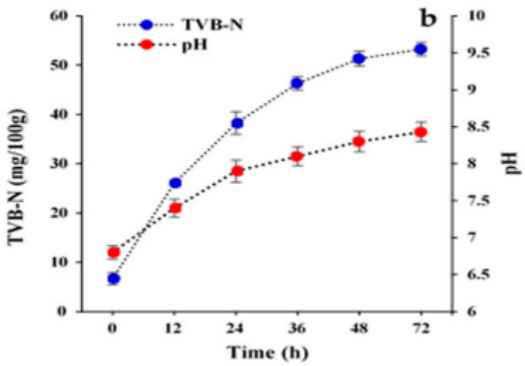
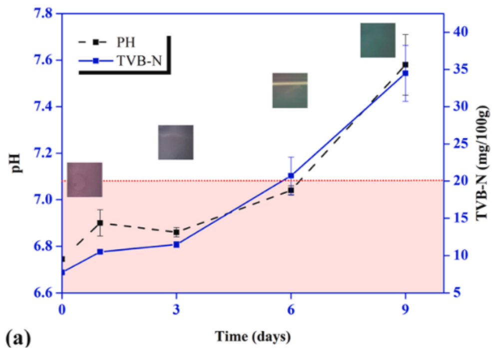
Source of anthocyanin	Color changes of on-packaging	References
Kyoho grape skin		(Abdillah *et al*., 2022)
Butterfly pea (*Clitoria ternatea*)		(Kim *et al*., 2022)
Red cabbage		(Nadi *et al*., 2023)
Red poppy (*Papaver rhoeas* L.)		(Tavassoli *et al*., 2024)
Dried Hibiscus (*Hibiscus sabdariffa*)		(Khezerlou, Tavassoli, *et al*., 2023)
Barberry		(Khezerlou, Alizadeh Sani, *et al*., 2023)
Saffron		
Grape skin		(Kafashan *et al*., 2023)

Table 4. TVB-N and pH values of packed fisheries product during storage

Smart Film Material	TVB-N	pH	References
Whey protein isolate/chitin nanofiber/red poppy anthocyanin			(Tavassoli *et al*., 2024)
Basil seed gum/chitosan/red cabbage anthocyanin			(Nadi *et al*., 2023)
Gelatin/chitin/ saffron petal and barberry anthocyanins			(Khezerlou, Alizadeh Sani, *et al*., 2023)
Chitosan/*Hibiscus sabdariffa* L. Anthocyanin			(Khezerlou, Tavassoli, *et al*., 2023)
Gelatin/agar/ *Clitoria ternatea* flower anthocyanin and zinc oxide nanoparticles			(Kim *et al*., 2022)

CONCLUSION

The review results showed the pH-sensitive indicators could be used to visually detect fish spoilage during the storage. Anthocyanin is a potential natural pigment used to develop a smart system by applied in the manufacture of fishery product freshness detectors that revealed visual color changes. Color changes indicated the pH conditions in the packaging caused by the protein denaturation of fish product. The appearance of green or yellow on the smart film suggested the condition of the fishery product in the packaging has lower quality. Accordingly, TVB-N produced from spoiled fishery products, thus supporting changes in pH that are visualized by changes in the color of the smart film. The advantages of this packaging system include simple and inexpensive production, which could provide "best before" information, and reduce unnecessary food waste. Smart packaging can potentially ensure fishery products' safety and quality. In addition, the proposed system has beneficial because of its simple manufacturing process and visual color changes.

ACKNOWLEDGEMENTS

The authors are grateful to Universitas Airlangga for the funding (Airlangga Research Fund with grant number 2228/B/UN3.FPK/PT.01.03/2024)

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