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CURRENT TRENDS IN PACKAGING

Emine Arman Kandirmaz
Marmara University, Faculty of Applied Sciences, Printing Technologies, Istanbul, Turkey

Abstract: *The basic duties of packaging include protecting the product, providing information about the product, and facilitating transportation. With developing technology, decreasing resources, and increasing population, extra duties have been needed in addition to the basic duties of the packaging, such as protecting the life and freshness of the product, providing information about the product inside, improving the usage areas of the product, ensuring its correct use, and ensuring sustainability conditions. In this sense, sustainable, smart, and active packaging technologies are increasing day by day. The use of these functionalized packages is generally more common in the healthcare, food, and logistics industries. This study examines how active, sustainable, smart packaging can revolutionize packaging. The research aims to provide specific insights into the potential of functional packaging technologies. The study also discusses the promising future of functional packaging, with technological development and consumer needs ecological for friendly products. In conclusion, this work reveals how functional packaging can transform packaging industry accomplish limitations and compensation consumer demands, supply advanced product safety, quality, and sustainability.*

Key words: active packaging, smart packaging, traceability, food safety, functional packaging

1. INTRODUCTION

Packaging has an important and critical role in the product supply chain. The main task of packaging is to contain the product, keep it in its content, transport the product efficiently in all logistics stages, prevent physical damage that may occur during supply and transportation, and resist deception. In addition, packaging prevents undesirable chemical and biological changes in the product and ensures the quality and safety of the product in the process from production to consumption (Rahmawati et al., 2024). As can be understood from here, packaging has a barrier feature that protects the product from external factors, chemicals, and microbiological pollution such as oxygen, moisture, light, dust, pests, volatile substances, etc.

Packaging generally provides passive protection. That is, the packaging acts as a barrier between the in-package environment and the out-of-package environment around the product. However, sometimes gas-permeable packaging materials can also be used in the packaging of fresh products. This second type of packaging can protect the life of the product for a limited time (Pirsa, 2024). Nowadays, people do not want to increase the usage and shelf life of the product by adding additives to it (Bodie et al., 2024). The undesirable side effects that added additives may cause on the body of the user of the product cause concern in end consumers. In this sense, the fact that the products are produced with minimum processing and fewer or no additives (clean content) attracts the attention of conscious consumers. This interest has made the product protection feature of the packaging more important. Nowadays, new packaging technologies such as modified atmosphere packaging (MAP), active packaging (AP), smart and intelligent packaging (SP/IP) and nanomaterial applications are being developed day by day in order to improve the protective properties of the packaging (Mahapatra et al., 2024).

In addition, in the last fifty years, the advantages of plastic packaging such as cost, lightness, ease of production, perfect compatibility with the product, and ease of processability have enabled it to be used more than other traditional packaging materials (glass, metal, paper and cardboard, etc.). However, the fact that most plastics used in the packaging industry are produced from petroleum, the difficulty and long time it takes to break down these petroleum-based plastics, the microplastics that emerge when they break down, the pollution and energy requirements that occur in the cycle from their production to waste, make consumers concerned about the use of plastic packaging. To overcome this problem, the packaging industry is paying more attention to packaging made from biodegradable bioplastics produced from biomass (Mohapatra & Singh, 2024).

Innovative packaging solutions have emerged because of increasing population, conscious consumer demands, decreasing resources, increasing environmental awareness and developing technologies (Francis et al., 2024). Innovative packaging trends include smart, active, and sustainable packaging (Khandeparkar et al., 2024). While these packaging technologies increase efficiency in the supply chain of products, they ensure product safety, reduce product loss, and eliminate product waste, and ensure the communication of the product with the consumer. The increasing diversity of publications on innovative packaging in recent years proves that the subject has attracted attention from both the academic and industrial environments.

Packaging that offers “something extra” in addition to wrapping, protecting, and transporting the product is called smart packaging. Said “extras” can include anything from improving the freshness of the food, monitoring its conditions, or extending its shelf life, etc. Smart packaging technology is a technology that enables the product inside the package to communicate with the consumer. If we compare traditional and smart packaging applications, traditional packaging provides limited information, basic protection, manual monitoring, while smart packaging has features such as enhanced protection, traceability and safety, real-time monitoring, interactive features (Li et al., 2024).

Even though smart packaging systems have early applications, they have found many areas for themselves. These include monitoring the freshness of the food, sharing the data with the end user, and keeping the stocks of the products trackable and traceable. Smart packaging analyzes the storage conditions, quality, and internal/external environment of the product with the help of various sensors, indicators and devices. Smart packaging uses sensors, indicators, and monitoring systems to monitor and communicate the status of the product. Sensors added to the packaging, or its design are the most important component of smart packaging. With sensors, parameters such as temperature, humidity, gas composition, microorganism rate and pH levels of the internal environment of the package can be determined and shared with the consumer (Hasanin et al., 2024). Smart packaging can constantly monitor one or more of the above features and constantly inform consumers about the quality of the product. For example, smart packaging technologies are used to prevent problems that may occur if the cold chain of the vaccine packaging is broken (Figure 1).

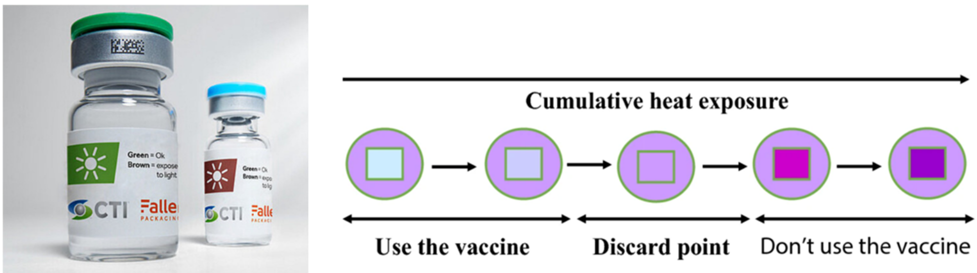

Figure 1: Examples of smart tags used in vaccines (Smart Labels, 2015; Ramakanth et al., 2021).

Another example of the use of smart packaging applications is thermochromic inks (Figure 2). Thermochromic inks are materials that change colour depending on temperature changes. Smart packaging systems are used to share with the consumer the ideal drinking temperature of a beverage or whether a canned food that needs to be heated has reached the ideal eating temperature. By choosing appropriate colours, hidden messages such as “DRINK NOW” or “TOO HOT” can become visible and provide a visual cue to the consumer.

Figure 2: Thermochromic smart labels and packaging items (Intelligent Packaging, 2024)

Time temperature indicators (TTI) are one of the most well-known smart packages. It is a design embedded in a label or packaging that communicates with visuals or data showing whether the product has deviated from the specified temperature in its storage and logistics, whether it has been exposed to adverse conditions, and whether there has been a loss of quality as a result (Figure 3) (Ahmed et al., 2018). TTIs allow product tracking from producer to consumer, allowing informed decisions to be made. TTIs have advantages such as ensuring the protection of the product by allowing real-time information transfer about temperature increases or decreases during the logistics and storage of the product, warning the relevant parties in case products that can be affected by temperature such as medicines, vaccines, or food encounter undesirable conditions, and reducing the risk of consuming spoiled food depending on the information provided. It also has disadvantages such as not being concerned with other quality factors of the product as it only allows temperature monitoring, and the need to apply an additional sensor to the packaging, which increases the cost.

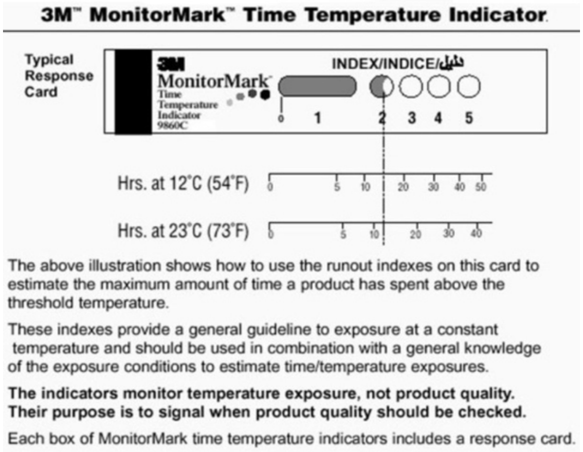

Figure 3: Monitor Mark™ time temperature indicators (Wang et al., 2015).

Technologies such as Radio Frequency Identification (RFID) and Near Field Communication (NFC) are also used as smart packaging components that enable tracking and tracing of the product from production to consumption. Information about the product's location, temperature, etc. can be monitored instantly with RFID tags or NFC-enabled tags added to the packaging (Athauda & Karmakar, 2019). In this way, theft and counterfeiting are reduced, while product safety is increased by quickly recalling the product in case of damage, etc (Figure 4).

Figure 4: RFID / NFC Labels (RFID / NFC Labels, 2024)

Another technology used in smart packaging technologies is gas sensors that can determine oxygen, carbon dioxide, ethylene levels, humidity, pH, and other volatile components in the packaging. With the information obtained from these sensors, the freshness, ripeness, and quality of the product can be determined (Hasanin & Abdelkhalek, 2024). For example, with the ethylene gas sensor (Figure 5), it can be determined whether an unripe fruit is ripe or not. Some of the fruits release ethylene gas as they ripen, and ethylene gas sensors can give us information about the ripeness of the product depending on the presence and amount of ethylene gas. Smart packaging using gas sensors can be used to continuously monitor the freshness of products that are likely to deteriorate quickly and spoil (fruits, vegetables, and dairy products), to inform the end user more easily about the expiry date and freshness, to raise the awareness of the end user and to reduce waste by consuming products that are about to deteriorate earlier. While it has advantages, it also has disadvantages such as increased cost due to the addition of additional packaging members, and in some cases, the complexity of the design in case of energy requirements such as batteries (Matindoust et al., 2016).

Figure 5: Ethylene gas sensor (RipeSense) for ripening of fruit (Label to Sense Ripening of Fruits, 2024)

Another type of smart packaging uses interactive elements to attract the attention of the end user and enable them to use the product better and more effectively. For example, with the element added to the packaging design, additional information such as recipes for different dishes to be made with the purchased product or the nutritional values of the product can be added. QR codes or quick response codes provide access to product information, market promotions or market loyalty programs in the packaging (Figure 6) (Elkhattat & Medhat, 2022).

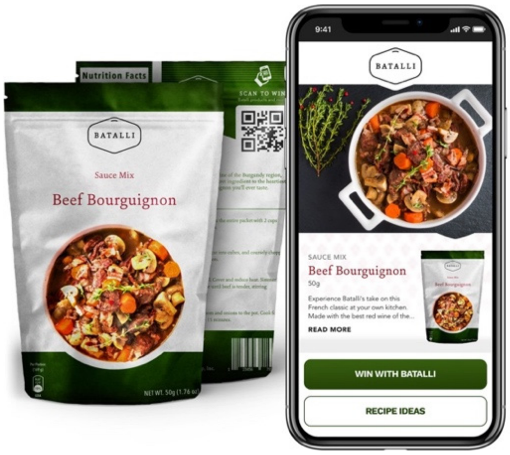

Figure 6: QR code embedded smart package (Epacflexibles, 2024)

A large part of smart packaging research is related to bio-based sensors, where the sensors to be used in product packaging are natural substances and biopolymers. In this type of smart packaging, the sensor notifies the end user of changes in the product or the environment where the product is located (inside the packaging), thus ensuring that the consumer has precise information about the condition of the product. Such sensors are also called freshness indicators. Freshness indicators generally work by determining the metabolites or microbiological materials released as a result of chemical reactions occurring in the structure of the food. For example, nitrogen derivatives may be released because of spoilage in food, which causes a change in pH, so information about freshness can be easily obtained by using substances that change colour with pH change. Freshness indicators can operate directly or indirectly. Direct freshness indicators work by detecting the freshness of the product using a specific analyte directly from the fruit. Indirect freshness indicators work by detecting the deterioration of the product based on the spoilage reaction products due to effects of temperature and/or time, etc. (Liu et al., 2022).

Depending on the development of microorganisms in the product, food may spoil or lose its freshness. With the help of freshness indicators, the released metabolites (volatile nitrogen molecules, carbon dioxide, biogenic amines, ethanol or sulfur compounds) can be determined. In order to perceive quality in perishable products, harmful metabolites released during food spoilage must be minimized. Even if these metabolites cannot be minimized, determining the number of metabolites is important. While acetic acid, n-butyrate and biogenic amines released by microbial growth should be determined as freshness indicators to be used in meat, total volatile basic nitrogen (TVB-N) and biogenic amines should be determined in fish and shellfish. Ethyl alcohol and carbon dioxide released during the decay of food accelerate the decay. If these metabolites can be determined with the freshness sensor, food waste can be prevented (Panjagari et al., 2021).

pH-sensitive sensors are sensitive to changes in acidity or alkalinity occurring in the product's environment and can warn the consumer by showing different reactions in case of a change. Some substances used in these sensors not only change pH-sensitive colour but also provide the packaging material with the ability to protect the product against different bacteria, fungi, or viruses (Motelica et al., 2020). However, it should not be forgotten that any substance added to the film may change the properties of the films (mechanical, barrier and optical, etc.). Therefore, the quantities of substances used must be precisely adjusted and optimized (Riahi et al., 2024).
Although synthetic colorants provide very effective results in freshness indicators, caution should be exercised in their use in food applications as they may have toxic properties. Colorants obtained from natural sources (plants and fruits) are preferred instead of synthetic colorants in freshness indicators. Natural colorants have positive properties such as being easily biodegradable in nature and in the human body, low toxicity and very low environmental impact, and negative properties such as low colouring ability and low light fastness (Chiu & Yang, 2024).
Anthocyanins are one of the colorants used to create pH-sensitive biosensors in smart packaging applications (Figure 7). Anthocyanins are known to be antioxidant, antibacterial and pH sensitive. One of the biggest disadvantages of anthocyanins is that they are not stable against light and heat. For this reason, low temperatures must be used in the preparation of the polymeric matrix used in smart packaging design. In addition, the smart packaging materials produced are either exposed to less light on the inside of the package. Forming a two-layer film with substances such as ZnO will facilitate its use. Due to the low observability of colour capacity at low concentrations, the polymer matrix to be used is expected to be colourless so that the colour of the anthocyanin is easier to detect. Some colour differences may occur depending on the pH of anthocyanins from different sources. In addition, the use of excessive amounts of anthocyanins will create aggregation problems and have a negative effect on the mechanical properties of the film. Plasticizers can be added as reinforcements to increase the mechanical and barrier properties of the films.

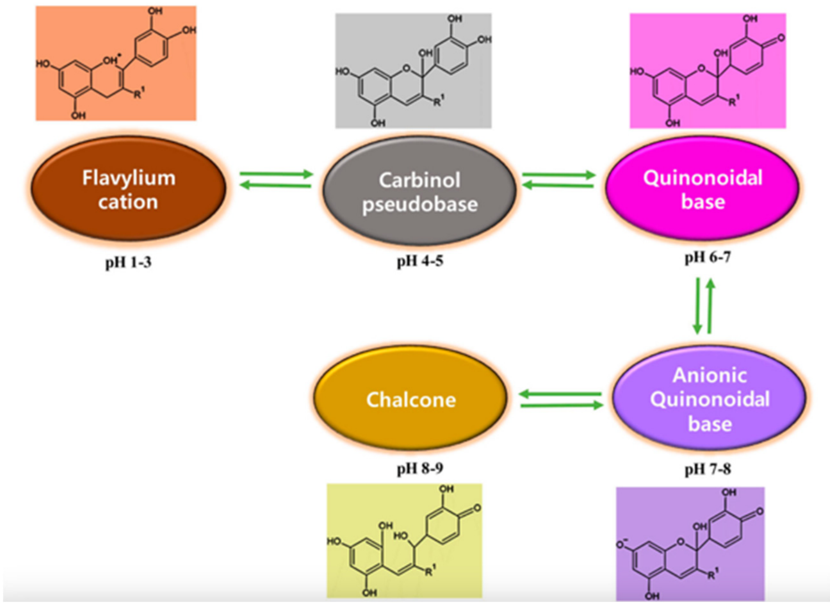

Figure 7: pH-dependent chemical structures of anthocyanin (Roy & Rhim, 2021).

Curcumin obtained from turmeric is also used in studies on smart packaging application (Figure 8). It has been determined that the addition of curcumin in smart packages, in addition to its colour change against pH, has a high level of antibacterial activity against foodborne pathogens such as *Escherichia coli*, *Salmonella spp* and *Listeria monocytogenes* etc. in films made from pectin/chitosan mixtures and chitosan-based materials. In addition, it has been concluded that curcumin is a good candidate material for smart packaging systems because the films added to curcumin do not lose their transparency and improve their properties such as mechanical, barrier, hydrophobic and thermal stability. Apart from these, there are studies on the usability of carotenoids and chlorophyll in smart packaging applications (Zheng et al., 2022).

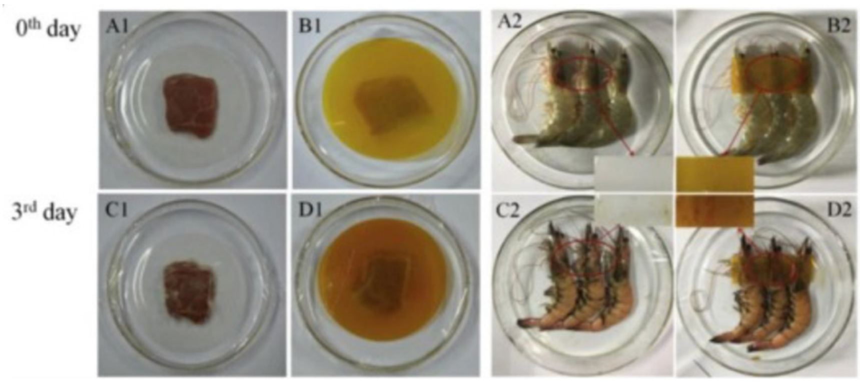

Figure 8: Curcumin based smart label (Roy et al., 2022).

Smart packaging methods provide valuable insights and information to both consumers and supply chain stakeholders. It enhances user experience, improves product safety, and reduces waste. However, the choice of smart packaging method should be compatible with the specific needs and characteristics of the product, and the advantages and disadvantages should be carefully considered to ensure effective application.

Another new generation packaging application can be considered active packaging. Active packaging works by incorporating active materials into the packaging to provide features such as extending the shelf life of the products and maintaining their current quality (Nian et al., 2024). For example, oxygen scavengers can be added to packaging material to prevent oxidative degradation. Another example is humectants. These prevent mould formation by reducing the water vapor in the food. The most used types of active packaging include oxygen scavengers, carbon dioxide scavengers, ethylene scavengers, self-heating or cooling cans and antioxidant releaser films (Rani et al., 2024). In order to remove harmful and unwanted gases contained in the packaging, various gas regulators such as absorbent sachets, absorbent porous pads, dust types placed in paper/cardboard, semi-permeable membranes, strips and self-adhesive labels can be used to contain the gas content. Although sachets are the most used active packaging type, alternative approaches such as adding functional materials to polymer matrices attract attention due to high packaging costs and safety concerns.

Oxygen scavengers aim to remove oxygen from the packaging environment and thus prevent problems that may occur in the product (Figure 9). Iron powder, ascorbic acid, enzymes, unsaturated fatty acids and yeasts can be used as oxygen scavengers (Gupta, 2024). When the literature is examined, it is seen that most studies are based on iron oxidation. The risk of swallowing oxygen scavengers, which are usually added to the packaging in small packets, is one of the biggest usage restrictions. In addition, possible package explosions and contamination of food with iron dust are other factors that need to be taken into consideration. Another problem encountered when sachet oxygen scavenger is added to the packaging is that there is difficulty in capturing oxygen due to the lack of air flow. For this purpose, integrating oxygen scavengers into the packaging material will overcome the problems. Oxygen scavengers have advantages such as extending the shelf life of food, medicine, etc. that are spoiled by oxygen, slowing down the decomposition by inhibiting aerobic bacteria, but also have disadvantages such as accelerating the decomposition of fresh products that require oxygen and being costly (Vermeiren et al., 2003).

Figure 9: Oxygen scavenger sachet (What is modified atmosphere packaging, 2024)

Ethylene gas is a plant-based chemical that affects some fruits and vegetables (Figure 10). Breathing ethylene gas accelerates ripening, thus causing food to rot earlier. To extend the shelf life of food products and slow down decay, ethylene must be restricted or removed from the environment. Potassium permanganate is the most used ethylene scavenger (Kumar et al., 2024). Potassium permanganate is reduced by reacting with ethylene; thus, ethylene is removed from the environment, and with the reduction, the colour of the permanganate changes from purple to brown, which gives us information about the lifespan of the scavenger. Ethylene scavengers can be useful in packaging foods with high usage areas such as apples, apricots, mangoes, bananas, tomatoes, avocados, carrots, potatoes and similar (John et al., 2024).

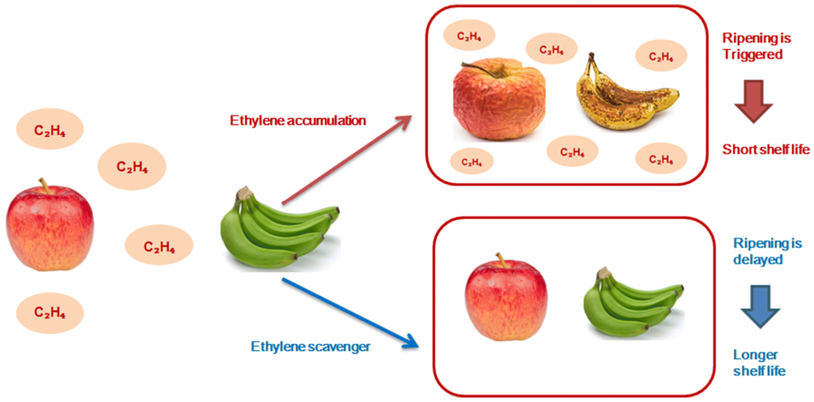

Figure 10: Ethylene scavenger working principal diagram (Gaikwad et al., 2020)

Carbon dioxide (CO_2) is released as a result of spoilage and respiratory reactions in some foods (Figure 11). This gas released causes both the food to deteriorate faster and the packaging to swell and explode. For this reason, this gas accumulated in the packaging must be removed. The most common way to remove carbon dioxide is to react it with calcium hydroxide. As a result, calcium carbonate and water are released. The problem can be eliminated by collecting the resulting water in the pad (Rani et al., 2024).

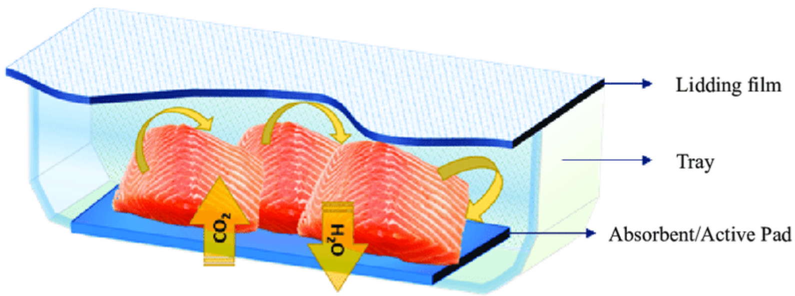

Figure 11: CO_2 scavenger sachet (Boz et al., 2018)

When recent studies are examined, improving the capabilities of materials in new generation packaging attracts attention. Bio nanocomposites are used to improve the thermal properties of materials and provide barrier properties. While providing these properties, an antimicrobial effect can be achieved by adding nanoparticles. While providing these features, there are factors such as the cost of the material produced, the safety of bio-nano composites in contact with food and compliance with health/safety regulations in order for the new generation packaging to be commercially applicable. Although biosensors used in smart packaging are an interesting component, their adaptation to the packaging poses some difficulties. Microstructures, sensitivities, specificities, and detection limits of biosensors, and ensuring consistent sensitivity over time are some of these. Despite all their positive capabilities, the commercialization of new generation packaging technologies is still in its infancy. In this sense, more research is needed on new generation packaging technologies. A comprehensive understanding of next-generation packaging technologies is crucial to creating sustainable and affordable smart packaging materials.

In order for smart packaging systems to be used in the market, strict regulations must be established

regarding the materials used and the labeling to be done. For example, care should be taken to clearly label products that should not be eaten, such as oxygen-scavenging sachets. To eliminate such problems, studies are being carried out on the development of packaging-integrated systems.
Promoting sustainability in the packaging industry requires considering issues such as the type of packaging material used, recycling, reusable products and the environmental damage caused by packaging waste. In addition, the resistance that antimicrobial materials used in new generation packaging technologies will create on bacteria should not be ignored. Even though smart and active packaging technologies try to meet market demands, the positive properties of synthetic polymers still make them preferred in use. However, studies continue at full speed to ensure that sustainable and environmentally friendly bioplastics, which emerge with evolving personal and social perceptions, provide the desired properties. Even though most of the currently developed materials are at laboratory size, it is thought that food-contact packaging will increase the safety of food in the future. Going back to nature is not only about polymers, but studies on selecting active ingredients from natural sources are continuing rapidly. The development of new naturally compatible bioplastics and the modifications of the resulting biofilms are promising in new generation packaging. In addition, there is a need for more research, scaling and evaluation specific to products, so that new regulations can be introduced, and the most appropriate packaging systems can be implemented. With the regulations in the light of these developments, consumers' trust in new generation packaging systems and thus the packaging market will develop.

2. CONCLUSIONS

As a result, new generation packaging systems have enabled us to take significant steps into the market by increasing food safety, shelf life, quality and sustainability. Real-time monitoring, sensors, indicators, and tracking systems have reduced product waste, ensuring consumer awareness and better experience. Integration with IoT platforms has opened the doors to supply chain management, traceability and correct use of products. The concept of sustainability has become more prevalent in our lives with environmentally friendly, recyclable and reusable packaging. It is clear that these technologies will develop further in the future when more conscious consumers, higher quality products and less waste will be provided by using new generation approaches in the packaging industry.

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