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Recent Advances in Packaging Technology of Seafood Products

İrem KILINÇ [1*], Berna KILINÇ[1]

[1]Faculty of Fisheries, Fish Processing Technology Department, Ege University, 35100 Bornova-Izmir, Türkiye

A B S T R A C T

Packaging is developing about the development of consumer demands and awareness day by day**.** Packaging technology is a technology that is constantly evolving. Monitoring seafood products at all stages from the moment they are caught to the moment they are consumed is extremely important for the quality of seafood products and prevention of diseases caused by seafood. Therefore, by using of improved packaging techniques, not only can be prevented the contamination of fishery products with microorganisms, but also the quality and suitability of fishery products for consumption can also be monitored at every stage. In this review, conducted studies regarding advanced packaging materials and products for seafood products have been mentioned and studies on recent advanced packaging applications in fresh and processed fishery products in recent years were compiled.

Keywords: recent advances, packaging technology, seafood products, fishery products

A R T I C L E I N F O

REVIEW

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*** CORRESPONDING AUTHOR**

kilincirem75@gmail.com
Phone : 0 534 911 98 81

Su Ürünleri Ambalaj Teknolojisindeki Son Gelişmeler

Öz: Ambalaj teknolojisinin gelişimi ile ilgili tüketici talepleri ve farkındalığı her geçen gün artmaktadır. Paketleme teknolojisi sürekli gelişen bir teknolojidir. Su ürünlerinin yakalandıkları andan tüketiciye ulaşana kadar her aşamada izlenmesi hem ürünlerin kalitesi açısından hem de su ürünleri kaynaklı hastalıkların önlenmesi açısından son derece önemlidir. Bu nedenle, geliştirilmiş paketleme teknikleri kullanılarak, sadece su ürünlerinin mikroorganizmalarla kontaminasyonu önlenmekle kalmaz, aynı zamanda su ürünlerinin tüketime uygunluğu ve kalitesi de her aşamada izlenebilir. Bu amaçla yapılan bu derleme çalışmasında, gıda ürünleri için ileri ambalaj malzemeleri ve ürünlerinden bahsedilmiş ve son yıllarda taze ve işlenmiş su ürünlerinde ileri ambalaj uygulamalarına ilişkin çalışmalar derlenmiştir.

Anahtar kelimeler: son gelişmeler, ambalaj teknolojisi, su ürünleri, balıkçılık ürünleri

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Introduction

Nowadays, food production and consumption activities improve many packaging requirements and the development of new forms of packaging (Bose et al. 2021). Advanced food packaging technologies not only ensure the safety of foods from microbial pathogens and pollutants, but also extend the shelf-life of the food products (Rangaraj et al. 2021). The improvement of synthetic packaging materials has many advantages that it leads to more attractive and safe packaging of poultry, meat and seafood products (Torosaurus 2012). However, food packagings produced from petroleum-based plastics have a hazardous effects on the environment and also human health. For this reason, packaging from biodegradable polymers is needed to be improved for the food packaging industry (Florez et al. 2022). Conventionally, food packaging is used not only for developing food quality, but also for supplying consumers with annotations of the characteristics of food products. In recent years, a new generation of smart packaging is being progressed to observe the properties of packaged food products by providing real-time information such as quality, safety and maturity (Cheng et al. 2022). Smart packaging combines both intelligent and active components. The sensing properties of metal oxide nanoparticles, antimicrobial activity, oxygen and ethylene scavenging, bio-nanocomposite films are all in the research areas of smart food packaging (Nicolic et al. 2021). Active food packaging has also been used in recent years thanks to consumer desires for preservative-free and processed foods. Additionally, in terms of improving concern and overutilization of synthetic non-biodegradable polymers, there is a developing interest in renewable biopolymer products in packaging technology (Priyadarshi et al. 2021). Active packaging not only improves the condition of food packaging but also extends the shelf life of food products. However, smart packaging not only effects the condition of packaged food products, but also effects the environment surrounding food products (Florez et al. 2022). Hence, intelligent food packaging is being produced for monitoring of the properties of foods continuously during the stages of processing, transportation and storage of food products. This kind of innovative packaging has many advantages such as improving the food quality, reducing the safety problems of foods, decreasing the food waste, which gives rises to favourable to the improvement of a safer, healthier, and also stronger food supply chain (Poyatos-Racionero, et al. 2018). Edible packaging is one of the most popular packaging methods that many studies have been carried out on this subject for extending the shelf-life of food and fishery products. However, it has yet to be effectively applied to the markets. Packaging made of plastics is widely used in the markets instead of biodegradable packaging, which have been made from various biological resources, edible films and coatings. The antioxidant capacity and antimicrobial characteristics of these edible packagings can be developed by adding phenolic compounds, essential oils and fruit extracts (Yuvaraj et al. 2021). Even though the majority of novel solutions and their applications have been considered in the food packaging processes, elaborate research could be required for their extensive implementations in the food industry (Soro et al. 2021). The growth of active and intelligent packaging films has been observed in recent years that they caused the use of proteins, polysaccharides, and anthocyanins from different plant sources (Yong and Liu 2020). Applyling natural antimicrobial agents effectively eliminates many species of pathogenic and spoilage microorganisms (Zhang et al. 2021). Additionally, intelligent pH-indicator polysaccharide-based films have been produced in recent years. However, further researches about the polysaccharide-based films in food packaging technology and their combinations with other materials could be studied in the future (Florez et al. 2022). Nano-biocomposites have been applied for developing the smart and active packaging at an accelerating pace (Tyagi et al. 2021). Recent advances have been made in the applications of graphitic carbon nitride (g-C3N4), hexagonal boron nitride (h-BN), 2DMs (including graphene, transition metal dichalcogenides TMDs), transition metal carbides and nitrides (MXenes), layered double hydroxides (LDHs)) in active packaging (such as antimicrobial activity, mechanical property, thermal stability and improving the barrier property etc.) and intelligent packaging (such as gas sensors, time-temperature indicators, pH indicators, intelligent labels, preparing leak indicators, etc.) (Yu et al. 2021). Furthermore, in the coming years growing technological advances together with the increasing market demands are leading to give the adoption of intelligent packaging in food industries (Poyatos-Racionero et al. 2018). Accordingly, the purpose of this review is not only can be outlined the recent advances about the food packaging technologies, but also can be summarized the effects of these advanced packaging technics on to the shelf-life of fishery products during transporting, marketing and storage.

Recent Advanced Materials and Instruments for Food Packagings

The processing, packaging and safety of foods have been effected from modern food science and technologies (Dzikunoo et al. 2021). Expanded polystyrene is widely applied in foam packaging. Thus, developing foams are required to apply biodegradable packaging for food products by using renewable materials such as starch-based foams instead of synthetic plastics (Tapia-Placido et al. 2022). But EPS-based foams lead to environmental problems in terms of little recycled and non-biodegredable. So, developing foams are needed for applying biodegradable packaging for food products by using renewable materials such as starch-based foams instead of synthetic plastics (Tapia-Blacido et al. 2022).

Active packaging comprises active compounds such as antimicrobial peptides (AMPS) that it is inclusive of them in different nanocarriers to obtain their controlled release for preserving of the food products during storage. In addition, AMPs have a good potential materials in food packaging because of eliminating the infectious bacteria and foodborne pathogens (Liu et al. 2021). Active packaging materials are improved to extend the shelf life of food products with antioxidants and antimicrobials, whereas smart packaging materials are improved to observe the maturity, quality and safety of foods in real time. Additionally, photoactivated materials can photocatalysis or photoluminescence for being used to produce these active and smart food packagings. Moreover, photocatalysis-based instruments can be used as color indicators for gas removal and to eliminate a broad spectrum of microbes, whilst photoluminescence-based sensors can observe environmental changes in food packagings such as freshness, the apperance of specific microorganisms and gas leakage (Xu et al. 2022).

Nanotechnology is also one of the most important areas of advanced packaging, which transports food products safely without spoiling the quality, nutrition and taste. Additionaly, it also prevents the microbial contamination and preserves the mechanical, chemical and physical properties of food products. Many nanomaterials have been applied in food packaging technology to provide bio-based, active, advanced and intelligent packagings (Chausali et al. 2022). Silver-based nanomaterials have been used in different applications in food packaging sector, which contain thermal resistant high performance packages, edible nanocoatings, functionalized packagings with antimicrobial and also improved physicochemical properties (Mathew and Radhakrishnan 2021).

Increased rates of the using plastic materials have hazardous effects on the environment, aquatic animals and human health (Bulat and Kılınç 2020). Therefore, in recent years, the active biofilms obtained from biopolymers, fibers and mineral clays have been considered a good alternative instead of the synthetic plastics in food packaging (Bourakadi et al. 2021). Additionally, the continuously increasing usage of plastic materials cause to improve the presence of nano and microplastics contamination in variety of food products. Therefore, their potential remaining effects on human health are uncertain in the future (Shruti et al. 2021). Because of this approach, alternative sustainable packaging material is necessary to develop for human health and also for environment instead of using plastic packaging (Haghighi et al. 2020). Instead of being used petro-based materials, innovative antimicrobial packaging materials can be improved by using antimicrobial agents. Edible packaging typically uses biodegradable and sustainable materials that is very suitable for coating or wrapping around the foods (Petkoska et al. 2021). Antimicrobial agents into the biopolymer-based edible films has been a significant improvement in active food packaging technology (Chawla et al. 2021). The commercial usage of biodegradable protein films is still very limited in the industry because of their poor barrier and mechanical performance. In contrast to this approach, processing of proteins may be able to be a good impact on the properties of biodegradable films (Romani et al. 2018). These biodegradable films are being produced not only from the animals (gelatine, myofibrillar protein, collagen), but also plants (maize, rice, wheat, barley etc.), sunflower and aquatic plants for improvement of packaging material (Assad et al. 2020). A lot of antimicrobial substances can also be combined with the materials in the packaging technology, including antimicrobial polymers, biotechnological products etc. (Singh et al. 2016). Essential oils and also their compounds can be added into the packaging that are especially very important for environmental concerns. These bio-based packagings have been mostly used in many types of foods such as fish, fruit, meat, raw and processed food with effective results. The preservation of foods occurs not only can be obtained by diffusion of the active compounds of essential oil, but also it can be incorporated into the packaging to the foods (Ribeiro-Santos et al. 2017), but also packaging films include antimicrobial agents can be extended the shelf life of foods by inhibiting the spoilage (Singh et al. 2016). Although, many studies have been done on the usage of bio-based materials for food packaging, further studies are needed to develope their functioning mechanisms, performances and also improve greener methods for the processing and production of these bio-based materials (Wang et al. 2022).

Nanoemulsions of natural oils are gaining importance in various fields containing agriculture and food sectors, in terms of efficiency, possess developed functionalities and more stability. For example; neem oil and its nanoemulsions as well as pectin, starch and chitosan based active packaging of foods containing vegetables and fruits have also been used (Kumar et al. 2022). Chitosan is a nontoxic, biodegradable, and biocompatible natural polymer. It is a good option for antimicrobial films due to its film-forming properties, ability it absorbs nutrients used by bacteria and inhibiting a variety of bacteria species with its ability to adhere to water with enzyme systems (Darmadji et al. 1994). Additionaly, it is one of the properest polysaccharides in the nature that it has a lot of properties such as antifungal, antimicrobial, antioxidant activity and non-toxicity characteristics. For these reasons, active or intelligent chitosan-based films have been developed for the usage of food packaging in recent studies (Florez et al. 2022). Biopolymer-based food packaging such as starch has been replaced in recent years because it is eco-friendly, inexpensive biopolymer and sustainable. Thermoplastic starch is one of the best materials for obtaining starch derivatives that is applied for food packaging. Although, it has some disadvantages, including inadequate water barrier characteristics, hygroscopic nature and low gas permeability (Bangar et al. 2021). Clodextrins have some benefits that they have been garnering increasing attention day by day because of being formed supramolecular structures and several complexes. So, they are not only used for food packaging but also they can be used for the applications in other fields of science (Liu et al. 2022). Plant-based food wastes can also be used as raw materials in biodegradable packaging for improvement of packaging performance (Zhang and Sablani 2021). Kefiran is an exopolysaccharide obtained from the microflora of kefir grains that it has tremendous potential in food packaging applications due to its film forming, biological properties, electrospinning abilities, biocompatibility (Carvalho and Conte-Junior 2021). Cellulose containing composites is the reinforcing material such as nanocrystal or nanofibres, which are becoming more frequently, when compared with cellulose-based packaging (Garrido-Romero et al. 2022). The clay-polymer nanocomposites containing bioactive compounds for food packaging applications can provide some advantages by affording barrier properties, enhancing the mechanical properties of the polymer matrix, stabilizing the bioactive compounds and also a vehicle for their controlled release (Cheikh et al. 2022).

Variety of food packaging technologies are applied individually or in mixture for observing effective food conservation such as active food packaging; oxygen scavengers; carbondioxide emitters; moisture regulators; antioxidant and antimicrobial packaging; intelligent packaging, including freshness indicators; retort pouch processing and edible films; time–temperature indicators and leakage indicators; coatings/biodegradable packaging (Kontominas et.al. 2021). Nanotechnology offers exciting opportunities for the integration with the packaging, the development of active components, communication, miniaturization and batteries. However, the use of nanotechnology in intelligent packaging is still limited (Ros-Lis and Benitez 2021).

Intelligent packaging integrated with O_2 sensors has been developed and demonstrated its ability to monitor O_2 content throughout the food supply chain of many different packaged foods (Cruz-Romero et al. 2019). Many commercial intelligent packaging products have been given such as integrity indicators, time temperature indicators, freshness indicators, and radio frequency identification tags (Poyatos-Racionero et al. 2018). Freshness indicators are not only efficient intelligent and simple products, but also they can be scientifically and directly monitored the freshness of foods without damaging packaging and food easily. The overall control of food safety and quality can be monitored by these intelligent technologies such as sensor, bar code etc. (Shao et al. 2021). These freshness indicators can be produced as a label, ensuring a rapid response to storage temperature or food quality that changes according to the color changes. Additionally, Electrospinning, as a sophisticated and an efficient method of preparing continuous nanofibers that it has been developed as an encouraging to produce food packaging materials. Subsequently, electrospun nanofibers have been recycled as a novel product to improve intelligent packaging (Forghani et al. 2021). Moreover, the safety and quality of packaged foods were ensured developing oxygen indicators by electrospinning process that they detected the damaged food packages during the supply chain (Yılmaz and Altan 2021). Electronic nose is one of the most important monitoring device that it is a good alternative for measuring the characteristics of flavour and aroma in relation to volatile compounds in the quality of food products. Nowadays, the improvement of the usage of e-nose applications for the food industries has been increasing because of the emergencing of gas-sensing detection; it has a new potential (Ali et al. 2020). Nanomaterials of different kinds expose a immense potential for intelligent food packaging. Nanosensors obtain selective and sensitive platforms that they cause to sense of deteriorative markers (Mohammadpour and Naghib 2021). Furthermore, two-dimensional materials can be widely used in food packaging and they have some good advantages such as high mechanical performance, unique electrocatalytic activity and large specific surface area. (Yu et al. 2021). The popularity of nanotechnology in food packaging is also increasing day by day in terms of the various bio-nanocomposites including nanohybrids, organic and inorganic nanomaterials that are very suitable for food packaging materials due to their antimicrobial, antioxidant, thermal mechanical, barrier advanced properties (Perera et al. 2021). In addition to this, nanoclays have been used with essential oils and bio-extracts that included both synthetic and bio-based polymers to manufacture nanocamposites with improved the antimicrobial, barrier and antioxidant activities (Nath et al. 2022). Although the risks and benefits of engineered nanoparticles in food-contact applications are discussed, they can be also examined whether or not and in which conditions they can be released from the food contact polymers (Enescu et al. 2019). In addition to this; proper risk assessments are developing enormous rate by using the composite films for example metallic micro-/nanoparticles in food contact materials, regarding the effective evaluation, human toxicity and and confirmation of the advantages on the use of metallic particles are necessary to declared (Videira- Qintela et al. 2021). Moreover, smart biomaterials can also be interacted with the food product or the headspace for ensuring a preferred result for bio-derived products due to enhance the sensor activities, safety and also shelf life. However, the environmental influences should be arranged by specific standards to sustain more efficient food packaging for future markets (Reshmy et al 2021). Additionaly, the contaminants in food packaging technology and the determination of the most appropriate safety assessments of these contaminants are also required to determine in this rapidly increasing field (Karmaus et al. 2018).

Recent Advanced Packaging Technologies in Raw and Processed Seafood Products

Fish, poultry, meat are very perishable that they should be packed using the most probable technique and they should be processed very quickly. Retorting is heated in hermetically sealed containers that it extends the shelf life and also preserves the food products. According to this method; retort-processed seafood products are ready to eat food products that they have a shelf life of more than a year in optimal temperatures (Bindu et al. 2012). The application of the packaging, temperature/pressure treatments, the use of microbial-derived compounds, natural compounds (e.g. biopolymers, plant/algal extracts, gelatin) and various combinations of these applications have been provided to extend the shelf life of fishery products (Nie et al. 2022). Proper packaging maintains the quality of seafood for a long time after processing (Nagarajarao 2016). The effects of packaging technics on the microbiological flora of the packaged seafood have been reviewed by Kılınç and Çaklı, (2001). Additionally, many packaging technologies have been used for extending the shelf life of raw and processed fishery products such as vacuum and modified atmospheric packagings (Kılınç and Çaklı 2004). Advances published on vacuum and modified atmosphere packaging of seafood products have been discussed between the years 2000 and 2010 (Fletcher 2012). Alternative renewable materials began to take place with the polystyrene materials for packaging (Hansen et al. 2012). In present years effect of vacuum impregnated grape seed extract and fish gelation on quality of seabass during storage (4°C) suggested that FGG is a good promising for sea bass preservation (Zhao et al. 2021). Many studies have been done and developed about the application of new and alternative packaging technics. Nonwoven fabrics, containing bamboo and silver have been used for packaging of somon fillets to have a longer shelf life (Kılınç et al. 2017), whereas the effects of absorbent pads containing black seed and rosemary oils on the shelflife of sardine (*Sardina pilchardus*) fillets have been carried out (Kılınç and Altaş 2016).

Edible coatings can cause to develop the quality of a variety of seafood products by retarding microbial growth, moisture loss and reducing lipid oxidation. Additionally, food additives have some special properties that are contained antioxidant and antimicrobial agents. Biodegradable edible coatings have also many advantages that they have edible and generally more environmentally (Dehghani et al. 2018). Many types of edible films have been used on the surface of seafood products for increasing the shelf life and quality. These films include many special characteristics of compounds that they have antioxidants, chemical and natural antimicrobial agents, vitamins, enzymes, minerals (Janes and Dai 2012). Bioactive films produced from marine gelatin are being improved for food packaging to do continuation good alternatives to other synthetic materials. The use of these films in food packaging for the protection of fish, meat and vegetable products will become widespread commercially (Abdelhedi et al. 2022). In recent years, the production of fish gelatin and chitosan has also been improving commercially. Moreover some bioactive components can be separated from gelatin extraction or chitosan to produce film-forming formulations. They not only cause to extend food shelf life, but also they lead to produce packaging and reduce the food losses (Caba et al. 2019). The improvement of gelatin-based films for usage in food packaging has attracted more attention because of their biodegradability, non-toxicity, renewability and availability recently. Advanced properties of gelatin film have been studied by incorporating modifiedkappa-carrageenan and zein nanoparticles for active food packaging that it showed the valuable potential for the application of the various food products (Maroufi et al. 2021). Further, the addition of plant essential oils, plant extracts and nanoparticles to starch films can develope their antioxidant, antibacterial, and barrier properties. In addition to this, adding anthocyanins into the starch films can make not only the films pH-responsive, but also can indicate the degree of spoilage in fish products and achieve the purpose of warning consumers (Cui et al. 2021).

Nanotechnology applications in food packagings and importance for seafood have been reviewed by (Sürengil and Kılınç 2011). Additionally, incorporation of natural anthocyanins and TiO2 nanoparticles developed the bacteriostatic properties, moisture, mechanical resistance and inhibited oxidative reactions of smart films. According to the fish degradation, which was well correlated with ammonia production, the films changed the color. These active/biodegradable smart films are not only able to improve quality of fish, but also can be prolonged the shelf life, inhibited the fish spoilage and reduced the fish wastes (Sani et al. 2022). Novel techniques containing biosensor, colorimetric sensor, electrochemical biosensor, enzyme biosensor, electronic nose, electronic tongue, computer vision techniques, fluorescence spectroscopy, HSI spectroscopy and Vis/NIR spectroscopy as rapid and reliable tools for evaluating fish freshness in timely manner and an effective methods have been used (Wu et al. 2016). New approaches in packaging technology are improving increasingly by using different natural functional additives and combination methods. Although they had some difficulties about consumer acceptance and sometimes incomplete development or low retail and legal restrictions, intelligent packaging systems are still being innovated and show good potential for developing the present methods for providing the safety of packed meat products (Schumann and Schmid 2018). Smart deep learning-based attitude has been used for non-desructive freshness diagnosis of common carp fish. This method is well ability of classifying and monitoring fish freshness as a precise, low-cost, non-destructive, automated and real-time techniques (Taheri-Garavand et al. 2020). Composite active/intelligent food packaging film was improved with polyvinyl alcohol and gelatin combine with amaranthus leaf extract to observe the freshness of fish. Fish packed in neat films had a shelf life of 3 days, while samples in active films spoiled after 12 days. On the other hand, the films were active as they minimised oxidative rancidity and delayed microbial growth of chilled fish (Kanatt 2020).

The development of new fish processing and packaging technologies not only give rise to produce alternative novel products, but also achieve good management, reduce food waste and improve the shelf-life of raw and processed fishery products (Tsironi et al. 2020). Intelligent packaging in food products indicates many types of packaging that includes intelligent agents such as sensors and detectors. This type of packaging is used to warnings about possible problems in food packages, convey information about food safety and quality of foods. Markers and sensors are capable for measuring not only chemical, biological or physical variables in food products but also, biosensors and color sensors are mostly applied in the food packaging industry as well as color sensors are commonly used as labels in intelligent packaging (Pirsa et al. 2022). Additionally, a non destructive method, observing the volatile compounds based on trimethylamine of packed cod fillets has been developed that this method monitors the changes in freshness quality of fillets (Heising et al. 2015).

The use of electronic sensors in the seafood packaging industry have many advantages in manufacturing processes. This not only gives rise to pack seafood products properly but also, immediately detect the pollution particle in fishery products and improve the processing of seafood industry by doing the packing process faster (Badilla and Gaynor 2018). Oxygen absorber are used for prevention of rancidity and discoloration, whereas antioxidant releaser are used for enhancement of oxidative stability for fatty fish. Furthermore, moisture absorber is applied for declining of moisture condensation within the package and shelf life extention of fresh fish, whilst carbon dioxide emitter is used for reducing in head space volume of modified atmosphere packaging and shelf life extention of fresh fish. Besides, antimicrobial releaser is practised for retardation of microbial growth and shelf life extension of fresh and smoked fish (Kontominas et al. 2021). Label with a dye in intelligent packaging that changes color in accordance with a chemical reaction, which is affected by temperature or compounds. Physical (e.g. temperature) or chemical (e.g. pH, volatile composition) factors affecting or producing a chemical reaction that changes the color of freshness indicator (Azeredo and Correa 2021). pH is used as non-destructive methods for observing the changes in the freshness situation of packed cod fish examined, whereas volatile compounds in packed fish that affect the electrode signals of the electrodes with increasing the volatile amines content of fresh cod fillets stored at 0–15 °C (Heising et al. 2014). A wireless basic volatile sensor have a good correlation with the ammonia gas concentration and microbial analysis, identify that it shows a potential instrument for monitoring of fish spoilage for both 24°C and 4°C storage conditions (Bhadra et al. et al. 2015). Intelligent food packaging (A dual-channel indicator), including a built-in sensor inside the fish bags, can be able to real-time monitoring of fish safety and quality by visibly discernible out-put signals due to the increasing production of amines according to the fish spoilage (Duan et al. 2022). Additionally, the freshness label produces a noticeable color change according to the fish spoilage with increasing the level of the total volatile basic nitrogen (TVB-N), which can indicate the spoilage of the fish. (Wang et al. 2022). The development of colorimetric and optical sensors is highly not only attractive, but also they give rise to real time operation and easy visualization (Ma et al. 2021). Aggregation-induced emission indicator is very sensitive to ammonia vapor for detecting the spoilage of the seafood. The color variation of this indicator was in agreement with the increasing tendency of the value of total volatile basic nitrogen and total viable bacteria count, which confirmed the accuracy of the this indicator (Zhu et al. 2021). A biopolymer-based pH indicator was carried out to monitor the spoilage of fish at (23°C) room temperature in terms of the color change of pH indicator from red to yellow after 1 day (Sobhan et al. 2022). The developed novel paper based pH-sensitive intelligent detector can be used for different variety of samples and also in different packaging sizes by adjusting the detector's pH. This detector is not only inexpensive, but also can detect freshness level and spoilage in the form of an on-package detector (Alamdari et al. 2021). The polyvinyl alcohol/glycerol film incorporated with curcimin and anthocyanins at a ratio of 2:8 (v/v) could provide three different colors, which were assigned to spoilage for packaged fish, medium freshness and the sign of freshness (Chen et al. 2020). The intelligent pH indicator films were made by incorporating curcumin-loaded Pickering emulsion with polyvinyl alcohol matrix and corn starch. The pH indicator films made with curcumin-loaded Pickering emulsion were prepared on examining fish freshness that they had more pronounced color change from yellow to red (Liu et al. 2021). Intelligent colorimetric indicator films with 10% purple tomato anthocyanin caused to change their color during spoilage of fish, indicating their potential usage for monitoring fish freshness and spoilage (Li et al. 2021). The intelligent packaging film based on bacterial cellulose and pelargonidin had a great color difference from red to colorless with changing of total volatile basic nitrogen and sensory scores, when operated to observe the freshness of tilapia fillets (Huimin et al. 2021). Hydroxypropyl methylcellulose/microcrystalline cellulose biocomposite film combined with butterfly pea (*Clitoria ternatea*) anthocyanin as a pH-responsive indicator was improved. In lights of aboveapproach; the spoilage level of mackerel (*Scomber scombrus*) was determined. According to the changes in the color of this indicator as follows; blue, green ocean, and colonial blue colors showed that it was spoiled, violet color showed that it was suitable for eating, deep purple and light purple colors showed that it was fresh. (Boonsiriwit et al. 2021). Gradient colorimetric indicators were prepared by using piezoelectric inkjet-printing to observe the freshness of packaged ocean perch, catfish and wild haddock fillets during storage. Based on the spoilage of fish products, the color changes of the indicator labels were determined with the increasing of trimethylamine, total volatile basic nitrojen and dimethylamine levels in the packages (Luo et al. 2021). pH-responsive chitosan-based film incorporated with alizarin, which was very sensitive to ammonia vapor with changing a pH and also the color from slightly yellow to purple, was improved (Ezati and Rhim 2020). Cellulose nanofibers and carboxymethyl cellulose intelligent pH responsive color indicator films were developed using shikonin. The monitoring of color changes of indicator films from a reddish pink to blue-violet indicated as the spoilage of fish (Ezati et al. 2021). A halochromic indicator produced from polylactic acid and anthocyanins for monitoring the visual freshness of fish roe and shrimp were improved. This developed indicator showed the levels of the spoilage of products as fresh, medium fresh, and spoiled (Ghorbani et al. 2021). For monitoring the shrimp spoilage correlated with the increasing ammonia vapors; the novel pH colorimetric film was developed from sugarcane wax on agar matrix combined with butterfly pea flower extract (Hashim et al. 2022).

Table 1. Intelligent Packaging for Raw and Processed Fishery Products

Type of Packaging	Type of changes/ increasing product	Potential Benefit	References
The use of pH and conductivity electrodes	Volatile compounds	Freshness status of packed cod fish for sensing non-destructively	Heising et al. 2014
A hydrogel-pH-electrode based near-field passive volatile sensor	Basic volatile spoilage compounds	Non-destructive detection of fish spoilage	Bhadra et al. 2015
A chitosan-based pH-responsive film	Ammonia	Determining of the fish spoilage	Ezati and Rhim 2020
Visual pH-sensitive films containing curcumin and anthocyanins	Volatile amines	Non-destructively monitoring the real time freshness of fish products	Chen et al. 2020
Intelligent pH-responsive color İndicator films	pH changes	Monitoring seafood quality	Ezati et. al. 2021
pH- responsive indicator	Ammonia	Sustainable, Monitoring of the freshness of mackerel	Boonsiriwitt et al. 2021
Inkjet –printed gradient colorimetric indicators	Volatile amines	Monitoring the freshness of ocean perch, catfish or wild haddock fillets	Luo et al. 2021
A novel paper based pH-sensitive intelligent detector	pH changes	Detecting of the freshness level and spoilage of seafood	Alamdari et al. 2021
Colorimetric and optical indicators	Total volatile basic nitrogen	Non-destructively and visual monitoring of seafood spoilage	Ma et al. 2021
Aggregation-induced emission indicator	Ammonia	Monitoring of seafood spoilage	Zhu et al. 2021
Intelligent colorimetric indicator film	Total volatile basic nitrogen	Monitoring of the freshness of tilapia fillets during storage	Huimin et al. 2021
The intelligent pH indicator film	pH changes	Monitoring of fish freshness	Liu et al. 2021
Intelligent colorimetric indicator films	pH changes	Monitoring of fish spoilage or freshness	Li et al. 2021
A halochromic indicator	Total volatile basic nitrogen	Monitoring of the freshness of fish roe and shrimp	Ghorbani et al. 2021
A dual-channel indicator	Amines	Monitoring of fish spoilage	Duan et al. 2022
Fish freshness indicator label	Total volatile basic nitrogen	Tracking of fish freshness visually and non-destructively	Wang et al.2022
A biopolmer-based pH indicator	pH changes	Cost effective, simple, environmentally friendly, mitigate the impact of possible outbreaks and detecting fish spoilage	Sobhan et al. 2022
A novel pH colorimetric film	Ammonia	Optical tracking of shrimp freshness	Hashim et al. 2022

Together with these trends; number of challenges have been appeared for fish producers in accordance with the development of new product, processing and packaging technologies that ensure the seafood products have maintained their sensory and nutritional qualities before they reach to the consumers (Hyldig et al. 2012). Nevertheless, migration of potentially toxic materials and their transformation products from packaging materials are required to be monitored continuously in terms of human health (Szczepanska et al. 2018).

Discussion

The continuous improvement of technologies cause to the development of packaging techniques. Ensuring that fish and aquatic products are monitored at every stage until they reach consumers can only be achieved by using improved packaging techniques.

In addition to the advantages brought by the development of packaging technology, it is necessary to focus on the disadvantages and not to prefer the use of materials and methods that will harm human health in packaging. As a result, thanks to improved packaging techniques, determining that seafood products can be consumed or not consumed without the need for analysis to determine their quality will not only eliminate the analysis costs, but also will lead to give many advantages in terms of time. In addition, it is also envisaged that packaging techniques will be more advanced in the future than today and that today's unknown topics related to advanced packaging techniques will be solved.

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