# The Impact of Technology on Food Waste: Smart Packaging

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## ABSTRACT

Food waste, which is constantly increasing and requires urgent intervention at all stages of the food supply chain, is a major problem. Failure to address this issue leads to larger problems such as biodiversity degradation, the climate crisis, and migration. Technological products are seen as a significant opportunity to prevent waste. Therefore, this study aims to explore the impact of technology on food waste, with a specific focus on smart packaging. By reviewing the literature on the subject, the study discusses and explains technological solutions to food waste (such as mobile phone applications, smart devices, waste recycling, and smart packaging), the relationship between packaging and food waste, and the importance of smart packaging in reducing food waste. In conclusion, it has been determined that technology is a crucial element in combating waste, new technologies should be supported, and the smart packaging system, in particular, plays a key role in preventing waste at the retail and consumption levels.

**Keywords:** Food waste, Smart packaging, Technology

## Teknolojinin Gıda İsrafına Etkisi: Akıllı Paketleme

### ÖZ

Gıda tedarik zincirinin tüm basamaklarında devamlı artış gösteren ve acil müdahale gerektiren gıda israfı büyük bir sorun olarak karşımıza çıkmaktadır. Bu sorunun çözülememesi biyoçeşitliliğin bozulması, iklim krizi, göç gibi daha büyük problemleri doğurmaktadır. İsrafın önüne geçmede teknolojik ürünler önemli bir fırsat olarak görülmektedir. Bu sebeple çalışmada teknolojinin gıda israfı üzerine etkisi ortaya konularak akıllı ambalaj özelinde değerlendirilmesi amaçlanmaktadır. Konuya ilişkin alan yazın taranarak gıda israfına çözüm olarak sunulan teknolojik ürünler(cep telefonu uygulamaları, akıllı cihazlar, atıkların geri dönüşümü, akıllı paketleme), ambalaj ile gıda israfı ilişkisi ve akıllı ambalajların gıda israfındaki önemi tartışılarak açıklanmıştır. Sonuç olarak; teknolojinin israf ile mücadelede önemli bir unsur olduğu, yeni teknolojilerin desteklenmesi gerektiği ve özellikle akıllı paketleme sisteminin perakende ve tüketim basamaklarında israfın önüne geçmede kilit rol oynadığı tespit edilmiştir.

**Anahtar Kelimeler:** Gıda israfı, Akıllı paketleme, Teknoloji

## INTRODUCTION

The Food and Agriculture Organization (FAO) has stated that an estimated one-third of all food produced for human consumption is wasted [1]. Therefore, food waste has been as an extremely important global problem for societies [2]. While food still has social, economic, and nutritional values at the service sector and household levels, food waste, which refers to the decision to discard or throw away, creates environmental and socio-economic problems [3, 4]. The World Bank states that more than US$1 trillion in food is

wasted every year [5]. However, the report prepared by the United Nations Environment Program stated that 783 million people are struggling with hunger. Considering this number, which is approximately 122 million more than 2019 data, it is important to prevent food waste and use resources efficiently [2]. National and international organizations, the private sector, non-governmental organizations, and researchers are trying to ensure the applicability of the solution suggestions by carrying out important studies at this point [3]. As a result of the studies carried out in this direction, 12 percent of the food produced globally in 2022 was wasted in the retail process [2]. As the cause of waste in the retail process; lack of protective packaging, lack of temperature and humidity control, lack of proper display conditions, tendency to deliver perfect products and inadequate inventory management [3]. The reasons for the waste, which is found to be 60 percent at the household level, are identified as incomplete purchasing planning, ignorance about date labels, inappropriate storage conditions, over-prepared and inedible foods, and incorrect preparation techniques [2, 3]. However, it is stated that the highest food waste belongs to the fruit and vegetable group (31.2 percent). This situation is explained by the perishable nature of fruits and vegetables. Meat and other animal products are detected as 13.1 percent, but it is stated that data collection is insufficient. Roots and tubers are the third group in which food waste occurs with 11.9 percent. Cereals and legumes are found to be the group with the lowest food waste [6]. For example, reasons for wasting bread include buying too much bread and not liking stale bread and the fact that the participants do not know how to evaluate bread [48]. According to the FoodWaste Index Report (2024) when we look at the amount per person, it is concluded that almost one-fifth of all food offered to consumers is wasted, with 132 kilograms [2].Food waste occurs at the retail and household levels in high-income countries. Even though high-income countries have advanced technology, food waste occurs due to household consumption behavior. Food waste in low- and middle-income countries generally occurs at post-harvest and processing stages. This is attributed to low-income countries' lack of proper storage facilities and distribution, limited awareness, and lack of technological advances. The lower waste detected at the retail and household levels is explained by financial impossibilities [7].

When the situation in Türkiye is examined, it is seen that 19.1 million tons of food is wasted every year [8]. The largest share of this waste is calculated to belong to the fruit and vegetable group, similar to the global scale [9]. It is determined that 25-40 percent of the grown vegetables and fruits are wasted and it is stated that this is more than four times of Türkiye's total fruit and vegetables exports. However, it is stated that 4.9 million loaves of bread per day and 1.7 billion loaves of bread per year are wasted in Türkiye [10]. In this regard, the most important work carried out to prevent waste in Türkiye, where the concept of waste is culturally avoided, is the "Bread Waste Prevention Campaign". With this campaign, 1 million 50 thousand loaves of bread per day and 384 million loaves of bread per year were saved from being wasted [11].

Studies continue to determine the causes of food waste both in Türkiye and the world. In this context, it is necessary to focus on practices that will prevent waste in storage and distribution processes, which are seen as one of the important causes of waste [12]. Research indicates that creating technological infrastructure to keep properties such as temperature, humidity, and light constant during the storage process will prevent food waste [13]. However, it is stated that digital applications in technology will play a key role in preventing food waste in the distribution process [14]. It has been stated that technology is effective in product traceability and stock control and also plays an important role in improving the business environment [15]. As a result, it is emphasized that technology is an important element in preventing food waste [16].

## TECHNOLOGICAL PRODUCTS AS A SOLUTION TO FOOD WASTE

Food waste emerges as a growing problem that requires intervention at all stages of the food supply chain. Practices such as durability codes and expiration dates used in this regard create an obstacle to waste. With developing technology, it is considered important to make these systems smarter at the consumer level [17]. Technological products that can be used at every stage of the food chain appear as an important opportunity in reducing food waste [18, 19]. These technological products; mobile phone applications that allow customers to order their meals in advance (Blue Apron, Gram evde, Too Good to Go, No Food Waste, Food Cloud, Yo No Desperdicio, etc.), smart devices (smart pan, smart fork, smart scale, smart refrigerator, etc.) aiming to minimize waste during storage and production in individual kitchens used by middle- and high-income families, systems that enable the conversion of food waste into energy, three-dimensional printing devices that can use alternative raw material sources to produce functional products according to individual consumer needs, and smart packaging. [18, 20].

***Mobile Phone Applications:*** These are expressed as practices that aim to prevent food waste by providing food exchange, e.g., bringing excess food to those in need individually or corporately (cafes-restaurants) before it is wasted, fighting against hunger, businesses' delivering the products they will throw away at the end of the day to consumers by applying discounts, customers looking for discounts can follow the discounts created to prevent food waste, ensuring the exchange of raw and cooked food, evaluating companies that produce food waste, and applications that aim to prevent food waste by making food donations easier as the main purpose [21].The program FOODDY provides reliable information by scanning food with a phone camera, providing educational food storage to raise awareness of the environmental impact of food[49]. Similarly, the FoodImage mobile app calculates food quantities through uploaded photos so users can see how much food is eaten and wasted daily [50].

**Smart Devices:** They are defined as devices that exhibit smart behavior with built-in or embedded sensors in household items such as dinner sets, refrigerators, stoves, coffee machines, ovens and sinks. These devices aim to provide information about the expired product, at what temperature the product should be cooked and for how long, to shop knowing the amount of food available, to determine the amount of consumption needed and to provide information about it, to prevent overeating and to prevent waste that will occur due to overconsumption [22]. For example; smart refrigerators are used as a preservation method that can detect the quality and quantity of food inside through mobile applications and thus prevent food from spoiling and reduce waste [52]. This system, which works integrated with artificial intelligence technologies and smart devices, uploads fresh images of foods and enables it to detect their properties such as texture and shape. The information captured with the help of cameras and sensors placed inside the refrigerator is analyzed and an audible notification is provided to the user. In smart refrigerators, the data obtained with Natural Language Processing Technology and the Internet of Things is recorded and later enables measures to be taken to prevent food waste such as preparing a shopping list, ensuring the consumption of perishable food, reducing the amount of over-produced food, improving inventory management and producing according to consumer demand [53, 54].In addition, the programmable smart lid technology developed to prevent mold formation in open foods; It is presented as an important opportunity to extend the shelf life of food and thus prevent food waste [55]. Another smart device, smart pans, provide information about cooking thanks to the communication of the temperature sensor placed on its base with the mobile device and prevent food waste resulting from the consumer's lack of cooking knowledge. Smart devices developed to measure egg freshness, smart forks and smart scales that determine the calories and nutrients the consumer should take and provide information about how much they eat, smart cocktail shakers and coffee machines developed to apply the right recipe, smart jugs that inform the consumer about the spoilage of the milk in them are smart devices used to reduce food waste [22].

**Recycling of Waste:** Food waste is divided into two categories: edible and non-edible food waste. Edible food waste is defined as unused, damaged products and food that could have been eaten before being thrown away, and occurs for a number of reasons, including over-purchasing, inadequate preparation, inadequate storage and large portion sizes. Non-edible food waste includes parts that are not produced for human consumption but ultimately end up in the trash, as well as waste from food or beverage preparation. Examples of non-edible food waste include meat fat and sinews, eggs, fruit and vegetable peels [51]. It is provided by the discovery of biomass energy resources consisting of non-fossilized plant and animal organic substances. It is classified as solid biomass, liquid biomass (biofuels) and gaseous biomass (biogas). Solid biomass (plant residues, wood, dung, etc.) has been

used for purposes such as heating and cooking since ancient times. It has also been observed that liquid and gas biomass resources have been used recently [23]. Organic waste in the kitchens of food and beverage establishments is used as biogas. It is possible to use it for water heating, lighting and natural gas in kitchens, depending on the methane gas level it contains [12]. Another method used in recycling waste is compost production. Compost production is defined as the process of decomposing organic substances into simpler organic and inorganic substances. With the production of compost, a material with soil regulator properties and fertilizer value is obtained. This material benefits the soil and the growing plant [24].

**3D Food Printers:** It allows personalized meals and digitalized nutrition, taking into account individuals' age, physical/health status (fitness), nutritional status and energy needs. It is stated that it provides energy, time and cost savings, shows high efficiency and is useful in reducing food losses [20].

**Smart Packaging:** It provides information about pH, temperature, humidity of the environment where the food in the package is located. With smart packaging, activities are carried out to reduce food waste, such as gaining information about the shelf life, safety, quality of food, possible problems and monitoring and detecting these problems [25].

## RELATIONSHIP BETWEEN PACKAGING and FOOD WASTE

It is not possible to consume food products where they are produced and in a short time. The fact that food products can be consumed at different times in different regions requires preservation. Food packaging is defined as a food production stage that delivers food to the consumer safely [26]. The main task of packaging is to protect the food against external factors and ensure that it reaches the consumer in a safe, fresh and delicious way for a maximum period of time [27]. Packaging plays an active role in maintaining food quality, food integrity and food safety. It facilitates distribution and storage processes [28]. In relation to changing living conditions and technological developments, there is a need for packaging to have different features in addition to its protection feature. These features are expressed as providing more information about food and preventing more harmful and wasteful food for the environment [29]. Although packaging largely prevents food waste by ensuring the protection of food, it can also be among the causes of food waste due to its design. Failure to use food-grade packaging material, size and shape can lead to food waste [30]. It is important to choose packaging designs that can reduce food waste and to adopt innovations in food packaging [28]. Studies have expressed the necessity of developing new and improved packaging types while maintaining food safety and quality [27]. Developing packaging that provides better protection helps keep unsold products fresh while they reach those in need or are returned. Preparing packaging for its intended purpose is seen as a practice that will prevent

waste throughout the supply chain and makes it easier to understand where and why waste occurs. Designing the packaging itself to be recyclable helps prevent environmental problems. Raising consumers' awareness about reading labels is seen as a practice that will prevent the waste of food that is still edible. However, developing packaging that will appeal to smaller households prevents household waste. It is considered important to adopt new packaging materials and technologies such as smart packaging in order to extend the shelf life of food and reduce outdated stocks [31].

## SMART PACKAGING

Smart packaging refers to packaging material that can monitor and control various parameters such as humidity, temperature and gas composition that can interact with products [32]. Smart packaging is defined as packaging systems that provide information to the consumer about the safety and quality of food [33]. Smart packaging used in products such as food and medicine includes embedded sensor technologies [32]. Packages with temperature-time indicators and packages with biosensors can be given as examples of smart packaging, which has features such as sensing, monitoring and signaling. Its working principle is related to temperature-time measurement, enzymatic quality changes, microbiological activity measurement and traceability [27, 34]. Temperature time measurement is a technology that provides a visual summary of the cold chain process and refers to devices used to record thermal history and indicate the remaining shelf life of perishable products throughout their storage, distribution and consumption. It is based on the principle of irreversible color change resulting from the cumulative effects of temperature and time [35]. Biosensor packaging provides information about the development status of microorganisms [36]. Biosensors are defined as analytical tools that detect, record and transmit biochemical reactions. These tools consist of a bioreceptor that detects the target sample and a transducer that converts biochemical signals into measurable electrical messages. Bioreceptors consist of organic materials such as antigens, enzymes, nucleic acids and hormones, and systems such as electrochemical, colorimetric and optical, depending on the parameter measured by the transducer. [37]. It is stated that this technology will be developed in the future and different systems designed for various spoilage reactions in foods will be produced. For example, packaging that increases the purchasing intention by emitting a pleasant scent as the consumer approaches the consumer in the aisles can be given [34].

Considering all this, an innovative smart packaging approach that is effective in preventing food spoilage is vital in solving the challenges of sustainable food production and combating food waste [38]. It is stated that smart packaging will provide positive effects in reducing food poisoning, contamination and especially food waste [39]. Similarly, it is stated that people will be warned with smart packaging techniques and thus waste will be reduced [40]. It is emphasized that by knowing the current quality status of the food at the retail stage, foods with a short shelf life will be sold earlier and waste will be avoided [41]. Consumer awareness through smart packaging is considered important in preventing fresh food waste [42]. Studies indicate that the shelf life of food can be extended and food waste can be reduced by incorporating betalains (e.g. betacyanins and betanin) into smart packaging systems [43]. Additionally, it is emphasized that food waste can be prevented and recycling can be achieved by including food waste in the smart packaging design process [38]. Shelf-life length impacts food waste, with longer shelf life leading to less waste. Examples include the trend toward "clean labels" improving product storage conditions, purchasing behavior to minimize food waste, and alternative smart approaches that support effective home inventory management [56].

## CONCLUSION

It is stated that the increase in food waste will cause less availability of food products, which will lead to a rapid increase in food production [44]. Food production requires many resources such as water, energy, fertilizer, pesticides, herbicides, land and labor. Considering that a land mass larger than China is needed to grow food products, it is predicted that serious problems such as deforestation, species extinction, climate change and migration will arise [7]. In order to prevent the emergence of these problems, there is a need to produce urgent solutions for food waste.

Such processes as air pollution, water pollution, and pandemic create disruptions in the supply chain. These disruptions result in food insecurity, defined as a situation in which people do not have access to adequate food due to limited resources [45]. The increase in food insecurity drives people to make decisions such as panic buying, stockpiling, and not buying for fear of being infected [46]. This situation increases food waste, especially in the retail process. Smart packaging, defined as a system that facilitates people's decision-making processes, prioritizes food safety, and includes smart improvements such as monitoring, observing, documenting and communicating, emerges as an effective system at this point [7]. The smart packaging system that guarantees the microbiological, chemical and physical suitability of foods for consumption has not yet been adopted commercially. Therefore, it is necessary to develop cost-effective systems that are fast, sensitive, user-friendly, prioritize food safety and quality, and comply with the legislation and meet consumer demands [47]. Smart packaging tools will be one of the fundamental tools in establishing traceability systems for sustainable food safety. By checking the validity of the "Expiration Date", it will be possible to prevent the consumption of products that have not been stored under the right conditions; since the freshness of the products can be determined, food-borne poisonings can be prevented, thus protecting the health of the consumer and preventing economic losses [37].

Ultimately, the future of food packaging lies in smart packaging that can do more than protect and preserve.

It is thought that waste will be prevented at the retail and household levels with the smart packaging system. In this regard, more studies on the subject need to be done. It is thought that it would be beneficial for public and private sector organizations to focus on solving food waste with technological methods.

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