The use of agrarian and industrial waste as raw materials for re-use in industry – a review

Wykorzystanie odpadów rolniczych i przemysłowych jako surowców do ponownego wykorzystania w przemyśle – przegląd

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Abstrakt

Według danych Organizacji Narodów Zjednoczonych ds. Wyżywienia i Rolnictwa (FAO) szacuje się, że aż 45% wyprodukowanej żywności jest marnowane co stanowi ponad 1,3 mld ton rocznie produkowanej żywności na całym świecie. Oznacza to, że ponad 30% żywności nadającej się do spożycia jest tracone. Ze względu na złożoność łańcucha żywnościowego - jego wieloetapowość i skomplikowaną strukturę organizacyjną - proces zarządzania racjonalnym przepływem i zagospodarowaniem żywności, jest dużym wyzwaniem. Identyfikacja efektywnych rozwiązań wykorzystujących cenne składniki żywności stanowiące odpad przemysłowy czy konsumencki dotyczy wszystkich uczestników łańcuchów dostaw żywności, od sektora rolnictwa i przemysłu do detalistów i konsumentów. Szereg rozwiązań można wdrożyć w zakresie właściwego gospodarowania odpadami spożywczymi oraz uszeregowania ich pod względem ważności w sposób podobny do hierarchii gospodarowania odpadami. Pierwsze kroki nadchodzącej zmiany koncentrują się na przemianie społecznej świadomości gospodarowania i lepszego wykorzystania żywności. Dzisiejsze technologie pozwalają na wykorzystanie odpadów żywnościowych w produkcji biopaliw lub biomateriałów. Dalsze kroki przewidują powrót do obiegu składników odżywczych z żywności. Ostatnimi opcjami są spalanie i składowanie.

Abstract

According to data from the Food and Agriculture Organization of the United Nations (FAO), it is estimated that as much as 45% of food produced is wasted, which accounts for over 1.3 billion tons of food produced worldwide annually. This means that more than 30% of edible food is lost. Due to the complexity of the food chain - its multi-stage nature and complicated organizational structure - the process of managing the rational flow and management of food is a major challenge. The identification of effective solutions using valuable food ingredients constituting industrial or consumer waste concerns all participants in food supply chains, from the agricultural and industrial sectors to retailers and consumers. A number of solutions can be implemented to properly manage and prioritize food waste in a manner similar to the waste management hierarchy. The first steps of the coming change focus on changing the social awareness of the management and better use of food. Today's technologies allow the use of food waste in the production of biofuels or biomaterials. The next steps involve recirculating nutrients from food. The last and least desirable options are incineration and landfilling.

Słowa kluczowe: odpady spożywcze, wytwarzanie, profilaktyka, biorafineria, biopaliwa, bioprodukty, odpady garbarskie
Keywords: food waste, generation, prevention, biorefinery, biofuels, bioproducts, tanning waste

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1. Introduction

The concept of circular economy (called: circular, circular, looped, "Cradle to Cradle" - C2C) is not a new one. Although it had not been developed until the 21st century, its assumptions and theoretical foundations appeared in 1976 from the works of W.R. Stahel and G. Reday. The authors described the vision of a circular economy based on the product life cycle model, its impact on job creation, competitiveness economic and resource saving and waste prevention [1].

In Poland, the published data states that food and agricultural production is responsible for the waste of nearly 6.6 million tons of food, while households waste is over 2 million tons. The agri-food industry is considered to be the main source of food waste in Poland, which proves the poor efficiency in the way fresh materials are being processed. The main difference between Poland and other Western European countries is the fact that the greater level of food waste in the EU is caused by consumers. In the European Union, it is allowed to introduce waste into the environment directly from agricultural production, the fertilizing values of food products are known [2].

The current economy model (linear model) is based on the model inherited from the industrial revolution under the concept of the constant supply of products with a short lifespan, this forces manufactureres to produce more to satisfy the consumer's constant needs. Linear economy (extract, manufacture, and disposal) increases the indiscriminate exploitation of limited natural resources that would give a way to a significant environmental and economic crisis [3]. Such by-products are those food losses and waste (FLW). It is known that in the United States, the FLW covers 40% of the whole food production chain [4], North Africa and West and Central Asia account for 32% of the global FLW volume [5], The European continent represents a 20% of the FLW generated worldwide [6], while in Latin

America FLW is estimated at 15% of the total food production, which represents 6% of FLW worldwide.

In Figure 1, classification of food waste types is proposed, which considers the sources and modes of food losses and waste generation during the food chain from farm to fork [7].

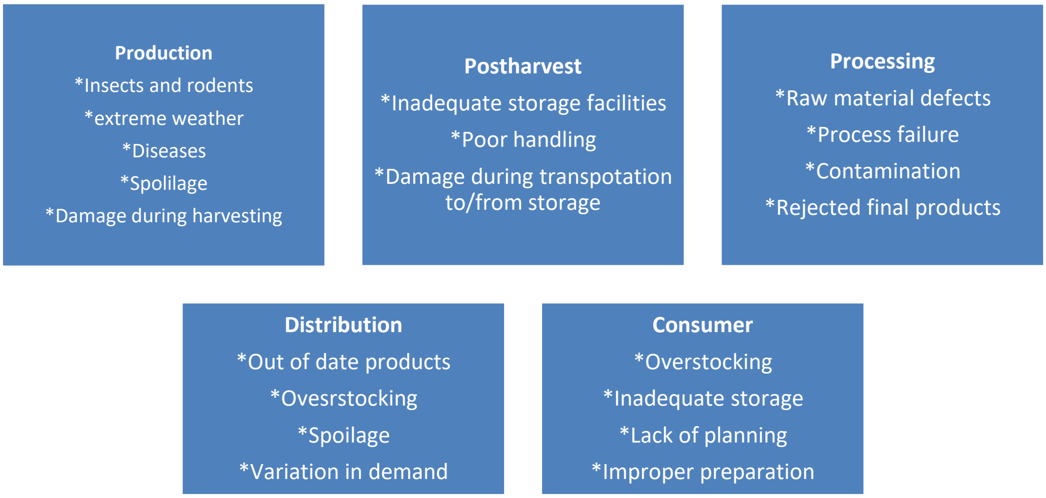


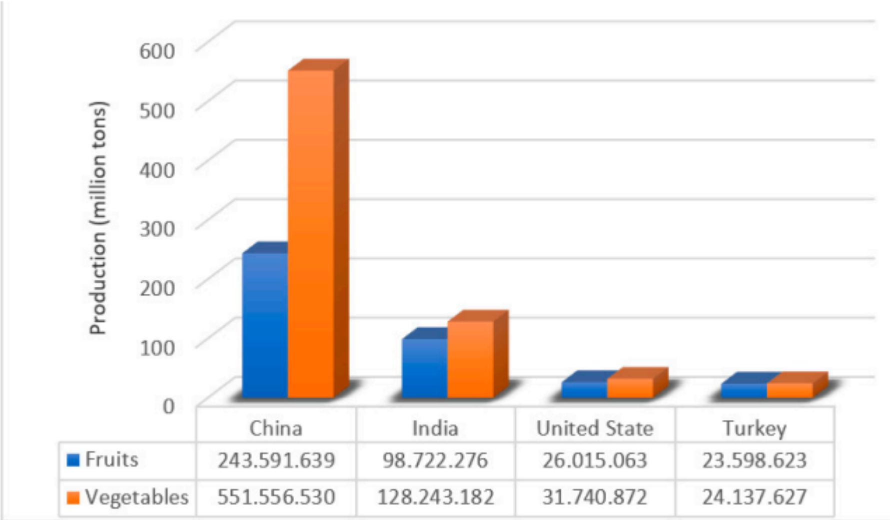
Fig. 1. Food loss and waste throughout the food chain [7].

2. Fruit and Vegetable Production – plant waste

Figure 2 shows the production of fruit and vegetables in individual countries. Among the fruits and vegetables with the highest production are:

- tomato (Solanum lycopersicum),
- apple (Malus domestica),
- onion (Allium cepa),
- orange (Citrus × sinensis),
- Cole (Brassica oleracea var. Capitata),
- gherkin (Cucumis sativus L.),
- eggplant (Solanum melongena),

- mango (Mangifera indica),
- carrot (Daucus carota),
- guava (Psidium guajava L.),
- pepper (Capsicum anuum) [8].



	China	India	United State	Turkey
Fruits	243.591.639	98.722.276	26.015.063	23.598.623
Vegetables	551.556.530	128.243.182	31.740.872	24.137.627

Fig. 2. Primary fruit and vegetable producer (2018 production) [8].

The horticultural industry generates significant losses of consuming raw material due to its high production. Food losses and waste constitute a biomass rich in bioactive compounds, enzymes, vitamins and fibers. The waste biomass obtained in extraction processes and/or as a result of chemical transformations can be used for animal and human nutrition, and even for biorefinery applications [8]. Fruit and vegetable processing generates a lot of valuable waste such as skins, seeds, stalks and pomace. These by-products generally come from specific processes necessary for food processing and conditioning such as grinding, peeling, straining and blanching. Unused fruit particles often end up in landfills, burdening the environment and creating a landfill problem that threatens the sanitation of local communities and the environment. Changing the way fruit and vegetables are managed by using all their parts is a change from a linear to a circular economy [8]. The valuable ingredients that can be used in further processing should be specified in detail in each part of the plant, for example:

2.1 Peels and seeds

Seeds and skins are the most common waste in fruit and vegetable processing. Seeds account for 15% to 40% of the total fruit. Fruit seeds contain many nutrients such as proteins - 35% and lipids - 25% [9]. The most commonly processed fruit is tomato, and its seeds are the most common production waste while it provides an essential source of unsaturated fatty acids, especially linoleic acid [10]. X.Ruelas-Chacon and others. carried out a study whose aim was to evaluate the parameters of enzymatic extraction of lycopene from tomato waste with the use of enzymes - cellulase and pectinase. Tomato waste was obtained from the local market, then chopped and added to 100 ml reactors, at the same time the enzyme was added to the treatment and control reactor. The reaction mass was continuously stirred, and the extraction reaction time was evaluated at predetermined pH and temperature parameters. After the enzymatic process, the concentration of lycopene was measured spectrophotometrically at a wavelength of 520 nm. The effect of the conducted process was the recovery of lycopene from tomato waste at a concentration of 0.93 mg/g of fresh waste using cellulase and 0.48 mg/g of lycopene from fresh waste using pectinase [25].

Seeds are also a rich source of nutrients. An example can be mango seeds which are highly valued due to the possibility of extracting edible oil and an interesting profile of fatty acids [11]. On the other hand, the skins are formed at the stage of peeling fruits and vegetables when the pulp is separated from the plant cover [8]. It is estimated that from 3% to 50% of skins are produced in the fruit and vegetable industry based on the fresh weight of the fruit or vegetable. Fruit peels are an excellent source of cellulose, hemicellulose, but also a rich source of natural food dyes and polyphenols [12].

2.2. Pomace from fruit

The pomace is waste generated during fruit and vegetables processing, it forms a mixture of fruit or vegetable pulp, seeds and plant skins. The pomace is a valuable source of fiber and, for example, in the case of grape marc, it can also provide various phenolic constituents such as catechins, anthocyanins, flavanol glycosides, phenolic acids, and stilbenes [13].

2.3 The Root and Tuber

The food products with the highest proportion of carbohydrates are found in roots and derivatives from tubers such as potato (Solanum tuberosum), yam (Dioscorea esculenta), and cassava (Manihot esculenta) [14]. The production of tubers in most regions of the world (China, South America, India) is a very valuable source of fiber, starch, polyphenolic substances, and vitamins. The processing of tubers is the basis to produce flour and fermented drinks. The most important processing process is the production of flour - the basic ingredient of homemade foods such as tortillas, arepas, fritters, cakes to mention but a few, and in the industry of products for direct consumption such as bread and desserts [15]. The most important elements for possible reuse in the processing of tubers are skins, pulp, and pomace [16].

3. The industrial protein wastes

In addition to by-products of plant origin in the economy, which are a rich source of nutrients (carbohydrates, proteins) and bioactive ingredients (vitamins, minerals), there is also a large number of proteins from the waste of the tanning or fish industry with the potential for reuse. The food industry and the processing industry of natural hides and skins (cattle, sheep, pigs, poultry, fish) generate significant quantities of by-products. The industrial protein waste that through biotechnological processing generates amino acids and peptides, successfully completes alternative sources of nutrients and can be used in agriculture as biostimulator and fertilizers [17]. Also, they can be used in various applications as adhesives [18], packaging [19], surfactants [20], auxiliaries for leather processing [21] or as a chelating agent for metals in actions to decontamination [22]. Moreover, fish collagen from protein waste of the fish industry can be successfully used in various biomedical applications, including wound healing, tissue engineering and regeneration, drug delivery and other therapeutic applications [23].

Recent literature data indicate work on the modification of the collagen matrix with extracts of natural origin (Melissa officinalis extract, Willow bark extract) in order to obtain a biomaterial with improved mechanical properties, better adhesive properties of the material, which contributes to improving the functional capabilities of the biomaterial.[24].

4. The use of agricultural waste

Sustainable waste management practices include not only the recovery of nutrients from waste but also the production of biogas or biofuels from waste plant or animal biomass.

4.1. Biosorbents

Oputu Ogheneochuko et al. worked with virgin (RPP - row pineapple skins) and modified (carbonized, CPP and chemically treated, CTPP) pineapple wastes to remove Co (II) ions from the aqueous system. Cobalt was chosen as the target heavy metal because it is suspected to be a human carcinogen. Co (II) finds its way into surface waters in industrial applications such as mining, electroplating, paints, pigments and electronics. The produced biosorbents were characterized by FTIR, SEM and BET techniques. High saturation of biosorbents with Co (II) ions from real wastewater has been demonstrated [26].

4.2. Biochar

Another innovative approach to waste management for sustainable resource use and biomass recycling explored an innovative circular model of biochar production in an ash pit using a variety of readily available biomass waste and animal manure. Biochar derived from animal waste has greater potential as an additive to fertilizers, while biochar derived from crop residues may be more effective in sequestering carbon and reducing greenhouse gas emissions [27].

4.3. Biofuels and bio-based products

Increasing efforts are now focused on identifying effective and sustainable ways to obtain biofuels and bio-based products. The high demand to produce energy from renewable sources has directed some research towards the effective use of waste for the production of biofuels. Pequi wastes are lignocellulosic materials whose disposal is a heavy burden for the environment, pyrolysis is a safe alternative to these processes. Pyrolysis and gasification are thermal processes seen as alternatives to the incineration in waste management. Pyrolysis of food waste at temperatures from 400 ^{o}C to 800 ^{o}C converts the material from a solid state into a liquid product and/or gas that can be used as a fuel or raw material for subsequent industrial or chemical production. Pyrolysis products are therefore gaseous, liquid, and solid, and their proportions depend on the pyrolysis method and reaction parameters. Gasification is the partial oxidation of food waste to produce a combustible gas mixture. The gas produced can be burned directly or used as fuel for gas engines and gas turbines, or as a raw material to produce chemicals. The applicability and feasibility of these processes depend on the properties of the waste being treated such as elemental composition, calorific value, ash content, moisture and volatile organic compounds matter. The pyrolysis process can provide a viable alternative to the use of these cellulosic wastes, for example by converting Pequi peel into energy in the form of biofuels and compounds of high importance to the chemical industry. As a result of the work, it was found that Pequi (as an example of lignocellulosic waste) pyrolysis can be a source of energy, bio-oil and raw materials of great importance for the chemical industry. Biochar has the potential to be used as an adsorbent and solid fuel [28].

4.4. Biorefineries

Biorefineries are conceptually at the heart of the industrial use of food waste. It is well known that oil refineries convert crude oil into fuels and ingredients for use by a wide range of consumers, similarly biorefineries convert organic waste and biomass (corn, sugarcane and other plant materials) into a range of biofuel ingredients or bio-based products. Fresh food production is concentrated in specific locations, which creates the potential for the development of industrial recycling processes based on symbiosis, where waste from one sector is fed into other industrial sectors [33]. The industrial symbiosis of fresh food processing and biorefinery creates opportunities to fully use food processing waste.

Food waste valorisation pathways in biorefinery chains include two steps – extraction of high-value components already present in feedstocks for use in food or pharmaceutical purposes, and conversion into chemicals, materials or biofuels through the use of chemical or biological processes [29]. Depending on the origin and type of food production, food waste may differ in composition and may include, for example, a mixture of carbohydrates, lipids, and proteins. If the food, e.g., vegetables, fruit, is produced in specific agro-industrial areas, it may be rich in one of the listed ingredients. The production of biofuels from food waste may involve the production of various biofuels using bioprocesses or thermochemical processes, taking into account the chemical composition of the raw materials [30]. Pham et al. and by Kiran examined that food waste can be converted into biofuels or energy through the following processes: transesterification of oils and fats for the production of biodiesel, fermentation of carbohydrates for the production of bioethanol, biobutanol, anaerobic digestion to produce biogas (methane-rich gas), dark fermentation to produce hydrogen, pyrolysis and gasification, hydrothermal carbonization, combustion [31].

Incineration of food waste is a mature technology, but it is less and less popularly used to reduce the amount of waste and produce electricity and heat due to the high humidity of food waste. This property limits the use of combustion methods and, additionally, local communities are concerned that hazardous substances are emitted into the air during the combustion process. An alternative is anaerobic digestion, which is a technology with growing interest. The high biodegradability and moisture content of food waste are ideal properties for biogas production and the digestate can be used as a soil improver or as a source of nutrients. Any source of fatty acids can be used to prepare biodiesel. Thus, any animal or vegetable lipid should be a ready-made substrate to produce biodiesel. However, the use of edible vegetable oils and animal fats to produce biodiesel has traditionally been a major concern due to competition with food production. The use of inedible vegetable oils in the production of biodiesel is as questionable as grain production for fuel. The use of soil, energy, and water to produce non-food goods is a wasteful use of valuable natural resources. An alternative to typical cooking oils in the production of biodiesel is processed cooking oil or oils from the leather industry [32].

5. Conclusions

Sustainable economy mechanisms take into account the need to reuse waste from agricultural and food production and/or waste from the tanning industry. The need not to waste the active ingredients contained in this waste is related to the introduction of the principles of a sustainable policy of saving the environment and farming, as well as conducting industrial food production.

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