doi: 10.7251/ZSAN2302047G **Review paper**

RECOVERY OF FOOD WASTE FOR THE PURPOSE OF REDUCING THE IMPACT ON THE ENVIRONMENT AND HUMAN HEALTH*

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Abstract: *Part of the food is lost along the supply chain, respectively food is wasted. Competent institutions estimate that more than one-third of the total amount of produced agricultural and food products in the world is not used in human nutrition, but is wasted or ends up as waste. Taking into account the growing number of malnourished people in the world and the depletion of natural resources, food waste management systems are included among the goals adopted in Agenda 2030. According to the adopted plans, food losses should be reduced by 50% until 2030. The aim of this work is to focus the attention of all interested parties on the need to reduce food losses and the possibility of using food waste as a raw material for the production of energy and fine chemicals, and to point out measures to mitigate the adverse environmental and social-economic consequences caused by solving the waste issue food. During the writing of this review, the authors analyzed a large number of scientific publications in international and domestic journals and reports of relevant domestic and international institutions. The paper presents several proposals for waste management and solutions through the creation of new products that have added value. In the conclusion of the paper, it is stated that the valorization of waste, including by-products from the food supply chain, represents a concept of sustainable development that all participants in the food supply chain should adhere to. By-products created in the food sector can be used as raw materials for the production of new food products for human consumption and in the production of animal feed. These products are biomass suitable for the production of biodiesel, biogas and other energy sources, as well as a large number of fine chemicals that are used in the food, pharmaceutical, cosmetic, chemical and other branches of industry.*

Key words: *Food losses, Food waste, Environmental and health impacts, Valorization of waste*

Introduction

Some food is lost along the supply chain. These losses occur at all stages: starting from primary agricultural production, through processing, to distribution, retail and households. According to existing analyses, food losses and food waste in

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the world (expressed in the energy needed to feed people) represent about 24% of the total amount of food produced. FAO research from 2019 indicates that 13.8% of food produced in 2016 was lost during the supply chain, including the retail stage and household food use [1]. Considering the growing number of malnourished people in the world and the depletion of natural resources, food waste management systems are included among the goals adopted in the 2030 Agenda [2]. The concern over the constant increase in the amount of food waste calls for taking decisive measures to mitigate adverse environmental and social-economic impacts. It is necessary to reduce food losses by 50% by 2030 [1].

The interest of researchers, companies, non-governmental organizations and official authorities in the world in the problems related to food wastage and food waste has been constantly growing in recent years. The term food wastage combines the terms food waste and food loss. In addition to food and food parts, which represent the largest part of waste in food processing processes, waste includes parts of used raw materials and other substances used during work, substances created during maintenance, cleaning and disinfection and other substances [3]. In every step of production, processing, distribution and use of food, a certain amount of secondary products (by-products) is created. In this form, secondary products have no market value for producers and the food industry, and are therefore considered waste [4]. However, there is a general interest in by-products and other types of food waste being processed into new useful products.

Several methodologies are used to determine the amount of generated waste. A number of studies based on the direct measurement method have been published. The indirect FAO method [5] combines several methods of direct measurement of the amount of food waste [6]. According to this methodology, the amount of waste is calculated as the difference between the amount of edible and inedible parts of food. However, many researchers believe that food waste estimates using the FAO methodology are insufficiently precise [7, 8]. The total amount of food waste may be higher than the current estimate obtained using the FAO method [5]. When determining the amount of waste according to the FAO method, subjective interpretations cannot be avoided, which lead to overestimation or underestimation of the amount of waste. In addition, the provided data are often approximations [9]. The United Nations Environment Program (UNEP) published the Food Waste Index Report [10] which showed that previous estimates of food waste were significantly underestimated.

Food waste and the growth of food waste are a cause of concern worldwide [11]. The consequences of food waste are numerous. Food waste can reduce the income of producers and increase costs for consumers. Food loss and waste have different impacts on the environment (for example, greenhouse gas emissions or inefficient use of water and land). For effective food waste management, it is necessary to know all potential sources of waste generation along the food supply chain and a good understanding of measures to prevent and mitigate waste generation, i.e. in a specific sector it is useful to apply "best practices" [12]. Preventing the occurrence and reducing the amount of food waste contributes to a more rational use of natural

resources, reducing environmental pollution and increasing the earnings of food producers and processors [13].

Food waste is a resource that has great energy, chemical and material potential. Several factors affect the possibility of treating and recycling food waste into value-added products. Kaur et al. [14] mention the following factors: the efficiency of the collection system, the chemical composition and the possibilities of applying different processing technologies. Thanks to the application of various biological, thermal and chemical transformations, food waste can be processed into a large number of innovative products of high value (chemicals, biomaterials, biofuel, bio-oil, etc.). A large number of technologies are used in the production and processing of food, whereby a huge number of products of plant, animal or microbiological origin are obtained. Certain types of waste are associated with each type of production. Dealing with waste generated along the food supply chain, including by-products, is an issue that is being addressed by a large number of researchers around the world. In the continuation of this review, the results of those studies and some proposals for food waste management and valorization of food waste through the creation of new products with added value will be presented.

Waste generation in the food supply chain

Waste in the food supply chain consists of edible and inedible substances [4]. An example of the most common ways of generating waste along the food supply chain and the types of generated waste are shown in Figure 1.

After slaughtering the animals, carcasses are obtained. They are processed into food suitable for human consumption. In addition to basic products (i.e. carcasses, meat in pieces and meat processed from meat), slaughtering produces side products of slaughtering (by-products) and solid waste, which do not have a great economic benefit for the factory owner. Waste materials from slaughterhouses and the meat processing industry include: organic side products (by-products), hazardous materials, materials with a specific risk, waste water, gases and odorous materials. In addition, this group includes waste and parts of raw materials generated during the cutting of carcasses and meat processing, which are not for human consumption [15, 16]. A large amount of waste water is generated during the washing of carcasses, removal of garbage and cleaning of equipment and premises. In modern factories, the capacity of meat processing lines has increased many times, and thus the amount of basic and secondary products and all kinds of waste.

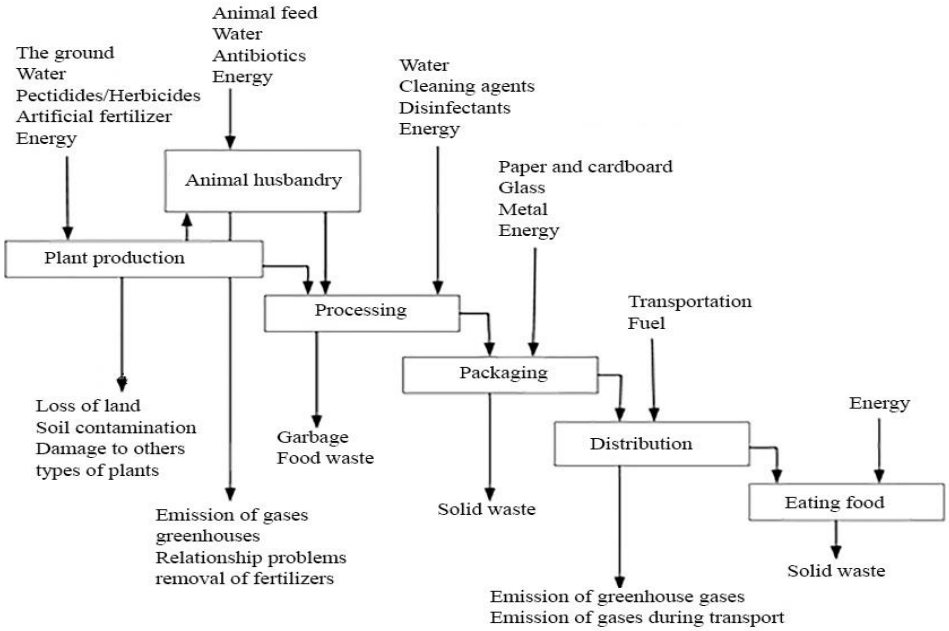

Figure 1. Waste generation during the food supply chain [(Adapted from [4]

Non-edible by-products are traditionally used for non-food purposes (for example, leather for footwear and clothing, feathers for bedding). Part of the by-products can be used to restore nutrients intended for human or animal consumption. In addition, by-products can be used as raw materials in other branches of industry. Some components (for example, digestive tract contents, bile and effluent) have no practical use and are disposed of as waste.

Edible products of the meat industry are mostly exported to low-income countries or used as raw materials for the production of industrial products (for example, cured sausages, nuggets, etc.). The potentially high costs of storage and transport, and the need to reduce the processing time of carcasses, have led to the use of edible by-products being diverted to purposes other than food and the manufacture of non-food items [17]. The use of "mechanically deboned meat" is an example that illustrates the consequences of a rapid change in the strategy of using the by-products of the slaughterhouse industry [18, 19].

By-products of plant origin, residues of unused food products and other types of edible waste from the food industry can be used in the production of animal feed. This contributes to reducing the competition between the production of human food and animal feed. When analyzing the origin and possibility of using food waste, it is necessary to consider procedures for reducing food waste at the level of distributors and consumers. It is as important as reducing waste at the level of industrial production [13]. By preventing food waste at the consumer level, around 26 million tons of food can be saved annually.

Safety and health effects

Food waste and by-products from the food industry have long been viewed as creating a problem or increasing the cost of food production. As a reason for such an opinion, many authors cite the risk of a high microbiological burden, the need to safely remove food waste from production lines, and concern for the environment and public health.

By-products and food waste may contain chemical contaminants or potentially pathogenic microorganisms, which endanger the health of consumers. The risk of contamination is extensive in the area of valorization of food by-products. Quality assurance and safety of by-products is of great importance for the development and application of the strategy of valorization of by-products and food waste [20]. In this sense, the possibility of contaminant transfer from the raw material to the valorized product must be taken into account, as well as the creation of new dangerous substances or an increase in their concentration during the processing of food by-products.

Impact on the environment

Reducing food waste significantly contributes to reducing production costs and increasing the efficiency of the food sector. In addition, it has a great contribution to environmental sustainability. According to FAO research [21], the global carbon footprint due to food waste and waste, including emissions due to land-use change, is estimated at 3.3 gigatons of CO_2. Food waste and food waste contribute to an increase in the consumption of surface and underground water in the amount of about 250 km^3. Almost 1.4 billion hectares of land are used to produce food, which is later thrown away. Food waste contains a large number of biodegradable components, which represent a favorable environment for the development of pathogenic microorganisms that cause infectious diseases. Reducing food losses and waste has a positive impact on environmental protection. This can be expressed through more efficient water management, mitigation of the consequences of climate change, protection of marine resources and terrestrial ecosystems and biodiversity.

Waste management, sustainability and valorization solutions

Rational management and use of primary products and by-products necessary to protect the interests of consumers and reduce the impact on the environment. In addition, it is of great importance for the sustainable development of the modern food industry [22]. The diffusion of processed ready-to-consume products dramatically increases the share and concentration of potential by-products generated during industrial processing, which in the past were directly managed by end users. Therefore, the implementation of planning and management strategies, sustainable improvement of production and efficient use of by-products have become key tasks for the food industry.

Reventive activities to prevent the creation of waste and the use of edible parts of waste in the production of other products intended for human consumption are the most desirable forms of waste management in the food supply chain, including by-products from agricultural production and the food industry. Food waste can be used in industry as a substrate for the production of biofuels and value-added products. The extraction of nutrients is one of the ways of using food waste. As mentioned, organic waste from the food industry is a suitable raw material for composting. In the end, when all options for waste disposal have been exhausted, the remaining options are incineration and disposal of food waste in a landfill. This is considered the least desirable practice.

Waste and by-products from the food industry must not be seen as useless waste ("garbage"), but as an important (renewable) resource for further processing. Renewable sources are the basis of the circular economy concept. The circular economy minimizes the problem of waste storage, reduces pressure on non-renewable energy sources and reduces energy and raw material dependence. These activities have a positive impact on the preservation of the environment and lead to mitigation of climate change [23]. Biomass from food waste and by-products of agriculture and food industry represents a great potential for the production of fuel and chemicals.

Traditionally, food waste is incinerated or landfilled. This causes air/water pollution and soil/food contamination. Disposing of by-products and other types of food waste in nature can have serious consequences for the environment. All over the world, the reduction of food waste is being promoted and new opportunities are being sought for the use of by-products from the food production process. Various measures are taken to utilize waste and by-products to make other useful products. Waste from food processing can be used for composting and soil fertilization [24]. Large quantities of by-products from the food production process are used as animal feed or as raw materials for the production of bioactive ingredients. Part of the waste can be used as raw material (biomass) for the production of energy and biogas. Disposal of food waste, which cannot be used in any of the previous ways, is acceptable. This amount is very small compared to the total amount of generated food and non-food waste.

Use of by-products from the food industry

The meat processing industry has developed a new strategy that enables the processing of most of the edible and inedible by-products into products that will be sold on the market [16, 25]. Baldi et al. [10] provided insight into current and innovative strategies aimed at the valorization of by-products from the meat processing industry. Inedible products from the meat industry have become raw materials for a number of processing plants specialized in the production of proteins of animal origin intended for the manufacture of pet food. Animal fats are used as a raw material for the oleochemical industry, the cosmetic industry and the soap making industry, and for the production of biodiesel [26].

Participants in the food supply chain have recognized the benefits of minimizing the amount of food waste and are implementing various waste management measures in practice [27]. Despite this, the problems of food waste in the hospitality sector are

great. A new approach must be applied to minimize it. Filimonau et al. [28] proposed the principles of the so-called industrial symbioses (IS) through which cross-sectoral cooperation is emphasized and the efficiency of resource use is increased. IS focuses on maximizing value and reducing waste by involving more participants in the chain and strengthening business cooperation. Waste generated in one company can be used as raw material in another company. For example, the hospitality sector can partner with agricultural producers by more efficiently collecting food waste, which the agricultural sector will later use as animal feed or as fertilizer [28].

Food produced for human consumption, which is no longer suitable for human consumption, can be recycled into animal feed [29]. Pinotti et al. [30] give an example of the use of biomass obtained by processing fresh leaf lettuce in the production of food for ruminants. Although secondary products from agriculture and the food industry have been used for a long time in the production of animal feed, available modern innovative technologies represent better solutions for its use.

On-site composting of food waste and anaerobic digestion are usually limited by space, lack of finances, and additional problems are caused by unpleasant odors [31]. Instead of disposing of unused food in landfills, companies from the service sector can offer it to farmers [32]. Farmers can use this food in different ways: composting on the farm or using it for animal feed. In return, farmers can offer their products to catering operators for free or at a reduced price.

Recycling and reuse of secondary products from the food industry for the production of useful materials have become a trend in the development of the food industry. At the same time, the recycling of secondary products is a means of achieving the goals of sustainable development. Considerable efforts are invested in the valorization of by-products of food processing. This contributes to reducing the amount of total food waste, reducing environmental pollution and increasing the sustainability of these by-products [33].

Below is a presentation of several examples of the use of by-products from the food industry:

- Feathers are a by-product of industrial poultry processing, which is rich in proteins (91%), lipids (1%) and water (8%) [34].
- Poultry bones, skin and feathers contain proteins that can be extracted in the form of collagen and gelatin. These proteins represent an alternative source of gelatin for the halal and kosher market.
- During the processing of milk, a large amount of various by-products is produced. These by-products are rich in lipids, proteins, vitamins and other essential ingredients. Whey, which is the main by-product of the milk processing industry, is a rich source of proteins suitable for the production of various products (whey proteins, whey protein concentrates and whey protein isolate).
- During fruit and vegetable processing, peel, pulp and seeds are separated. They account for approximately 30–50% of the total weight of fruits and vegetables. If they are disposed of in nature, it can affect environmental pollution and human health. Methane is produced during the decomposition

of the mentioned by-products. Methane emission can endanger the environment [35]. These by-products are usually used as animal feed. However, considering that they contain a significant amount of organic ingredients (polysaccharides, proteins, lipids and other aliphatic and aromatic compounds), substances of great value can be extracted from them [33].

- By-products obtained in the food industry, either individually or in mixtures, are used for the production of biodegradable foils and packaging for smart packaging of food products [33].

Modern solutions for the valorization of food waste

In addition to the classic methods of waste removal (incineration and composting), other methods for converting food waste into energy (anaerobic digestion, fermentation, transesterification, bioelectrochemical systems, gasification and pyrolysis) are often used in practice. Waste and by-products from agricultural production are increasingly used in the production of bioalcohol (bioethanol and biobutanol), biogas, biodiesel, fine chemicals and a large number of other useful products [36]. In this way, the efficiency of the process is improved, the range of products is increased and the impact on the environment is reduced.

Production of phytochemicals and bioactive compounds

Non-edible parts of agri-food products can contain large amounts of phytonutrients and valuable bioactive compounds. After extraction, they can be used in food production (food additives, nutraceuticals, therapeutics, cosmetics, etc.). Due to their high bioactivity, many ingredients, after being separated from the by-products, are used as nutraceutical and functional food ingredients (biopeptides, carotenoids, dietary fibers and phenolic compounds) [37]. These compounds are used as antioxidants, antimicrobial agents, flavorings, colors, and texture-enhancing additives in the food and pharmaceutical industries. The production of better quality products is achieved by integrating several processes of biorefining of food waste.

Fruit by-products are usually used as animal feed or treated as industrial waste, which creates certain environmental problems. Polysaccharides, pectin, sugars, fibers, proteins, lipids, fatty acids, vitamins (A and E), essential minerals, polyphenols, anthocyanins, pigments, easily volatile aromatic substances can be extracted from by-products or waste from fruits and vegetables. These products can be used as a source of nutrients and bioactive compounds. Dietary fibers and phenols belong to the group of bioactive compounds, which stimulate the growth and activity of beneficial microorganisms, especially lactic acid bacteria. Many of these compounds are used to improve the nutritional and functional properties of food products. Compounds from by-products of fruit processing represent potential prebiotic ingredients. Some of the bioactive compounds from fruit by-products are natural antioxidants, which are important in preserving human health and preventing inflammatory processes, especially in the gastrointestinal tract [38]. After extraction, bioactive compounds from waste generated in fruit and vegetable processing processes can be used in the production of cosmetic and food products, nutraceutical or dietary supplements, etc.

Animal by-products contain bioactive peptides [39]. Seafood is a rich source of PUFA, collagen, gelatin, polysaccharides, minerals, vitamins, antioxidants, enzymes and bioactive peptides, which can be used in the food and pharmaceutical industry. Liver extract is a good source of vitamin B12, so it can be used as a supplement to treat anemia. Collagen from fish waste can be used as a drug carrier, and in the treatment of hypertension and osteoarthritis-related diseases [40]. Various nutraceuticals have a beneficial effect on muscle anabolism and metabolic recovery, which is why they are commercially added to sports nutrition. In addition, they can be used as nutritional supplements, because they have a beneficial effect on the gastrointestinal tract, regulating bowel function, lowering blood pressure, etc. [40]. Martin et al. [41] reported that grape seed oil was used as the basis of lipid nanocarriers to optimize the therapeutic efficacy of antitumor drugs and reduce their toxicity. Valorized food by-products have also found great use in the cosmetic industry. For example, grape seed oil can be used as an ingredient in skin moisturizing products, which have a soft texture, do not leave marks when applied to the skin, and do not cause allergic reactions [41]. Ground coffee extracts appear to be promising candidates for incorporation into cosmetic products intended to prevent skin aging [42].

The valorization of food waste and by-products, in addition to increasing their utilization in the production of nutrients or bioactive compounds, contributes to solving environmental problems caused by discarding "waste" materials. In addition, the processing of by-products from food production has significant economic potential.

Production of bioethanol, biofuel, chemicals

The operation of biorefineries, which use food waste, is based on various biological processes (for example, fermentation, anaerobic digestion and electro-fermentation). Waste from livestock and agricultural production are clean sources for bioenergy production [43]. During these processes, different types of biofuels (bioethanol, biohydrogen, methane and biodiesel), bioplastics, biofertilizer, proteins and enzymes are obtained. This contributes to strengthening the circular economy [44-46]. Bioethanol is usually produced from sugar cane, sweet potato, sugar beet and cereals [47]. The production of bioethanol in this way represents competition to the food industry. As a result, other forms of ethanol production, such as the use of food waste, are being studied [48]. The production of bioethanol from food waste represents the future of biofuels. Residues during industrial processing of fruit (apple, grape, pomegranate, mango, pineapple, banana, citrus, melon, watermelon), vegetable residue and food waste can be used for biofuel production [49]. Soy is the main raw material for biodiesel production in Brazil [50]. Bioconversion of waste generated at different stages of the food supply chain into ethanol can provide a sustainable solution to the depletion of energy resources and a sustainable way to solve the growing global food waste problem. The high content of carbohydrates and nitrogen in food waste makes the waste an ideal alternative substrate [51].

Among the innovative technologies used for the evaluation of waste and by-products from the agro-food industry, the following are most often mentioned in the References: electrotechnologies (pulsed electric fields, high-voltage electric discharges, non-pulsed electric fields), ultrasound, high hydrostatic pressure and liquids under pressure (sub- and super-critical fluid extraction), nanotechnology, radiofrequency drying, ultrasound-assisted extraction, and nanotechnology [52]. Such technologies improve prospects for waste utilization, creating pathways to sustainable industrial development, which is one of the fundamental pillars of public health.

Conclusion

The valorization of waste, including by-products from the food supply chain, is a concept that offers sustainability, rather than dumping waste in landfills or uncontrolled dumping into the environment. Food waste and by-products from this sector represent raw material for the production of new food products for human consumption and animal feed production. As part of biomass, these by-products are raw materials for the production of biodiesel, biogas and other energy sources, as well as a large number of bioactive compounds and other fine chemicals, which are used in the food, pharmaceutical, cosmetic and chemical industries.

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VALORIZACIJA OTPADA OD HRANE U SVRHU SMANJENJA UTICAJA NA ŽIVOTNU SREDINU I ZDRAVLJE LJUDI

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Sažetak: *Dio hrane se gubi duž lanca snabdijevanja, odnosno hrana se rasipa. Nadležne institucije procjenjuju da se više od jedne trećine od ukupne količine proizvedenih poljoprivredno-prehrambenih proizvoda u svijetu ne iskoristi u ishrani ljudi, već se oni rasipaju ili završavaju kao otpad. Uzimajući u obzir sve veći broj neuhranjenih ljudi u svijetu i iscrpljivanje prirodnih resursa, sistemi upravljanja otpadom od hrane uvršteni su među ciljeve usvojene u Agendi 2030. Prema usvojenim planovima, gubici hrane treba da se smanje za 50% do 2030. godine. Cilj ovog rada jeste da se pažnja svih zainteresovanih strana usmjeri na potrebu smanjenja gubitaka hrane i mogućnosti korištenja otpada od hrane kao sirovine za proizvodnju novih prehrambenih proizvoda, energije i finih hemikalija, te da se ukaže na mjere za ublažavanje nepovoljnih ekoloških i socijalno-ekonomskih posljedica uzrokovanih rješavanjem pitanja otpada hrane. Tokom pisanja ovog preglednog rada autori su analizirali veliki broj naučnih publikacija u međunarodnim i domaćim časopisima i izvještaje relevantnih domaćih i međunarodnih institucija. U radu je dato više prijedloga za upravljanje otpadom i rješenja kroz izradu novih proizvoda koji imaju dodatnu vrijednost. U zaključku rada navodi se da valorizacija otpada, uključujući sporedne proizvode iz lanca snabdijevanja hranom, predstavlja koncept održivog razvoja kojeg se svi učesnici u lancu snabdijevanja hranom trebaju pridržavati. Sporedni proizvodi nastali u prehrambenom sektoru mogu se iskoristiti kao sirovina za izradu novih prehrambenih proizvoda za ishranu ljudi i u proizvodnji stočne hrane. Ovi proizvodi su biomasa pogodna za izradu biodizela, biogasa i drugih energenata, te velikog broja finih hemikalija koje imaju primjenu u prehrambenoj, farmaceutskoj, kozmetičarskoj, hemijskoj i drugim granama industrije.*

Ključne riječi*: Gubici hrane, Otpad od hrane, Ekološki i zdravstveni uticaji, Valorizacija otpada*