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# Valorisation of Food By-products as a Source of Prebiotic

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Abstract: In light of the global food waste dilemma, it is important to promote a circular bio-economy model, stressing the transformational power of waste and by-products to reduce environmental impact and maximize resource use with a minimal carbon footprint. Based on the studies from the literature, this study highlights the need for global action to combat food waste, highlighting programs not only Turkey's zero-waste program but also the European Green Deal as examples of successful worldwide outreach. By increasing research about the introduction of food by-products into the food production cycle as useful prebiotic sources, the study not only emphasizes the benefit of waste reduction but also the economic and ecological relevance of such a strategy. Prebiotics are mostly composed of oligosaccharides, such as fructooligosaccharides and galactooligosaccharides, and polysaccharides, such as inulin, which are short-chain carbohydrates. These compounds may be extracted using various methods, and their impact on probiotic microorganisms is investigated. Among the methods used at this point, there are novel technologies as well as solvent extraction. In this context, it was aimed to review the literature to contribute to the debate on creating a sustainable food ecosystem.

**Keywords:** By-product, valorisation, extraction, prebiotic, probiotic.

# Gıda Yan Ürünlerinin Prebiyotik Kaynağı Olarak Değerlendirilmesi

Özet: Küresel gıda atığı problemini dikkate alarak, çevresel etkiyi azaltmak ve minimum karbon ayak iziyle kaynak kullanımını en üst düzeye çıkarmak için atıkların ve yan ürünlerin tekrar kullanımıyla döngüsel biyoekonomi modelini desteklemek önemlidir. Bu nedenle, mevcut çalışmada, gıda israfıyla mücadele için yapılması gerekenleri içeren kaynaklar özetlenerek hem Türkiye'deki sıfır atık programı hem de Avrupa Yeşil Anlaşması vurgulanmaktadır. Aynı zamanda mevcut çalışmada, gıda yan ürünlerinin prebiyotik kaynağı olarak geri kazanılması ile ilgili çalışmalar ile hem ekonomik hem de ekolojik etkisine değinilmektedir. Prebiyotikler çoğunlukla fruktooligosakkaritler ve galaktooligosakkaritler gibi oligosakkaritler ve kısa zincirli karbonhidratlar olan inülin gibi polisakkaritlerden oluşmaktadır. Bu bileşikler, çeşitli yöntemlerle ekstrakte edilebilmekte ve probiyotik mikroorganizmalar üzerindeki etkileri araştırılmaktadır. Bu noktada kullanılan yöntemler arasında çözgen ekstraksiyonunun yanı sıra yeni teknolojiler de bulunmaktadır. Bu kapsamda, sürdürülebilir bir gıda ekosistemi yaratma konusundaki tartışmalara katkıda bulunmak üzere literatürde yer alan kaynakların incelenmesi hedeflenmiştir.

**Anahtar Kelimeler:** Yan ürün, değerlendirme, ekstraksiyon, prebiyotik, probiyotik.

Review

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## 1. Introduction

It is crucial to emphasize the significance of reducing and treating food waste, and its management system has been widely improved to apply sustainability efficiently in use. With the increment in population that led to more and more consumption every year, the consequences that the world is faced with are becoming challenging. Food waste management is a global issue that is becoming more prevalent in many countries, with some countries accounting for over 50% of total waste (Han et al., 2022). Therefore, it is important to reduce food waste and take a big step to treat it so the industry can reuse it. The production, handling, and post-harvest phases of food production is highlighted by waste at different points in the supply chain. For this kind of waste, industrial waste treatment is significant, and vegetable by-products are incorporated and utilized in the manufacturing process and daily lives. To ensure sustainable waste management, it is necessary to consider each component's economic and environmental burden and operate this mechanism continuously.

Additionally, in the application of sustainability, there are some practices globally. It is known that without food safety and quality, it is unfeasible to apply efficient sustainability goals. Some of the objectives in the near future that aspire to these goals are to support sustainable agriculture by eradicating famine and ensuring food security and good nutrition. With the help of these, it is possible to ensure sustainable food safety, leading to sustainable development (Soylu, 2022). Another essential implementation that European countries contributed to is the Green Deal. The Green Deal aims to make the EU the first short-term climate-neutral country by 2050. The EU plans to adopt a new grand strategy and reshape policies in its second revision, with the Green Memorandum encompassing various sectors, including industry, finance, energy, transport, construction, and agriculture (*The European Green Deal - European Commission*, 2021). According to Food Loss, waste of up to $26.04 million per year is a problem in Türkiye, especially regarding the most wasted fruits and vegetables. Also, in Türkiye, nearly 18 million foods are thrown away every year (Hamzaoğlu & Göktuna, 2022). However, various methods exist to utilize the waste and by-products as probiotic and prebiotic sources. Bozdağ et al. (2023) reported that Türkiye launched a zero-waste initiative to isolate the waste and convert it into energy or crude resources, aiming to increase its reusing rate from 13% in 2019 to 35% in 2023. Consequently, all these applications for reducing waste and sustainably establishing a system are important in national development and catching up on European standards.

Food waste is a global issue affecting economies, the environment, and society's well-being. It leads to increased hunger, resource depletion, and environmental damage. Effective food waste management is crucial to end hunger, ensure food access, and reduce the environmental impact of wasted food. Good management techniques promote sustainable behaviours, environmental stewardship, and social responsibility, preventing food shortages and promoting sustainable practices. The precautions can impact the consumer's behaviour by adopting it in their daily diet. Therefore, increasing re-cycling of the inedible parts and being utilized by the industry with various applications such as investigated in this search, valorisation of by-products as prebiotics or even obtaining probiotics from them are just some of the solutions that exist. Moreover, paving the way out with several techniques applied to waste are some of the key criteria that not only help the sustainable food consumption but also boost the aims to prevent food loss. Some measures are applied by both the government and private corporations that help reduce waste. It is obvious that prospering implementations can be achieved with education, and then white hope consequences can be achieved. One of the practices performed in Türkiye is Zero Waste 'Sıfır Atık'. By encouraging a sustainable economy and using waste streams as raw materials for new goods, zero waste is a novel approach to waste management that sees garbage as a useful resource. By concentrating on waste and pollution avoidance at its source, this strategy engages a variety of stakeholders, fosters collaboration, and generates job possibilities locally (Bilgili et al., 2023). Besides, various practices are applied by the Ministry of Agriculture and Forestry, and various collaborations are made with some of the private corporations and chain stores in Türkiye. One of the plans is 'Gıdanı Koru' which aims to reduce food loss and waste and encourages the customers to 'buy as you need and protect your future'. It also makes collaborations with chain stores that help customers buy the products with the best before-date close ingredients cheaper. It also prevents sensitive products like fruits and vegetables from being thrown away. Also, one of the novel practices is 'Fazla Gıda', an application aiming for the customers to buy products from both restaurants and groceries more cheaply before the shop closure and the products become stale. In addition to these, before becoming waste, food products were also used for extraction from fruits, vegetables, cereals, etc. of bioactive compounds, biofuels as energy suppliers, animal feed, and many more (Akgün et al., 2019). It is inevitable that with the increased and fast consumption, more techniques should be developed with the help of technology to ensure sustainable and green food production.

It is known that the food industry is evolving due to overconsumption aspects of population and economy. The fruit, vegetable, and cereal sectors produce by-products with financial and ecological value. This has led to attempts in the circular bio-economy to increase the value of these by-products because of their higher nutritional content, which benefits health and encourages sustainability in the food production cycle (Alexandre et al., 2023). It is advantageous for developing industrial manufacturing and proving waste management to reduce the impacts. Besides preferring green food that is sustainable and eco-friendly, it is important to have healthy food that not only supports the gut system but also helps to maintain overall body health. Although a healthy gut system promotes a wholesome immune system, it needs to be supported by booster microorganisms such as probiotics and supporter prebiotics to enrich the microflora. When used with by-products or used in procuring the by-products from waste, these microorganisms have a significant effect on the industry. As mentioned by Alexandre et al. (2023), the increased focus on individual health has created a market for functional foods that, in addition to providing proper nutrition, also have health advantages. These foods use natural bioactive compounds and additional ingredients like probiotics and prebiotics, satisfying consumer demands for affordable and palatable meals while highlighting their contribution to chronic disease prevention and quality of life preservation.

Depending on the context, this study aimed to review the research and applied methods examining the prebiotic properties of wastes as another alternative area of utilization.

## 2. Probiotic Microorganisms

Probiotic is derived from the Greek word "probios", which means "for life". Probiotics have a long history dating back to human history (Gasbarrini et al., 2016). The term "probiotic" has been defined in several ways. However, according to the World Health Organization and Food and Agriculture Organization, probiotics are live microorganisms that benefit the host if they are ingested in sufficient concentrations. It is important that the biological effects of probiotics may differ from strain to strain, and their success should be evaluated within their strain. Resistance to stomach and bile acids, complete safety for a host, positive effect on the immune system, antimicrobial effect, and prevention of intestinal diseases are the factors that play an essential role in evaluating a bacterial strain as a probiotic (Fijan, 2014). Probiotics have many applications that are beneficial to human health. Studies have shown that probiotics help lower serum cholesterol and lactose intolerance, reduce and prevent diarrhea and constipation problems, and reduce the risk of colon cancer (Villena & Kitazawa, 2017).

According to studies, microorganisms considered probiotics can be classified as *Lactobacillus* sp., *Bifidobacterium* sp., yeasts, and other microorganisms. They are considered probiotics because of their health benefits and ability to live in the intestines. Some probiotic bacteria species in the *Lactobacillus* genus are *Lactobacillus acidophilus*, *Lactobacillus fermentum*, *Lactobacillus plantarum, Lactobacillus casei,* and *Lactobacillus rhamnosus*. Some of the *Bifidobacterium* species that are considered probiotic are *Bifidobacterium infantis, Bifidobacterium adolascentis, Bifidobacterium longum, Bifidobacterium bifidum* and *Bifidobacterium breve* (Williams, 2010). In addition, *Saccharomyces boulardii, Saccharomyces cerevisiae, Saccharomyces carlsbergensis*, and *Saccharomyces lactis* are yeast species with probiotic properties (Das et al., 2022). The morphological structures of probiotic bacteria are spore-free, Gram (+), and bacilli traits (Fijan, 2014). Although more has been known about the probiotic properties of bacteria in the past, yeast species such as *S. boulardii* have also been shown to have probiotic properties. The necessary studies have been carried out for this purpose (Yıldıran et al., 2017).

## 3. Prebiotic compounds

The gastrointestinal system is a major key to a healthy diet and digestion. Additionally, carbohydrates are known as the primary energy source for the body and can affect the overall diet influencing entire well-being. In contrast, non-digestible carbohydrates significantly alter the gut microbiota's appearance and function, enabling the fermentation of prebiotics by intestinal microorganisms and providing energy for survival by breaking down indigestible bonds (Davani-Davari et al., 2019). Prebiotic complexes that are not possible to digest have favourable traces affecting the host with the help of selected revitalizing development and activity of a distinguished number of bacteria in the gut system, affecting gut health. Prebiotics can be classified as prebiotics according to a few factors, such as both the stomach and small intestine cannot hydrolyse or absorb the substrate. Apart from this, beneficial colonic bacteria, such as *bifidobacteria*, must be the only type of substrate used, and fermentation must have positive luminal and systemic effects on the host (Manning & Gibson, 2004). As a result, prebiotics are fundamental because they not only help to grow but also support the development of useful microorganisms such as probiotics within the intestine, cultivating a more advantageous microbiome and helping in assimilation and general well-being.

Additionally, prebiotics in the carbohydrate category comprise lactulose, galactooligosaccharides (GOS), and short- and long-chain β-fructans, or fructooligosaccharides (FOS) (Table 1). Additional substances under consideration include whole grains, pectin, arabinoxylan, resistant starches, and polyphenols that do not include carbohydrates (Valcheva & Dieleman, 2016). According to You et al. (2022), prebiotics convert into short-chain fatty acids (SCFAs) through fermentation, contributing to intestine health. Prebiotics stimulate intestinal obstruction, reduce inflammation, and prevent harmful substances from entering the system. They also balance the intestinal microbiota, potentially reducing the risk of certain infections and diseases. Prebiotics must be absorbed, promote beneficial microorganisms, be fermentable, safe for use, and have proven health benefits. Classification of prebiotics varies however, some types need to be mentioned such as fructans: β(2→1)-linked linear chains of fructose; and a significant class of prebiotics is GOS, nonetheless, oligosaccharides that don't include carbohydrates like flavanols obtained from cocoa promote lactic acid bacteria; resistant starch (RS) is useful for generating large amounts of butyrate improving health; polydextrose is an oligosaccharide produced from glucose; pectic oligosaccharides (POS) sourced by the pectin (Davani-Davari et al., 2019). It is known that prebiotics has numerous benefits, including improved digestion, immunity, bowel movement regulation, weight management support, reduced inflammation, improved mineral absorption, blood sugar levels, blood balancing, and potential support for mental health, all of which contribute to overall health by nourishing a healthy gut microbiome. Furthermore, they also serve as dietary fibers and low-calorie components added to diverse food products, enhancing their nutritional value, promoting health, and positively impacting their taste and texture (Hurtado-Romero et al., 2020). As a consequence, the use of these prebiotics is inevitably essential for a healthy microflora for overall well-being. However, it also cannot be ignored that innovative applications of prebiotics extend beyond their role in human health, finding utility in waste treatment processes, where their ability to stimulate beneficial microbial activity holds promise for enhancing organic waste decomposition; for instance, prebiotics like inulin have shown potential in optimizing anaerobic digestion systems by promoting the growth of methane-producing bacteria, aiding in the efficient waste breakdown (Rahul et al., 2014). Inulin, oligo-fructose, and FOS are nutritional supplements and functional food components in beverages, yogurts, biscuits, and spreads (Kelly, 2008).

Table 1. Studies conducted on prebiotics extracted by different methods.
*Tablo 1. Farklı yöntemler ile ekstrakte edilen prebiyotik çalışmaları.*

| **Prebiotics** | **Source** | **Extraction method** | **Microorganism** | **Key outcomes** | **References** |
|---|---|---|---|---|---|
| Carbohydrates, inulin, oligofructose | Rice bran | Ultrasound-assisted extraction (UAE) | Lactobacilli strains | In the extracts, no significant differences in prebiotic activity were observed between carbohydrates. Probiotic growth and prebiotic activity values were similar to or higher than those carbohydrates in *Lactobacillus acidophilus*, etc. compared to inulin and oligofructose. | (Antunes et al., 2023) |
| Cellulose | Banana peel | Enzymatic and diluted-acid hydrolysis | *Lactobacillus plantarum*, *Lactobacillus casei* | Water-soluble cellulose showed a higher prebiotic activity index than commercial prebiotics line inulin by increasing the growth of *L. plantarum*. | (Phirom-on & Apiraksakorn, 2021) |
| Dietary fiber | Bagasse and date seed | Alkaline hydrogen-peroxide extraction | *Lactobacillus acidophilus* | Probiotics increase the rate of cell death by consuming nutrients from the environment. The dietary fiber samples of both sources (5%) showed the greatest prebiotic activity. | (Afrazeh et al., 2021) |
| FOS, inulin | Edible mushroom | Solvent extraction (SE) | Lactobacilli strains | In comparison to commercial prebiotics like FOS and inulin, mushroom polysaccharides greatly encouraged the development of *L. acidophilus* and *L. plantarum*. | (Sawangwan et al., 2018) |
| Inulin | *Jerusalem artichoke* tubers | Hot distilled water (HWE) | The mixture of probiotic culture in yoghurt | Depending on the degree of polymerization of inulin, its effect on probiotics was remarkable. | (Li et al., 2015) |
| Oligosaccharide | Sweet potato (*Ipomoea batatas* L.) | Ultrasound-microwave-assisted extraction (UMAE) | *Bifidobacteria adolescentis* | Signifying that sweet potato oligosaccharides promote the growth of *B. adolescentis* with more efficiency with the help of UMAE compared with HWE, UAE. | (Guo et al., 2019) |
| | Dragon fruit (Pitaya) | SE, HWE | *Bifidobacterium bifidum*, *Lactobacillus delbrueckii* | Prebiotic characteristics of pitaya oligosaccharides include partial resistance to salivary α-amylase, acid resistance in the human stomach, and the capacity to promote the development of lactobacilli and bifidobacteria. | (Wichienchot et al., 2010) |
| Pectin-type Polysaccharide | Lotus leaf | Hot Water Reflux, Medium-Temperature Alkali, Ultrahigh pressure-assisted deep eutectic solvents (DES), high pressure homogenization-assisted dual enzyme extraction | *Eubaterium rectale*, *Bacteroides thetaiotaomicron*, *Roseburia intestinalis*, *Faecalibacterium prausnitzii* and other bacterial strains | The study discovered that lotus leaf polysaccharides with potent *in vitro* prebiotic activity may be prepared efficiently using reflux and high-pressure homogenization-assisted dual enzyme extraction while other methods were not appropriate. | (Ke et al., 2023) |

Table 1. Studies conducted on prebiotics extracted by different methods (continue).
*Tablo 1. Farklı yöntemler ile ekstrakte edilen prebiyotik çalışmaları (devamı).*

| Prebiotics | Source | Extraction method | Microorganism | Key outcomes | References |
|---|---|---|---|---|---|
| Polysaccharide | Bamboo shoots | SE, UAE, HWE, enzyme assisted (EAE), microwave-assisted extraction (MAE) | Bifidobacterial and *Lactobacillus* strains | UAE and EAE from bamboo shoots showed better prebiotic effects than FOS, but not as good. They have lower total carbohydrate levels, potentially exhibiting similar proliferative effects. | (Chen et al., 2019) |
| | *Zizyphus jujube* | DES, HWE, ultrahigh pressure extraction (UD) | Lactobacilli strains | While *Zizyphus jujube* polysaccharide (JP)-UD had the highest prebiotic response, all JPs demonstrated varying proliferative effects on the four Lactobacillus strains at different doses. | (Zou et al., 2022) |
| | Soy hulls | MAE | *Lactobacillus bulgaricus* | MAE of soy polysaccharides revealed more robust prebiotic activity. | (Yang et al., 2019) |
| Xylooligosaccharides | Rice Straw | Alkaline extraction | *Lactobacillus rhamnosus, Lactobacillus casei* | *L. rhamnosus* and *L. casei* growth were positively influenced by autohydrolysate treatments, particularly regarding xylobiose, xylotriose, and neutral XOS, with pure xylobiose having the greatest effect. | (Kaur & Mankoo, 2021) |

## 3.1. Inulin

Inulin-type prebiotic compounds found in root vegetables like Jerusalem artichokes, burdock, chicory, leeks, and onions belong to the broader group of "fructans". These substances are natural plant oligo- and polysaccharides primarily characterized by glycosidic bonds predominantly formed by fructosyl-fructose connections. Fructans typically contain at least one fructosyl-glucose bond, often serving as the initial link in the polymer chain. Inulin is also a bifidogenic substance, which promotes the growth of *Bifidobacteria* species in the gut. It is resistant to digestion by enzymes in the upper gastrointestinal system and makes it to the colon intact, where bacteria ferment it (Kelly, 2008).

## 3.2. Fructooligosaccharides

Fructooligosaccharides known as FOS, are an inulin-type prebiotic that helps increase gut flora, especially advantageous bacteria such as *Bifidobacterium*. It is a fact that FOS intake can boost *Bifidobacteria* numbers while lowering Bacteroides, Clostridia, and Fusobacteria whereas the amount of FOS consumed correlates with higher *Bifidobacteria* numbers. Additionally, FOS glycosidic links are mostly beta (2-1) linkages generated by transfructosylation with the fungal enzyme beta-fructosidase, and they are estimated as soluble dietary fiber; however, FOS may be made by partially hydrolyzing inulin or glucose, resulting in short-chain, low-molecular-weight inulin-type fructans with degree of polymerization values ranging from 2-4. Consequently, FOS manufacturing includes the application of specialized technology to fructan-containing dietary sources, resulting in a wide range of inulin-type prebiotic products (Kelly, 2008).

## 3.3. Galactooligosaccharides

Galactooligosaccharides (GOS), synthesized by lactose extension, are classified as excess galactose at C3, C4, or C6 and produced from lactose through enzymatic trans-glycosylation. They promote *Bifidobacteria* and *Lactobacilli*, stimulate Enterobacteria, *Bacteroidetes*, and *Firmicutes*, and some are prebiotics, while others, like raffinose family oligosaccharides, are yet to be discovered (Davani-Davari et al., 2019). GOS are soluble dietary fibers that may have some positive effects on health by encouraging the growth of *Bifidobacteria* in the gut. They have also been studied for their effects on infant infections and allergy symptoms, as well as adult plasma triacylglycerol concentrations and hepatic lipogenesis. GOS are frequently used as functional food ingredients in food products in order to support health claims and produce a harmonious sweetness profile. Lactose can be used to make them through enzymatic synthesis (Kelly, 2008).

## 3.4. Dietary fibers

Dietary fibers are indigestible carbohydrates that may be extracted from plants, offering physiological advantages for human health. Substances are classified as soluble and insoluble due to the inability of human small intestinal enzymes to break them down. Dietary fibers promote digestive health by providing the colon with a carbon source for fermentation. Colonic microbiota has identified them as fermentable substances, and they may be found in marine plants, mushrooms, cereal grains, and algae. The importance of prebiotic dietary fibers in intestinal health and general well-being is well-established. Examples of these fibers include FOSs, inulin, GOSs, and beta-glucan. They are classified into numerous groups, each with its own set of health advantages (Carlson et al., 2018).

## 4. Conclusion

As a result, this study emphasizes how important it is to manage waste sustainably in the face of rising food waste worldwide. To minimize waste and maximize resource usage, the research promotes a circular bio-economy by emphasizing the value-adding of waste and by-products. Initiatives like the European Green Deal and Türkiye's zero-waste responsibility demonstrate a worldwide dedication to decreasing food waste. By solving waste issues and enhancing gut health, the incorporation of waste by-products—which are prime examples of possible prebiotic sources—into the food production cycle provides a dual benefit. The study highlights the role that prebiotic substances and probiotic bacteria play in promoting general health. Prebiotics' creative use in waste treatment procedures, such as enhancing anaerobic digestion systems, demonstrates how well they may be used to solve environmental and health issues. By taking into account social, environmental, and economic factors, this all-encompassing strategy supports sustainability goals and opens the door for a more accountable and environmentally friendly global food system.

It is important to approach waste management from both an industrial and a global standpoint. Businesses should spend money on research to find the best ways to remove by-products from plants, so they may be used as prebiotics. Adopting circular economy ideas on a global scale entail setting industry norms that incorporate waste products into cycles of production. Global collaboration and information sharing can result in uniform methods for handling food waste throughout borders. It is possible to put into place policies that encourage sustainable production and waste management methods. Industries can support a more linked and sustainable global food system by rethinking the value of by-products.

## 5. Conflicts of Interest

The authors declare no conflict of interest.

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