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Use of information and communication technologies to reduce food waste
Uso de las tecnologías de la información y la comunicación para reducir el desperdicio de alimentos

María Calzada Gento[1]
macalz01@ucm.es
https://orcid.org/0000-0002-6534-909X
José Ignacio Alonso Esteban[2]
jignacio.alonso@uah.es
https://orcid.org/0000-0002-1593-2631
Marta Mesías García[3]
mmesias@ictan.csic.es
https://orcid.org/0000-0003-0905-1587

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ABSTRACT

The food supply chain has shown certain deficiencies regarding food waste control and prevention, mainly due to overproduction, lack of social awareness and commitment, and poor coordination between different levels in the food chain. This fact is leading to multiple environmental problems related to the emission of greenhouse gases, and economic and social losses. The development of Information and Communication Technologies (ICT) in the current digital era (Industry 4.0) contributes to greater traceability of food products, obtaining safer and higher quality food and sustainable and highly productive food systems. The use of ICT, together with changes in consumption habits, waste management, and new government laws, are key to comprehensively addressing the prevention of food losses and waste. The objective of this work is to carry out a bibliographical review on the use of ICT as a technological improvement applied in

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[1] Graduate in Pharmay, Complutense University of Madrid, Madrid, Spain
[2] Profesor Ayudante Doctor, University of Alcala, Alcala de Henares, Madrid, Spain
[3] Científico Titular, Institute of Food Science, Technology and Nutrition (ICTAN-CSIC), Madrid, Spain

the food sector to help solve the problem of waste in all stages of the food chain, "from farm to fork".

Keywords: Information and Communication Technologies (ICT), digital technologies, artificial intelligence, sustainability, food waste.

RESUMEN

La cadena de suministro de alimentos ha mostrado ciertas deficiencias en cuanto al control y prevención del desperdicio de alimentos, debido principalmente a la sobreproducción, la falta de conciencia y compromiso social y la mala coordinación entre los diferentes niveles de la cadena alimentaria. Este hecho está provocando múltiples problemas ambientales relacionados con la emisión de gases de efecto invernadero y pérdidas económicas y sociales. El desarrollo de las Tecnologías de la Información y la Comunicación (TIC) en la actual era digital (Industria 4.0) contribuye a una mayor trazabilidad de los productos alimentarios, a la obtención de alimentos más seguros y de mayor calidad y de sistemas alimentarios sostenibles y altamente productivos. El uso de las TIC, junto con los cambios en los hábitos de consumo, la gestión de residuos y las nuevas leyes gubernamentales, son clave para abordar de manera integral la prevención de las pérdidas y el desperdicio de alimentos. El objetivo de este trabajo es realizar una revisión bibliográfica sobre el uso de las TIC como mejora tecnológica aplicada en el sector alimentario para ayudar a solucionar el problema del desperdicio en todas las etapas de la cadena alimentaria, "de la granja a la mesa".

Palabras clave: Tecnologías de la información y la comunicación (TIC), tecnologías digitales, inteligencia artificial, sostenibilidad, desperdicio de alimentos.

Introduction

Currently, food waste is becoming a problem worldwide. The Food and Agriculture Organization of the United Nations (FAO) first defined food waste as any product that is discarded, lost, or degraded at any point in the food supply chain. It was subsequently clarified that food waste is a component of food loss, referring to the discarding or repurposing of food that is nutritious and safe for human consumption throughout the entire food supply chain, from primary production to end consumer. Approximately one-third of the global food production is estimated to go to waste (FAO, 2019). Within the European Union, 20% of the food produced is wasted, which represents around 88 million tons and a loss of 143 billion euros per year (EC, 2023).

From an ecological point of view, food waste represents 8% of anthropogenic greenhouse gas emissions (European Parliament, 2017), with the release of 3.3 billion tons of CO2 each year (FAO, 2019). These emissions are caused in the production phases and in the destruction of food and accumulation in landfills, due to the emission of methane gas (Liegeard and Manning, 2020), which is the third most important source of human-induced global warming and whose greenhouse effect is 25 times higher than that of carbon dioxide. On the other hand, it must be considered the natural resources invested in food that will ultimately be wasted, such as water, energy, and farmland (Liegeard and Manning, 2020), which represents a loss equivalent to 936 billion dollars a year (Ishangulyyev et al., 2019).

Food losses and waste are a sign of inefficient and uncoordinated functioning of food systems and a lack of social awareness. However, a notable distinction can be observed between developing countries and industrialized countries, as 40% of losses in developing countries occur during the early stages of food manufacturing and processing, while in industrialized nations, over 40% of losses occur during the later stages of retail and consumption (FAO, 2019). In industrialized countries, consumers waste between 173 and 290 kg per capita annually (Bellemare et al., 2017). To combat this social problem, the United Nations (UN) has included food waste as one of the Sustainable Development Goals (SDG) proposed in the 2030 Agenda, specifically within SDG 12, which corresponds to Responsible Production and Consumption. This Goal aims to change the current model of production and consumption to achieve efficient management of natural resources, implementing processes to prevent food loss, and promoting an ecological use of chemical products and a reduction in waste generation. Regarding food waste, SDG 12.3 endeavors to cut per capita food waste at the retail and consumer level in half and reduce food losses along the production and supply chains by 2030 (FAO, 2023).

Information and Communication Technologies (ICT) refer to a collection of technologies that facilitate the access, production, treatment, and communication of information in various formats, such as text, images, sound, etc., which moves around computing, microelectronics, and telecommunications, not isolated but interconnected and in inter-operational mode. The impact of ICT on environmental sustainability has been significant, and these technologies can play a pivotal role in mitigating food waste. The fourth industrial revolution (or Industry 4.0) introduces the concept of the Internet of Things (IoT) and promotes the use of digital technologies such as artificial intelligence, robots, big data analysis, etc., as tools to transform the operations of many companies and encourage the creation of new business models, all with the ultimate objective of enhancing profitability (Cane and Parra, 2020). The food industry requires an efficient management strategy to attain improved quality, better process control, and optimal utilization of raw materials, all of which are critical for preventing waste (Despoudi et al., 2021). Digital technologies strive to ensure the coordination of various links in the food supply chain, to help achieve an adequate shelf life in terms of food safety thanks to greater traceability of the products (Stevens and Johnson, 2016), as well as to study and facilitate the supply of the quantity of food to meet consumer demand while avoiding overproduction, which is considered one of the main strategies to avoid food waste (Tromp et al., 2016).

The current linear production system consists of the extraction of resources, industrial manufacturing by companies, the use of products by consumers, and disposal, becoming in most cases contaminant waste. The concept of circular economy advocates for a novel approach to production and consumption, wherein the significance of products, resources, and materials lies in their retention within the economy for as long as possible. The strategy aims to minimize waste generation and optimize the utilization of unavoidable waste to the greatest extent feasible (Plan de Acción de Economía Circular, 2021). All links in the food chain are responsible for preventing and reducing food waste, including food production and processing (such as farmers, food manufacturers, and processors), product distribution for consumption (such as the retail sector), and, ultimately, consumers (Flores Pimentel, 2022). Food waste is primarily attributed to households and processing, accounting for 47 and 17 million tons, respectively, which is

72% of the total food waste in the EU. The remaining 28% of waste comes from food service (11 million tons, 12%), primary production (9 million tons, 10%), and wholesale and retail (5 million tons, 5%) (as illustrated in Figure 1) (Stenmarck et al., 2016). Undoubtedly, food waste occurs in all stages of the food supply chain, “from farm to fork”.

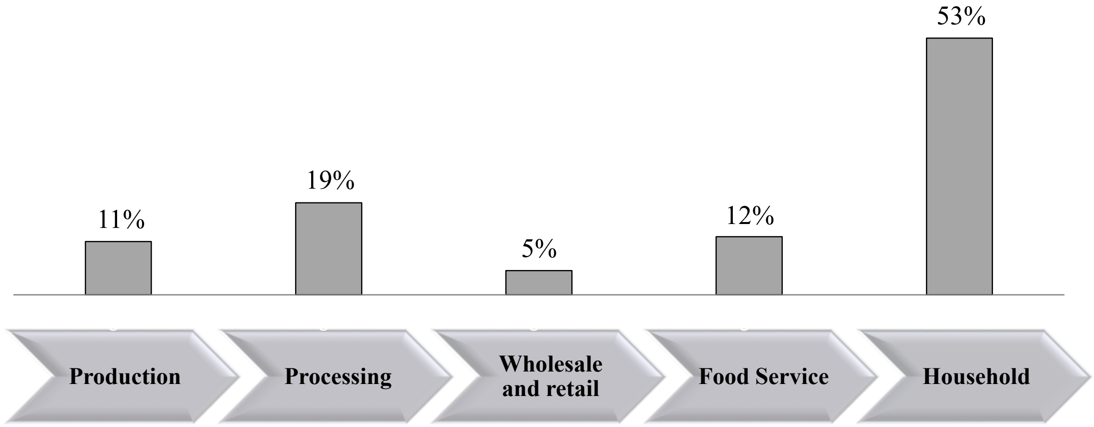


Figure 1. Distribution of European food waste in the different sectors of the food chain.

Source: Stenmarck et al. (2016)

In this context, the main objective of this work is to expose different technological innovations applied in the different links of the food chain whose use can contribute to reducing food waste and the environmental impact derived from it. A summary of the applications of ICTs to reduce food waste in the different sectors of the food chain is depicted in **Figure 2**.

Methods intended for food production

Traditionally the agricultural industry has depended on human labor with a limited application of mechanical equipment and machinery (Baur and Iles, 2023). However, several changes in today's society suggest a greater focus on the adoption of new technologies such as robotics and autonomous systems (RAS) in the food supply chain. Nowadays, it is estimated that more than 1.3-1.6 billion tons of food are wasted throughout the entire food supply chain worldwide. These amounts are equivalent to approximately one-third of the food production for human consumption of the world population and more than one-quarter of the global agricultural production (Papaioannou et al., 2022). In addition, the rise in the world population will increase the demand for food by 56% by 2050, which requires improving productivity (van Dijk et al., 2021). These aspects could be avoided with better automation and monitoring systems.

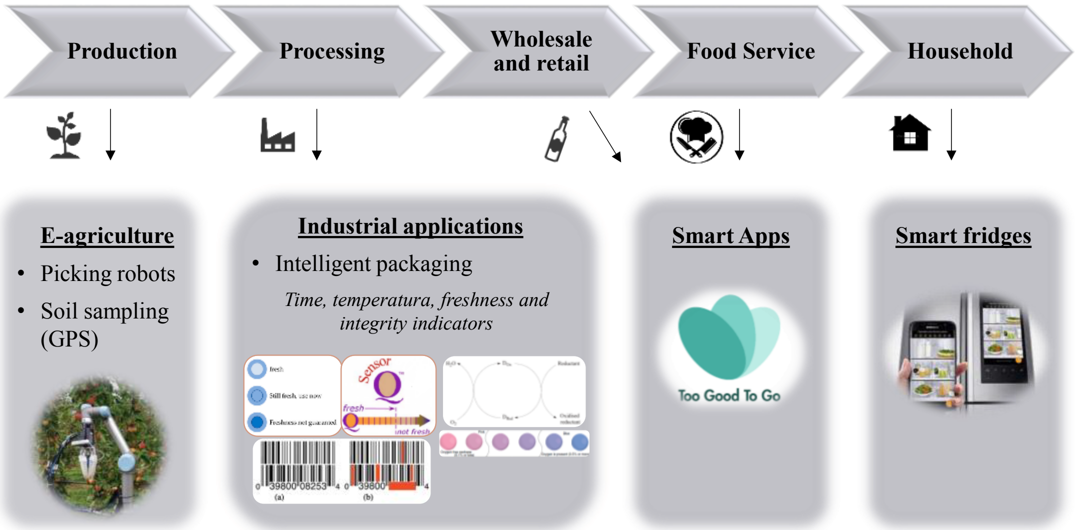


Figure 2. Applications of information and communication technologies to reduce food waste in the different sectors of the food chain

Source: own elaboration

According to the International Organization for Standardization (ISO), an industrial robot (IR) is a multifunctional, automatically controlled, reprogrammable manipulator in three or more axes, which can be stationary or mobile for use in industrial automation applications (ISO, 2012). Some of the benefits of using IR in food manufacturing are increasing production rates, reducing cost (by eliminating expenses associated with labor employment and insurance), decreasing production time (thanks to continuous production avoiding employee delays due to fatigue, sick leave or vacation), improving the quality and uniformity of products (due to its high precision), take care of the safety of employees (by removing them from tedious tasks or unfavorable conditions), and also improving hygiene and food safety (by eliminating human contact with food and reducing incidents of cross-contamination). However, the uptake of RAS technologies in the food processing industry is slow compared to other industries. IRs cannot replace humans, rather they are a means to improve work environments and ensure efficient food production. In fact, societal perception is a major impediment to further implementation (Bader and Rahimifard, 2020).

Picking robots

Harvesting is a fundamental agricultural activity. Most of the harvesting, whether of crops or fruits, is still done manually. However, the use of RAS in time- and labor-intensive agricultural tasks such as planting, spraying, pruning, and harvesting is raising with increasing urbanization and the lack of farmers, and it is expected to be used in 20% of future harvesting operations (Tang et al., 2020; Baur and Iles, 2023).

The development of harvesting robots is based on their artificial vision, 3D reconstruction and positioning capabilities. Machine vision allows robots to actively and accurately identify and locate targets from predetermined images, as well as to collect crop data, including information about the environment surrounding the fruit, geometry, and 3D coordinates (Daudelin et al., 2018). 3D reconstruction refers to the establishment of a suitable mathematical model for the representation and computational processing of spatial objects. However, picking robots still have many technical difficulties, which make it difficult for most to achieve real commercial applications. Much of the fruit fields have rough terrain with large obstacles, causing strong vibrations in the robots' vision system as they traverse the terrain and inaccurate target tracking and imaging. This complication requires the use of automatic image blurring and dynamic target tracking algorithms (Tang et al., 2020) that are still under investigation. On the other hand, the objects can have different sizes, shapes, colors and textures and the background and lighting of the crops varies continuously. For that reason, harvesting robots must be able to adapt to different types of crops and environmental changes (Zhao et al., 2016). Finally, the main function of the robot is to harvest the desired ripe fruit without damaging the branches or leaves of the tree.

Recently, Australian researchers have designed an autonomous apple-picking robot capable of identifying apples from the tree, rotating them to break the stem, and dropping them into a carrycot. The structure consists of a mechanical arm connected to a base, a series of cameras, a four-fingered gripper, and a suction system to grab the apples. The vision system allows it to identify 90% of the fruits of the tree in a distance of 1.2 meters thanks to the set of "deep learning" algorithms (or deep learning) and also identifies obstacles such as leaves and branches to calculate the optimal trajectory for extraction. The robot takes 200 milliseconds to process each image and 7 seconds to pick each apple if it goes to maximum performance, with a success rate of 85% of the achievable fruits. In addition, only 6% of the total fruit collected suffers damage. It works regardless of weather conditions and in all types of lighting, including strong sunlight and rain (Wang et al., 2022). The application of all these robotic tools during food collection favors a responsible and efficient collection of products, thus minimizing food waste.

Soil sampling

Soil sampling consists of analyzing and estimating the capacity of the soil to supply nutrients such as sulfur, boron, zinc, etc. to meet the needs of growing crops through technological systems. Different soil sampling kits based on Global Positioning Systems (GPS) have been developed to indicate nutrient and contaminant content, composition, and other characteristics such as volatile organic compounds, acidity, and pH level and to recommend the precise use of soil fertilizers. Marking reference sample collection locations using GPS helps reduce sampling variability in subsequent years and creates a better picture of changes from year to year. From the data collected, a map is created that is sent to the automated system that delivers the fertilizer to the field, so that the amount of fertilizer necessary for efficient crop production is applied in each zone. The technology used to carry out this procedure is known as variable rate fertilization technology (VRFT) and includes a GPS integrated into a computer in the tractor cabin to recognize the position of the vehicle in real-time and modify the dose of fertilizer (Sai Mohan et al., 2021).

The cost of spreading fertilizer based on sampling and VRT is higher, but it must be taken into account that excessive use of fertilizers can lead to increased emissions of nitrous oxide, a potent greenhouse gas (Nolte, 2011). In addition, this method allows for what is known as differential harvesting, which consists of harvesting selected areas of crops that meet certain quality requirements (such as fruits and vegetables with different characteristics of size, color, etc.) without damaging the remaining field to mature and dry. This ultimately reduces food waste due to the collection of food that does not meet the quality standards established by retailers. In fact, currently, one in three fruits and vegetables is thrown away based solely on the collective beauty standards of consumers (Grewal, 2019).

Methods intended for Industrial applications

In order to ensure food safety, microbiological and chemical tests are carried out during food production at an industrial level, but the changes that occur after processing are normally not monitored, leading to a great loss of products (Poyatos-Racionero et al., 2017). An example of this fact is the deterioration of raw meat through the supply chain. It is estimated that as much as 23% of production in the meat sector is lost and wasted, the largest share being generated at the consumption level (64%), followed by manufacturing (20%), distribution (12%), and primary production and post-harvest (~4%) (Karwowska et al., 2021). On the other hand, consumers constantly demand less processed, fresh, and high-quality food products, which require quality control during and after processing (Heising et al., 2014).

Until a few years ago, food packaging only played a passive barrier role, protecting food from those external factors capable of degrading it. However, there are currently innovative intelligent packaging systems on the market capable of permanently monitoring the quality status of food products and sharing information with the consumer. This permanent monitoring not only minimizes unnecessary food waste by improving food safety (Poyatos-Racionero et al., 2017) and reducing the risk of consumer misinterpretation (Liegeard and Manning, 2020) but also improves traceability throughout the supply chain, reduces time and material costs derived from the methods of analysis of packaged foods, decreases the environmental impact, increases the attractiveness of the packaging and maximizes the efficiency of the food industry (Poyatos-Racionero et al., 2017).

Intelligent packaging

Smart packaging can be defined as systems that monitor the conditions of food during its life cycle to provide information related to the quality of packaged products (Heising et al., 2014). The quality of food products changes during their life cycle since foods are perishable by nature, and the changes depend on the type of product, the type of packaging and the conditions in the supply chain. However, it must be taken into account that smart packaging increases the cost and therefore it will only be profitable if the income from the increase in sales and/or the reduction of waste is greater than the increase in price. This makes the cost and shelf life of the food important criteria for its application. In products with relatively stable intrinsic quality attributes and long shelf life (such as soft drinks, canned goods, and sweets) it is not appropriate to incorporate smart packaging. However, expensive and highly perishable products (such as meat or fish) are the main application areas since their intrinsic quality properties change rapidly after processing, are difficult to estimate, and cause significant economic losses from spoilage of these foods. In addition, the compatibility of the systems with the food must be monitored (Heising et al., 2014).

In the European Union, the development and application of smart packaging is still limited, although it is a very dynamic field with continuous advances (Realini and Marcos, 2014). Currently, packaging is generally authorized under Regulation (EC) No. 1935/2004 on materials and objects intended to come into contact with foods, which defines the special requirements that must be met. The main barriers to use that have prevented a more significant implementation in the market are the technical limitations associated with the use of these technologies, the high cost of packaging (which can amount to 50-100% of the total value of the final product) and the lack of consumer confidence in the security of these systems (Realini and Marcos, 2014). Another aspect that still needs to be clarified is the recycling of packaging since the additional waste generated by the installation and production of smart packaging is actually contradictory to the objective of reducing the amount of food wasted.

The intelligent function can be obtained through indicators or sensors (Realini and Marcos, 2014), which determine the presence, absence, or concentration of a substance in the food or the intensity of a certain reaction, with the following differentiation: the sensors measure a parameter or identify analytes in the food but must be connected to an external device to convert the sensor signal into an observable response, while indicators integrate the measurement system and provide information through directly visible change (for example, different color intensities). There are three types of indicators or sensors used in smart packaging (Heising et al., 2014):

- Environmental conditions: these indicators monitor the conditions that may give rise to changes in the quality characteristics of food, for example, time and temperature indicators, gas leak indicators, and relative humidity sensors. Depending on the monitoring factor, the systems are placed inside or outside the package.

- Quality attributes: indicators directly monitor quality attributes of the product itself, for example, biosensors and freshness indicators. They are generally located inside the container.

- Data carriers: the function of these indicators is to guarantee traceability, automation, protection against theft or protection against counterfeiting of food products, with the ultimate goal of making the flow of information within the supply chain more efficient (Müller and Schmid, 2019). They include barcode labels and radio frequency identification (RFID) tags and are often placed on tertiary packaging. Data carriers will not be developed in this work.

Time and Temperature Indicators (TTI)

Temperature is one of the most important environmental factors in determining food preservation. Deviations in it can cause the growth of microorganisms and compromise the safety and shelf life of food products. In addition, incorrect freezing can denature the proteins in meat or other products (Zhang et al., 2023). TTIs detect mechanical, physical, chemical, electrochemical, enzymatic, or microbiological changes that depend on the time elapsed since packaging and that accelerate with increasing temperature (Poyatos-Racionero et al., 2017). The measured values are expressed as visual changes, such as color changes or mechanical deformations, which must be irreversible and correlate well with the rate of deterioration of the quality of the food. They allow continuous monitoring of storage conditions and, consequently, they can report a break in the cold chain and be used as indirect indicators of shelf life.

Three types of TTI can be found: critical temperature indicators that reveal whether products have been heated above or cooled below a permissible temperature; partial history indicators that indicate if a product has been subjected to a temperature that causes a change in its quality; and full history indicators that record the entire temperature profile throughout the food supply chain (Müller and Schmid, 2019). An example of a full history TTI is Fresh-Check, based on a polymerization reaction. A clear center indicates that the TTI is new; if the color matches the outer ring, the product must be consumed soon, and if the center is dark, the freshness of the food is no longer guaranteed (Müller and Schmid, 2019).

Freshness indicators

Freshness indicators monitor the quality of fresh food products during storage and transportation by reporting changes that occur because of microbial growth or metabolism. Reasons for loss of freshness may be unfavorable conditions or exceeded durability. Changes in the concentration of metabolites such as glucose, organic acids (e.g. L-lactic acid), ethanol, carbon dioxide, biogenic amines, volatile nitrogen, ATP degradation products, or sulfuric compounds during storage indicate microbial growth, and then they can be used as indicators of freshness (Arvanitoyannis and Stratakos, 2012). On the market, freshness indicators used in smart packaging can be based on the indirect detection of metabolites through color indicators (for example pH) or direct detection of target metabolites using biosensors (Realini and Marcos, 2014).

An example of an anthocyanin-based pH detection freshness indicator is SensorQ™, capable of reporting the formation of biogenic amines of microbiological origin in packaged meat and poultry, although it has not achieved successful commercialization. The label detects the gaseous byproducts of foodborne bacteria growing inside the package and indicates that a critical level of bacterial growth has been reached by a color change (from orange to brown) (Panjagari et al., 2021).

A biosensor is a device that analyzes the concentration of a specific target component with a biological sensing element. Thus, it converts a biologically induced recognition event (for example, based on an antibody, an enzyme, or a microorganism) into a detectable signal through a transducer that converts the biochemical signals into a quantifiable electrical response (Naresh and Lee, 2021). An example is the Food Sentinel System, developed to detect foodborne pathogens with a specific antibody attached to a membrane that forms part of a barcode. The presence of contaminating bacteria causes the formation of a localized dark bar, making the barcode unreadable when scanned.

Integrity indicators

The simplest integrity indicators are time indicators, which report how long a product has been open. The tag is activated at the time of consumption so that when the seal is broken, a timer is triggered and the indicator changes color over time (Realini and Marcos, 2014).

Gas indicators report on the quality status of a food product based on the indoor atmosphere. Its usefulness is associated with the use of modified atmospheres in packaging (MAP), which usually replace oxygen with other gases (such as carbon dioxide or nitrogen) to increase the shelf life of food products. For this reason, most indicators monitor oxygen and carbon dioxide concentrations, although others also monitor water vapor, ethanol, hydrogen sulfide, and other gases whose concentrations closely correlate with the progress of food spoilage (Meng et al., 2014). As an example, MAP packaging for meat products typically consists of high CO2 levels (20–80%) and a residual O2 concentration (<0.1–1%, depending on the efficiency of the packaging equipment) (Realini and Marcos, 2014), therefore oxygen indicators are often used to detect leaks. The most common are colorimetric indicators, which consist of a redox dye (such as methylene blue) and a strong reducing agent (such as glucose in an alkaline medium). In the absence of oxygen (concentrations $\leq$0.1%), most of the dye is in the reduced and colorless state, but in the presence of levels greater than or equal to 0.5%, the dye is oxidized and is observed a color change.

Methods intended for wholesale and retail and for food services

In Europe, restaurants are the second source of food waste generated at consumption following households. Similarly, in the US, families and restaurants waste approximately 39 million tons of food per year (Principato et al., 2018). The development of ICT has radically changed the life cycle of food, with the appearance of numerous websites and applications to share and redistribute foods. These types of apps only help address symptoms, but raising awareness and taking action is the first step towards more sustainable behavior to reduce food waste. The motivations for their use must go beyond reducing food waste to make them useful and desirable for long-term use. For example, the Too Good To Go app allows users to save money while saving food, and thus reducing food waste, which is a secondary positive (Nguyen, 2020).

Too Good To Go

Too Good To Go (TGTG) was born in Denmark in 2016. The app uses the user's geographic location to offer them a "surprise pack" of nearby local stores at a reduced Price. The pack contains food that has not been sold and would otherwise have been wasted and that the user must pick up at set times. “Surprise packs” are so called because the consumer does not know in advance what products are included, which depends on the food that is going to be wasted that day and that the establishment cannot predict (Vo-Thanh et al., 2021).

TGTG is the leading application in the fight against food waste. Social, functional, and emotional values are the success factors for TGTG to fulfill its social mission of reducing food waste, which consequently helps reduce carbon dioxide emissions. On the other hand, it makes it possible to obtain an economic gain since its objective is to create a link between clients and producers, which can sell products that are going to be thrown away and recover expenses, while consumers save money (Nguyen, 2020). In addition, this app contributes to addressing social needs by allowing all people to have access to quality food at an affordable price that they may not be able to afford. Likewise, it helps users to acquire a sense of citizenship and social responsibility. Finally, it allows food companies to increase exposure to new customers, be more respectful of the environment, and strengthen their brand image (van der Haar et al., 2019).

Survey results from an experimental study indicated three main motivations for using the TGTG app by consumers: the desire to reduce food waste, save money, and have a surprise experience. On the other hand, despite the fact that customers pay a reduced price for a "surprise pack", 48% valued the purchased foods as a normal purchase, 46% valued it positively for avoiding food waste and only 7% rated the food as inferior to other regular products (Vo-Thanh et al., 2021). Results of other investigations also indicate that 58% of TGTG users have visited new establishments thanks to this application, of which

76% return as regular customer,s and therefore the application is a very useful commercial tool for business (van der Haar, 2019).

Methods intended for household

As mentioned before, 53% of food waste occurs at the household level (Stenmarck et al., 2016), of which up to 45.8% is avoidable and is related to the awareness and behavior of users (Cappelletti et al., 2022). For that reason, the development of strategies to prevent food waste is considered the first step to achieving ambitious goals in terms of sustainability, rather than focusing on the waste itself and how it is dealt with (Martin-Rios et al., 2018).

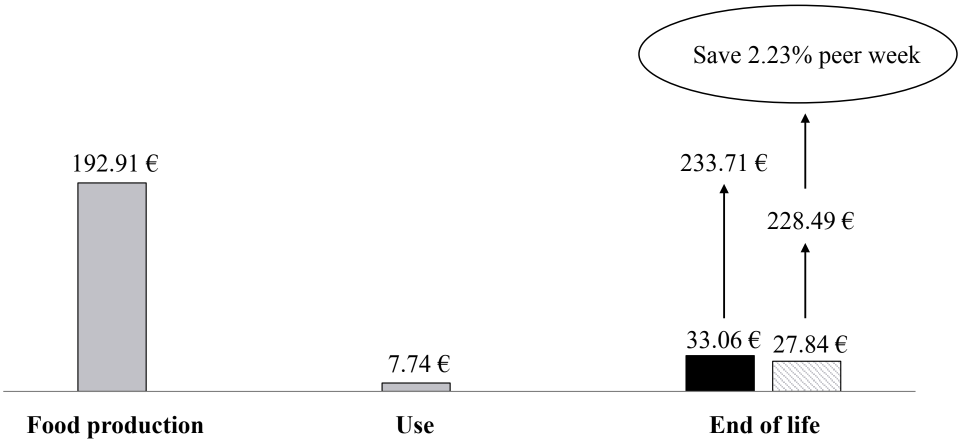
The main cause of waste by consumers is the acquisition of more food than necessary due to a lack of planning when buying and a lack of knowledge about the amounts of food consumed at home (Aschemannn-Witzel et al., 2015). Another of the main factors (15-30%) is the misunderstanding of the labeling (or lack of clarity of the product information) and the confusion between the expiration date and the best-before date (European Commission, 2016). At this point, it should also be mentioned the careless attitude of consumers regarding the proper storage and preservation of food, the anxiety about food safety, the limited awareness of the population about the scope of the problem, and the related environmental impact and the strategies of market, which encourage consumers to buy more products than necessary (Cappelletti et al., 2022). It is important to teach consumers how to buy, store, prepare and dispose of food in a more sustainable way. With this purpose, smart applications can be incorporated into the home, which have been proven to be an effective tool to reduce food waste.

Smart refrigerators

Smart refrigerators are able to connect to the internet and interact with consumers even from outside the home. Brands such as LG, Samsung, Siemens or Bosch have been incorporating them into their catalog of refrigerators, in order to answer the following questions: what products are there at home?, in what quantity?, where are they stored?, when were they purchased?, when did they expire?, were foods consumed?, and if so, totally or partially? (Cappelletti et al., 2022). It is important that the system be as intrusive as possible for users and that they are the center of the development process so that each new feature is incorporated according to their needs and requirements to be understood and accepted by consumers. These systems add additional functions to conventional refrigerators that can help reduce waste by monitoring data related to food products and preventing them from being thrown away. The most prominent are:

- Tracking of the food stored in the fridge, the quantity available, and the date of purchase, opening, and/or expiration. The smart expiration system can send push notifications to the mobile phone so that if something is expired, a warning message prompts the user to discard the item. However, in the case of the best-before date, the system recommends smelling or tasting the product before wasting it. Regarding products that are about to expire, the application can notify the consumer with visual alerts (for example, the expiration date turns red) and if a new product of the same type is purchased, remember to consume the oldest one in advance. At this point, it is important to note that the system should not overload users with warning messages (Cappelletti et al., 2022).
- Self-regulation of internal environmental conditions and proper placement of food in the refrigerator, both in order to optimize storage. This helps to increase shelf-life of foods, which will consequently lead to less waste (Liegeard and Manning, 2020).
- Management of the shopping list, remembering the products available at home, with relative quantities and expiration dates. Access to refrigerator information (for example, through a webcam) is possible from remote locations, which allows knowing the amount of food need to buy, if the shopping list has not been made. In addition, periodic products (considered those that are purchased at least once a week) can be added to the list of suggested products based on the remaining quantity (Cappelletti et al., 2022).
- Intelligent suggestion of recipes, ordering them according to the maximum number of ingredients available at home and those closest to their expiration date (Cappelletti et al., 2022).

Although they provide multiple advantages, there are limitations to their entry into the market, mainly including price, privacy concerns, data ownership and lack of control by consumers, and the time and effort required to learn how to use them, as well as the problematic in homes with low Internet connection (Chan et al., 2009). Despite its high cost, some research has suggested that the incorporation of these systems could save families up to 2.23% of their weekly purchase (Figure 3) (Chan et al., 2009).



Food production. Cost related to the purchase of food

Use. Cost related to the use of the household appliances to store and prepare meals

End of life. Cost related to the food purchased, but not consumed

■ without ▨ with technological solution implemented in the fridge

Figure 3. Weekly cost related to foods in a four-member family and save by the technological solution implemented in the fridge.

Source: Cappelletti et al. (2022)

Conclusions

Food overproduction and waste is a global problem in which all links in the food chain are involved, with great environmental, economic, and social repercussions. There is no single treatment to address the problem, and yet a transition to a more sustainable model is necessary to avoid the current environmental crisis. The food sector is constantly evolving due to growing demand, consumer needs, and the development of new technologies. The digital revolution of recent years (Industry 4.0) and the development of Information and Communication Technologies (ICT) are essential tools to fight against waste and contribute to optimizing processes, improving traceability, favoring coordination throughout the supply chain, as well as developing solutions for future challenges. Technical innovations such as the application of robotics in agriculture, the development of smart packaging and refrigerators, and the use of new mobile applications are some of the examples proposed to achieve greater efficiency and productivity and establish new forms of interaction, involving the consumer as an end-user, since a change in habits and responsible consumption would significantly help to reduce waste as a joint task of society. Future research should be aimed at improving the feasibility of ICT in the food sector and giving visibility to existing ones.

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