4. PACKAGING SUPPORTING FOOD SUSTAINABILITY

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Mariusz Tichoniuk

Department of Industrial Products and Packaging Quality, Institute of Quality Science
Poznań University of Economics and Business, Poland
mariusz.tichoniuk@ue.poznan.pl

Karolina Wiszumirska

Department of Industrial Products and Packaging Quality, Institute of Quality Science
Poznań University of Economics and Business, Poland
karolina.wiszumirska@ue.poznan.pl

Abstract

The chapter generally presents a new approach to the design of packaging and packaging materials that supports food sustainability. Concern for environmentally friendly packaging and packaging materials drives the development of their design for recycling and increasing popularity of reusable packaging. Food sustainability is also one of the main prerequisites in the packaging optimum approach and ensuring product accessibility via its packaging applied in the supply chain. Active packaging systems allow for extending the shelf life of food, and intelligent packaging supports the reduction of food waste and losses. Modern solutions for automatic data collection, such as RFID tags and geolocation systems, can also support the management of data on food products in logistics. The chapter presents successively new approaches to packaging design, design for recycling, reusable packaging, and smart packaging solutions supporting food sustainability.

Keywords: sustainable packaging design, packaging materials, active packaging, intelligent packaging, design for recycling.

JEL codes: L69, O39, Q01, Q56, Q59.

Introduction

Providing the population with food is one of the main tasks of the economy, both locally and globally. Economic activity, including food supply, is associated with costs and possible burdens for the environment. Especially the latter are particularly considered in the implementation of the sustainable development policy. The food supply chain is inextricably linked to the use of packaging as well as product labelling systems (Otto et al., 2021).

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Traditional functions of food packaging encompass the preservation of food from contamination and undesirable environmental conditions, as well as maintaining its freshness and quality, which leads to ensuring the product shelf life (Siracusa & Lotti, 2019). Further tasks for packaging relate to communication of required information about the product (e.g., nutritional content, expiration date), its storage and consumption conditions. Packaging also provides the convenience of product handling both by the consumer and other participants of the supply chain, which is also related to food containment (Kuswandi & Jumina, 2020). To support food sustainability, conventional packaging had to evolve in areas of waste preservation, logistic process optimisation, recyclability and reuse of materials. This meant recognition of new criteria in the design, which should be environmentally conscious to reduce the impact of both packaging waste and food loss (as well as food waste).

The differentiation between food loss and its waste is not firm and based on the recognition of the stage of the food supply chain involved in this adverse event. Food loss occurs in the stages of the food supply chain present before the product reaches the consumer. It is mainly related to food preparation and post-harvest processing (Ishangulyyev et al., 2019). It could be referred to losses caused by the evaporation of water and volatile substances, mismatch between transport or storage conditions and food requirements as well as sorting losses. Food waste refers to the losses resulting from the actions and decisions of the consumer that take place during the distribution and consumption of food (Conrad & Blackstone, 2021). Consumers, knowingly or unknowingly, generate huge amounts of food waste as a result of their neglect of food's suitability for consumption, accumulation of excess stocks or irresponsible purchase of unnecessary products. Table 4.1 shows examples of food losses and waste that can occur in the supply chain and how packaging can support food sustainability.

Packaging plays a very important role in the food supply chain and has great potential to reduce food losses and reduce food waste (Ganeson et al., 2023). Many sources of food loss/waste in the supply chain have the basis in inappropriate stock management, packaging mismatches and bad communication concerning the properties of packaged products. The packaging design can ensure a sustainable approach to both food products and their packaging, limiting the waste of resources and reducing the negative impact on the environment.

Perishable food with a short shelf life can easily become waste if it is not stored properly or the best-before dates are missed. The reduction of food waste could be facilitated by the introduction of active packaging technologies focused on their additional capabilities to directly enhance or maintain food quality. An additional advantage of active packaging application could be the reduction of food processing and chemical preservation, which supports sustainable food production. Absorbers (scavengers) can remove chemical substances that adversely affect the

Table 4.1. Potential food loss/waste in the food supply chain and possible packaging support for food sustainability

Food supply chain stages	Potential food loss/waste	Packaging support for food sustainability
Agricultural production and harvest	• improper post-harvest treatment and storage of food raw materials (e.g. mechanical damage, microbial contamination, field or barn loss)	• bulk packaging and protection against contamination (raw material loss) • reusable containers and packaging adapted to the supply chain
Food processing, packaging and storage	• food loss, damage and/or contamination during processing and packaging filling • incorrect selection of packaging in relation to product properties • over/underestimation of shelf life of packaged food in relation to specific storage conditions	• food preservation in packaging or product portioning in barrier-tight packaging systems • matching the packaging to the food product's storage and transport susceptibility—packaging optimum approach • active packaging extending food product shelf life
Food transport and wholesale distribution	• packaging failure/damage in distribution • multiple handling of raw food products • excess stock (oversupply) and/or poor stock rotation	• identification and tracking of supply chain losses • system packages and reusable containers adapted to the supply chain • intelligent packaging and data sharing within the supply chain
Retail or HoReCa supply	• food perishing in distribution and after sale • mismatch of the product portion to the final recipient (e.g., inedible portions)	• recognition of customers' shopping/eating habits and matching of food packaging • designed multiuse/refilled packaging or food distributors before final consumption • retail ready packaging
Final consumer storage and food consumption	• missed food expiration dates • food remnants left in packaging • inappropriate food packaging capacity	• accessible packaging design • packaging designed for recycling • intelligent packaging for consumer application

Source: based on (Ganeson et al., 2023; Verghese et al., 2013).

packaged product, emitters introduce the desired substances, while antimicrobial substances—also present in active packaging—limit the growth of undesirable microorganisms (Carvalho et al., 2021).

On the other hand, the reduction of food waste can be supported by the use of intelligent packaging and modern automatic data collection (ADC) systems. Intelligent packaging systems are able to indicate the real state of packed food (ripeness or spoilage) and monitor the environmental conditions that affect the product's shelf life (Schaefer & Cheung, 2018).

The choice of proper packaging supporting the sustainability of food products requires fast and reliable collection of information on products appearing in the supply chain. Automatic Data Collection (ADC) systems based on barcodes placed on the packaging allow for quick gathering of information about the packed foods and their properties. Even more efficient collection of information about the products can be ensured by the introduction of packaging equipped with optical 2D codes (e.g. QR codes) or RFID (Radio-Frequency Identification) tags.

4.1. New approaches to packaging design

Most products offered on the market are sold in packaging. To date, the approach to the packaging design process has largely been based on voluntary standards and sanctioned by regulations within a rather narrow scope, i.e. related to ensuring product and consumer safety. Many aspects with regard to the selection of packaging materials, the size and shape of the packaging, the method of printing and decorating or the choice of closing systems are left to the discretion of manufacturers and brand owners. Packaging has become an excellent tool for building competitive advantage in the market but with a whole range of (negative) consequences.

Designing optimal and sustainable packaging should balance ensuring product protection with the minimal negative environmental impact of packaging. This requires adequate packaging methods and systems, the ability to make improvements and innovations in transportation and distribution processes, the introduction of new sales and marketing concepts, as well as an efficient collection and recycling system. Innovations introduced at one stage may not cause hindrances at subsequent stages but can be the initiators of positive changes (Jepsen et al., 2019).

Designing packaging, or deciding to partially or completely eliminate it, must never conflict with consumer, product and environmental protection. The key protective function of the packaging must be maintained and ensured at an optimal level. The word “optimal” is used intentionally here because any packaging requires using resources for the packaging, and underpackaging or overpackaging will have a negative environmental impact (Jepsen et al., 2019).

Designing in terms of optimal resource utilisation aims to protect the product and minimise the number of waste streams introduced. For years, brand owners have been accustomed to using richly decorated packaging, multi-material laminates with very high barrier properties, thick and rigid packaging delivering excessive properties, without asking themselves what kind of packaging the product requires and what the customer expects.

“Ecodesign” or “sustainable packaging design” is based on multiple principles, the most important of which are presented below. The ecodesign process should:

- encompass holistically the packaging design and implementation process from a supply chain perspective,
- identify processes and relationships directly and indirectly related to packaging,
- predict and analyse the benefits and costs of marketing packaging,

- fit in and conform to the assumptions of the circular economy sanctioned by European Union policies and regulations,
- fit into the canon of good market practices oriented towards reducing the generation of packaging waste and eliminating impediments to mechanical recycling,
- conform to the packaging waste hierarchy, be recyclable in practice and on a large scale, as well as use recycled materials as much as possible,
- protect the product and prevent product loss and waste,
- provide convenient, user-friendly and safe solutions that take into account the needs of different user groups (accessible design),
- communicate high-quality, understandable, verified, reliable, relevant and timely environmental information (Jepsen et al., 2019; ISO 14021:2016, 2016; PPP, 2022, 2023).

A new approach to packaging selection and design should be based on the three pillars: elimination, reuse and material circulation (Ellen MacArthur Foundation, n.d.), and should focus on reinventing the role of packaging along with the reasons for its use. The design of packaging accompanying consumers over the past 20–30 years has reinforced the belief that better packaging means a better product. Moving beyond this pattern requires a change in the directions and mindsets not only of designers and brand owners but also of consumers themselves. The new era in packaging design starts by breaking down the packaging design patterns that have been duplicated so far, and prompts questions about the context and business model for delivering products and services to consumers in such a way that they have value for consumers and users, but at the same time reduce packaging waste on a global scale (Ellen MacArthur Foundation, n.d.).

Implementing change and upstream innovation in the packaging industry is not intended to take value away from products or limit their usefulness or marketability, but to achieve the desired effect by implementing new design tools and finding solutions. This can be done by verifying packaging at three levels:

1) business model analysis and verification of social, environmental and economic benefits—supply chain model, geographic coverage of the system, verification and fulfilment of the needs of user groups and the types of packaging and ancillary products used; use of volume packaging, introduction of in-home or station filling systems, use of returnable packaging, sale of products in bulk or filling of own containers, introduction of collection or exchange points (Ellen MacArthur Foundation, n.d.; PN-EN 13429:2007);
2) analysis of the product and the way it is sold and delivered—refers to the analysis of the recipe and the content of certain ingredients (including water content or fillers), the shape, size and actual amount of the product that users need and expect; in this area, it is possible to achieve a change in the physical state of the product or to reduce certain elements of the packaging due to

the transmission of digital information about the product (Ellen MacArthur Foundation, n.d.);

3) verification and reinvention of the design of the packaging based on the needs of users and to ensure the safety of the product—such analysis should verify the reasonableness of all packaging components and elements (including their weight, thickness, strength, barrier properties, etc.), materials from which they are made, size of the packaging and the ratio of the weight of the packaging to the product, void space, method of opening, dispensing and access to the contents, packaging components and their role as well as the possibility of their elimination, ease of sorting the packaging waste, compatibility with collection and segregation systems and recycling processes (mechanical, biological, chemical), as well as the possibility of using recyclables in closed and open loops (PPP, n.d.; Ellen MacArthur Foundation, n.d.).

4.2. Design for recycling

Packaging placed on the market must be designed and made in such a way that it can be reused and subsequently recycled, or at least recycled if reuse is not possible, or offer a form of recovery other than recycling if recycling is not possible (Act of 13 June 2013). This should be evaluated in terms of compliance with European harmonised standards for packaging design, which should meet at least three main criteria:

1) concerning production and composition (PN-EN 13428);
2) concerning reusability (PN-EN 13429);
3) concerning recovery: by material recycling (PN-EN 13430), energy recovery (PN-EN 13431) or organic recovery (PN-EN 13432).

Packaging design for recycling is one of the elements of packaging design with its full life cycle in mind, but the recyclability of packaging materials ensures their circularity (Act of 14 December 2012; Act of 13 June 2013; Act of 14 April 2023). This impacts future recycling targets (Regulation of the Minister of Climate and Environment of 19 December 2021) and the obligation to use recyclables in packaging placed on the market. As defined in Regulation 2022/1616, "'recycling technology' means a specific combination of physical or chemical concepts, principles and practices to recycle a waste stream of a certain type and collected in a certain way into recycled plastic materials and articles of a specific type and with a specific intended use, and includes a decontamination technology" (Commission Regulation (EU) 2022/1616).

Proper packaging design using different materials requires knowledge of collection, sorting, identification and processing technologies, as well as barriers affecting elimination from the process, reduction in the quality of recyclates obtained, or negative impacts on other materials in the stream.

The first stage is the collection of packaging waste from users, i.e. consumers (Post-Consumer Waste, PCW) or manufacturing companies (Post-Industrial Waste, PIW). This waste generally differs in its homogeneity, degree of soiling, as well as identifiability of materials and their properties. Consumers in Poland are required to sort packaging waste into five different fractions: paper, glass, metals, plastics, multi-material packaging waste and bio-waste (Regulation of the Minister of Climate and Environment of 10 May 2021). The quality of sorting by consumers largely depends on consumers' familiarity with packaging materials and signs on packaging indicating the type of material and/or additional information to facilitate sorting (Regulation of the Minister of Environment of 3 September 2014). The level of actual knowledge of Polish consumers regarding the guidelines for waste sorting is insufficient (Wojciechowska & Wiszumirska, 2021), resulting in the loss of valuable packaging waste that does not reach recycling streams from the mixed waste.

The collection stage is followed by further industrial processes of pre-sorting, identification, washing/cleaning and processing. The quality and efficiency of processing are influenced by the first stages of the process, i.e. pre-sorting and screening of contaminants and traceability. Sorting and screening of contaminants involve classifying materials by size. A drum screen used here is the most common method of sorting, which can reject parts with dimensions of less than 20–50 mm. These are fine organic and inorganic contaminants. In the case of sorting plastic waste, nuts, small labels or small flexible packaging also end up in the subscreen fraction. Thus, small-sized packaging or components detached from the main packaging may be rejected early in the process. The next stages of identification take advantage of different technologies (e.g., manual sorting, magnetic and eddy current separation, optical sorting or other technologies, such as X-ray). Each waste stream has different requirements and barriers. The most important examples are briefly discussed below.

4.3. Reusable packaging

Today's consumer is accustomed to the use of disposable packaging because its production is affordable and perfectly integrated into everyday consumption and business models. "Business as usual" has so far not given due consideration to the circularity of resources in the economy. The dominant linear ("take-make-dispose") economy creates value by mass-producing and selling as many products as possible. The circular economy is guided by the 3Rs principle (reduce, reuse, recycle). The difference in the two approaches (linear and circular) lies largely in resource efficiency in the circular model (reduce), maximising the use of products through their extended life cycle (reuse) and returning valuable raw materials through efficient, accessible, effective and safe recycling systems (recycle). The change in attitude towards the use through elimination, reuse, product-service swaps, repairability or regeneration and other models will increase eco-effectiveness. Reusable packaging is an excellent example of this; however, it is worth noting that it is not a remedy for the environmental problems caused by packaging waste and that it is one of the options available, which requires consideration of environmental, social and economic benefits and costs.

The design of reusable packaging and reuse systems must comply with current legal requirements, which indicate the framework and limits of their use in a given market. Reusable packaging design is second in the European waste hierarchy (right after prevention), which means it should be taken into consideration before choosing single-use packaging (Directive 2008/98/EC). The definition of "reusable packaging" includes several conditions that the packaging must simultaneously meet, including: design criterion, market criterion, usability criterion, end-of-life criterion (Act of 13 June 2013; Commission guidelines, 2021).

Reusable packaging is a cohesive part of the system. Based on PN-EN 13429:2007, three reusable systems can be distinguished: closed loop, open loop and mixed loop. In the closed loop system, packaging rotates within a single company or a group of cooperating companies. In the open loop system, packaging circulates between unspecified companies. On the other hand, the mixed loop system additionally uses disposable packaging, which acts as an auxiliary product, and reusable packaging remains the property of the end user.

To maximise the benefits of reusable packaging systems, it will be necessary to change the approach of broader packaging design. Paradoxically, reusable packaging may consume more resources than lightweight disposable packaging (per unit of packaging), but both the materials and their management systems should reduce the number of raw materials used and waste (including packaging) generated in the long run. In addition, the specific requirements for packaging design may change depending on the system in which the packaging operates.

The criteria for the operation of the mixed system, which assumes that the person emptying the packaging is also the filler who uses another disposable packaging for this purpose (e.g., refill at home), do not fit into the new legal perspective and do not prevent waste (PPWR, 2023). Instead, a refill station is proposed, where consumers can buy a product and refill their packaging with the same product or choose from a range of several products.

The refill/reuse models will enable new insights into the use of materials such as metals, glass and plastics. Reusable packaging must be designed to achieve a longer shelf life and a target number of rotations, as well as to be compatible in the stages of refilling, cleaning and disinfection, collection and return, and finally, be recyclable in practice and on a large scale.

To see the broad perspective of the innovation of reuse models and available solutions, it is worth looking at several solutions that offer product return or refilling systems (Ellen MacArthur Foundation, n.d.).

These considerations primarily apply to business-to-consumer (B2C) solutions, but this system also benefits the business-to-business (B2B) level, and there are many well-functioning solutions on the market. Transportation packaging and infrastructure should be standardised across the system, and some solutions can be offered as a service. Smart labelling, identification and tracking systems are also used throughout the supply chain to help optimise costs and logistics, such as the CHEP Pooling System based on the concept of "share and reuse" (CHEP, n.d.) or REUSA-WRAPS for reusable pallet wraps (REUSA-WRAPS, n.d.).

4.4. Smart packaging solutions supporting food sustainability

4.4.1. Active packaging systems extending the shelf life of food

Food shelf life is a derivate of such factors as the selection of raw food materials (suitable for treatment and/or storage), processing them with physical and/or chemical methods, as well as their recommended storage and transport conditions (including packaging selection) (Soro et al., 2021). The need for packaging applications originates from its practical aspect of holding a certain amount of food together and protecting it within the supply chain. According to FAO reports, about 14% of food products are lost in the supply chain before they reach the final consumer (FAO, 2019). Protection against adverse physical conditions as well as chemical and/or microbial contamination is a result of the barrier capabilities of packaging construction and its materials, which is a passive (conventional) way of product preservation against external factors (Schaefer & Cheung, 2018). Active packaging systems are developed to effectively influence packed food and/or its surroundings, which results in the extension of food shelf life.

European legislation, i.e. Commission Regulation (EC) No 450/2009 of 29 May 2009 (Regulation (EC) No 450-2009), defined active packaging and packaging materials as deliberately implemented components that would release or adsorb substances into or from the packed food or the environment surrounding the food. In this way, chemical compounds that adversely affect the packaged food (e.g., excessive humidity, ethylene, oxygen) are removed from the food or its environment, and substances that have a beneficial effect are introduced into the product or its environment (e.g., carbon dioxide, antimicrobial substances) (Carvalho et al., 2021). Active packaging systems influence mainly the rate of respiration (especially raw products from plant origin), reduce the growth of microorganisms, and limit oxidation or moisture migration (Kuswandi & Jumina, 2020). Application of active packaging systems could reduce the amount of necessary preservatives in food, and may eliminate or enhance another process used to prolong the food shelf life (e.g., modified atmosphere packaging) (Firouz et al., 2021).

A promising direction for the development of active packaging is the application of biodegradable compounds and bio-preservatives as well as nutraceuticals, antioxidants and antimicrobial agents of natural origin in packaging materials (Petkoska et al., 2021). Food product sustainability could also be supported by the replacement of fossil-based packaging materials with compounds obtained from natural sources (e.g., chitosan, starch, seaweed, animal proteins) and the development of bio-based films, which could be enriched with bioactive compounds such as essential oils, plant extracts, enzymes, chitosan and/or organic acids (Soro et al., 2021). This is in line with the global trend of developing environmentally friendly technologies and confirms that consumers tend to purchase sustainable alternatives over non-sustainable (Granato et al., 2022). A lot of active packaging is being developed in research laboratories, and a large part of them is available on the market—from simple moisture-adsorbent pads to complex systems for the absorption or emission of specific chemical compounds (Firouz et al., 2021). Recognisable active packaging systems applicable in the food supply chain are, for example, oxygen scavengers like Ageless® sachets (Mitsubishi Gas Chemical Co), Fresh-R-Pax® moisture absorbent trays (Multisorb Technologies Inc.), carbon dioxide emitter Fresh Pax type M (Multisorb Technologies Inc.) and antimicrobial agent Zeomic™ (Sinanen Zeomic).

4.4.2. Intelligent packaging solutions supporting reduction of food waste

Sustainable food production and distribution aims at providing the required amount of food products for local consumers (reducing unnecessary transport) as well as sufficient food supply for global recipients (e.g., in areas affected by famine). In both cases, food waste is an undesirable phenomenon (Ganeson et al., 2023). Unfortunately, according to FAO reports, over 30% of food produced for human consumption is lost or wasted (FAO, 2019). During the storage and distribution stages, it could be exposed to different harmful factors such as microbiological infection, violation of packaging integrity, temperature, and/or humidity other than optimal. Protection against the above factors is provided by various types of conventional packaging, while the need to monitor them in real-time has contributed to the development of intelligent packaging (Siracusa & Lotti, 2019).

The definition of intelligent packaging (Regulation (EC) No 450-2009) reveals the purpose of its development, according to which it is tasked with continuous control of food package conditions and the environment surrounding the food during storage and transport.

In general, the construction of intelligent packaging systems is based on an indicator or sensor that reacts specifically to defined phenomena such as the temperature change (e.g., time-temperature indicators), presence of recognisable chemical compounds (e.g., packaging integrity indicators) or microbiological contamination (e.g., freshness indicators) (Soro et al., 2021). Simple colorimetric indicators are the most user-friendly intelligent packaging solution because a change in their appearance can be easily recognised, signalling the presence of a monitored event, e.g., exceeding the limit temperature or occurrence of target chemical compounds (Schaefer & Cheung, 2018). Simple time-temperature indicators (TTIs) based on temperature-dependent chemical reactions, enzymatic activity or physical phenomena are also very applicable. Among some well-known representatives of this group are commercially available 3M™ Monitor Mark™ (3M Company), On Vu™ (Freshpoint) and Fresh Check® (Temptime Co).

More detailed information about the current state of packaged food products could be provided by integrity or freshness indicators, which are sensitive to specific volatile chemical compounds (Tichoniuk et al., 2021). Integrity indicators could detect gas from packed products or leaky packaging. Ageless Eye® (Mitsubishi Gas Chemical)—an integrity indicator—is one of the commonly used intelligent packaging elements, which are sensitive to the increase of oxygen concentration. It reacts positively in case of MAP packaging leakage (the loss of barrier against ambient oxygen), but it often has to be supported with some oxygen scavenger inside the packaging to avoid a false positive response because of residual oxygen released from the packed product (Schaefer & Cheung, 2018). Freshness (or ripeness) indicators are sensitive to different types of metabolites released into the packaging atmosphere during spoilage (or ripening) of packed food products (e.g., carbon dioxide, organic acids, esters, volatile sulphury or nitrogen compounds) (Kuswandi & Jumina, 2020). The simplest freshness indicators are based on the use of colorimetric markers sensitive to volatile substances that change the pH and colour of detection systems, and most often indicate the development of undesirable microflora associated with food product spoilage (Tichoniuk et al., 2021). Despite the many scientific reports on this type of indicators, they are relatively difficult to introduce into packaging systems on a larger scale due to difficulty with their integration (compatibility between materials, sizes, shapes, mechanisms of action), production costs (issues of mass production and indicator universality) and satisfactory analytical properties (specificity, sensitivity, detection limit, stability) (Sobhan et al., 2021). It is possible that the development of novel 3D printing technologies, such as stereolithography and extrusion-based 3D printing, will provide very precise and cost-effective tools for the fabrication of intelligent packaging (Tracey et al., 2022).

4.4.3. Novel automatic data collection (ADC) systems

Easily accessible and reliable information about the food product allows the supply chain participants to adjust the optimal packaging both in terms of its construction and materials, as well as following other properties required by the sustainable product. Specialised computer programs (connected with the IoT technologies) facilitate planning of the packaging needed to secure food products and optimise the arrangement of loads in means of transport or storage areas (e.g. as part of Warehouse Management System software) (Blanck, 2015). Labels and codes placed on the surface of the packaging, as well as electronic tags or chips placed in loads, allow for the automatic location of goods in the supply chains and protect them against product fraud and counterfeiting.

Radio Frequency Identification (RFID) systems are a kind of successor of automatic optical recognition technologies commonly used in ADC procedures because they offer a contactless transfer of information in real-time and possess a greater data storage capacity than traditional bar-codes (Bibi et al., 2017). RFID tags have various forms and are generally divided into groups of active, semi-passive and passive devices depending on their design. The transfer of data through the transmission of electromagnetic waves between RFID tags and receivers located in means of transport, elements of warehouse equipment and mobile devices helps to control the course of logistics processes, improves the flow of information about loads in the supply chain, and increases the possibility of tracking loads during transport and storage (Ahmed et al., 2018). RFID tags placed in primary or secondary food packaging, transportation containers or pallets allow for non-line-of-sign contact identification in the supply chain, which could significantly improve product traceability and inventory management. What is more, RFID tags in combination with sensors (temperature, humidity, volatile compounds, pH, integrity and traceability sensors) could strengthen the management of the food supply chain as well as indirectly influence the reduction of food waste and directly improve tools for food quality and safety control (Zuo et al., 2022).

Replacing RFID tags with NFC (Near Field Communication) labels allows ordinary consumers to read the deposited data using NFC-compatible smartphones. Additionally, chemoresponsive nanomaterials combined with NFC labels could estimate volatile chemical compounds in the packaging atmosphere (e.g., ammonia, water vapor) (Urbano et al., 2020). However, current consumers appreciate different types of labels included in a group of IoT solutions that extend the scope of information provided by the product packaging. QR (Quick Response) codes placed on food packaging surfaces can be scanned with a smartphone camera and redirect the consumer to websites containing a variety of product information (Khan et al., 2023). It can also be used for tracking the product throughout the supply chain, as well as for traceability in case of a recall (Trueqrcode, 2023). QR codes could provide consumers with additional information about sustainable practices used in the production of a given food item, such as organic farming, fair trade or non-GMO certifications. In addition, they can also educate in the area of responsible and sustainable consumption (also in connection with reduction of food and packaging waste). Using different types of IoT technologies and electronic information carriers on food packaging (RFID tags, NFC labels, QR codes) allows for the flexibility of updating the information connected with the product, without having to redesign the entire packaging (Zuo et al., 2022).

Conclusions

Products requiring packaging at various stages of production, distribution, and consumption attract special attention due to the need for their meticulous design. Packaging design is becoming more and more ingrained in industrial requirements, international standards, regulatory requirements, and best practices; it is no longer the sole purview of materials engineers. The goal of the new design methodology is to strike a balance between engineering, ecology, economics, and marketing. Reducing the harmful effects of packaging production and usage on the environment while preserving the highest level of food safety is the goal of the packaging industry revolution. The creation of food packaging is not as environmentally friendly as food losses resulting from improper packaging.

Packaging can also have a functional impact on the development of sustainable products and the promotion of sustainable food consumption. Active packaging systems equipped with absorbers of undesirable substances or releasing components that extend the shelf life of food increase its availability, stability, and possibility of consumption over a longer period. There is also scope for the introduction of biodegradable materials and/or components of natural origin that are more environmentally friendly. The impact of the environment on the packaged product and changes occurring in the food product can be continuously monitored by sensors and indicators that are the basis for the operation of intelligent packaging. Information about changes occurring in packaged food allows for effective control and reduction of food waste. More efficient management of food supply chains and easier transfer of information (also to the final consumer) is enabled by the development of modern systems for automatic data collection and augmented reality technologies related to packaging and labels.

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