Agri Articles
(e-Magazine for Agricultural Articles)
Volume: 06, Issue: 05 (SEP-OCT, 2026)
Available online at http://www.agriarticles.com
©Agri Articles, ISSN: 2582-9882

Food Waste as a Source of Nutrients and Bioactive Compounds

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More and more, food waste is understood to be a squandered supply of biologically active compounds and nutrients in addition to being an environmental and economic concern. Particularly during the processing and ingestion of fruits, vegetables, cereals, pulses, oilseeds, dairy products, and other foods, significant amounts of residues are produced across the food supply chain. Significant levels of dietary fibre, proteins, lipids, vitamins, minerals, polyphenols, flavonoids, carotenoids, phytosterols, essential oils, and other phytochemicals may be found in materials like fruit peels, seeds, pomace, vegetable leaves, cereal bran, oilseed cakes, and other processing leftovers that are often discarded. Certain bioactive chemicals are sometimes found in greater quantities in the rejected portions than in the edible ones.The valorization of food waste, which involves the retrieval and use of these ingredients, may help in the creation of functional foods, nutraceuticals, natural food additives, and other value-added products, as well as reducing the environmental impact of food disposal. Greener methods like microwave-assisted, enzyme-assisted, ultrasound-assisted, and supercritical-fluid extraction are now more often used in addition to typical extraction techniques like maceration and solvent extraction.However, food safety concerns, pollutants, extraction efficiency, stability, sensory properties, standardization, cost, and regulatory approval must be addressed before broad food applications. This article discusses the nutritional and bioactive potential of food waste, techniques for retrieving valuable compounds, their health-related attributes, applications in food systems, and future prospects for sustainable food production.

Keywords: Dietary fibre, antioxidants, bioactive substances, circular economy, food by-products, food waste, functional foods, nutraceuticals, polyphenols, and valorization.

Introduction

One of the most important environmental, economic, and nutritional concerns worldwide has become food waste. A significant portion of food that is grown for human consumption is lost or wasted during processing, handling after harvest, distribution, retail, and household consumption. The majority of the time, food waste has been seen as an undesirable substance that needs to be thrown away. However, a growing body of research has revealed that several food waste streams include substantial amounts of lipids, vitamins, minerals, pigments, proteins, dietary fiber, phytochemicals, nutrients, and other biologically active substances. As a result, food waste is being recognized more and more as a useful and renewable source for the extraction of high-value compounds, not just a problem for disposal.

Fruit and vegetable skins, seeds, stems, leaves, pomace, cereal bran, oilseed leftovers, spent grains, dairy-processing by-products, and other leftovers created along the food supply chain are among the many materials covered by the phrase food waste. Even if these materials

may be unsuitable for direct human intake due to their physical properties or processing history, they can still have considerable nutritional and functional value. For instance, fruit and vegetable leftovers are frequently loaded with vitamins, minerals, dietary fiber, phenolic compounds, flavonoids, carotenoids, and anthocyanins, while cereal-processing waste may include significant amounts of fiber, proteins, vital fatty acids, minerals, and phenolic acids. Likewise, oilseed, dairy, and brewing industries' agro-industrial by-products can be used as sources of lipids, polyphenols, peptides, and other functional components.

Recovering bioactive substances is one of the key areas of interest in the valorization of food waste. Beyond their basic nutritional functions, naturally occurring substances known as bioactive compounds can have physiological consequences. Polyphenols, flavonoids, carotenoids, anthocyanins, phytosterols, terpenoids, peptides, and a few vitamins are some significant examples. Antioxidant, anti-inflammatory, antibacterial, antidiabetic, cardioprotective, and other biological effects have been studied in these substances. Thus, food processing waste may be a good source of raw materials for the production of functional foods, nutraceuticals, dietary supplements, natural food preservatives, cosmetics, and products linked to pharmaceuticals.

The kind of food material, cultivar, geographical origin, ripeness, processing conditions, and storage practices all have a significant impact on the nutritional content of food waste. The edible pulp of fruits and vegetables often has lower concentrations of certain phytochemicals than their outer or discarded sections. For instance, skins and seeds may contain minerals, fibre, pigments, and phenolic chemicals as part of their defensive biological roles. Similar to this, cereal bran and germ fractions may have high amounts of minerals, phenolic acids, tocopherols, and dietary fiber. Because of these characteristics, food waste might be a significant supply of ingredients for enhancing the functional qualities and nutritional content of food items.

From an environmental point of view, the valorization of food waste is closely related to the circular economy's tenets. Greenhouse gas emissions, foul odors, leachate formation, and inefficient use of agricultural resources are all things that conventional disposal techniques like landfilling and uncontrolled decomposition might cause. Improving resource efficiency and reducing the environmental impact of food production can be achieved by recuperating important components before the remaining biomass is transformed into animal feed, compost, bioenergy, or other goods. Thus, resource recovery, economic growth, sustainable food production, and waste reduction can all be achieved through the valorization of food waste.

The prospect of recovering valuable chemicals from food waste has been enhanced even more by recent advancements in extraction and separation technologies. Traditional processes such pressing, solvent extraction, and steam distillation are being replaced or augmented by methods including supercritical-fluid extraction, microwave-assisted extraction, enzyme-assisted extraction, and pulsed electric field treatment. These technologies can improve extraction efficiency, facilitate the recovery of sensitive or thermolabile compounds, and lower solvent consumption. Because bioactive components vary greatly in terms of polarity, stability, solubility, and susceptibility to oxidation or degradation, selecting the best extraction method is crucial.

Despite this, there are numerous obstacles to transforming food waste into value-added goods. Raw materials' variability, seasonal availability, microbiological contamination, pesticide residue, heavy metals, anti-nutritional factors, and the possibility of food processing contaminants must all be carefully taken into account. Additionally, it is essential to evaluate the bioaccessibility, stability, bioavailability, toxicity, and organoleptic qualities of recovered substances before utilizing them in nutraceutical products or foods. Furthermore, in order to guarantee reproducible quality and safety, extraction processes and characterization techniques must be standardized.

Food Waste and Food By-Products

Food Waste: In general, food waste refers to food or food materials that are thrown away or lost because they are no longer thought to be appropriate or appealing for human consumption.

Examples include:spoiled fruits and vegetables, discarded cooked food, damaged produce, household food scraps, unsold food, food discarded because of aesthetic standards.
Food by-products: Secondary materials generated during agricultural or food-processing operations are known as food by-products.
Examples include:fruit peels, seeds, pomace, cereal bran, rice bran, vegetable leaves and stems, oilseed cakes, whey, coffee grounds, grape pomace, citrus peel.
In terms of diet, by-products might be very fascinating because their makeup is often somewhat consistent and they can be gathered in concentrated streams from the food-processing industry. Recent literature highlights that agro-food by-products may have high levels of useful chemicals, sometimes even more so than the portion of the meal that is generally consumed.

Major Nutrients Present in Food Waste

Dietary Fibre

One of the most important elements recovered from food-processing waste is dietary fiber.
Sources include:fruit peels, apple pomace, citrus peel, cereal bran, vegetable residues, seed coats.
Fibre can contribute to:

- improved bowel function.
- increased satiety.
- modulation of postprandial glucose response.
- cholesterol management.
- maintenance of a healthy gut microbiota.

Proteins

Protein can be recovered from:

- oilseed cakes
- cereal by-products
- legume residues
- whey
- fruit and vegetable processing residues.

Recovered proteins can potentially be used as:

- protein enrichment ingredients.
- Emulsifiers.
- foaming agents.
- texturizing ingredients.
- substrates for bioactive peptide production.

Lipids

Some food by-products contain valuable oils.
Examples include: grape seeds, citrus seeds, mango kernels, watermelon seeds, tomato seeds, avocado seeds.
These may contain fatty acids, tocopherols, phytosterols and other lipid-soluble compounds.

Minerals

Depending on the food source, by-products may contain:
Calcium, potassium, magnesium, iron, zinc, phosphorus.
Therefore, mineral-rich residues may have potential as ingredients for nutrient enrichment, although their bioavailability and safety must be assessed.

Vitamins

Food residues may contain vitamins such as:
vitamin C, vitamin E, provitamin A carotenoids, selected B vitamins.
However, vitamin stability depends strongly on processing and storage conditions.
Heat, oxygen, light and prolonged storage may cause degradation.

Bioactive Compounds in Food Waste

Polyphenols

Examples include:phenolic acids, flavonoids, tannins, anthocyanins, stilbenes.

They are widely distributed in fruit skins, seeds, peels and other plant tissues.

Polyphenols have been investigated for antioxidant, antimicrobial and other biological activities.

Flavonoids

Flavonoids include:quercetin, rutin, catechins, hesperidin, naringenin

Citrus peels, onion skins, apple residues and other plant by-products can be important sources.

Carotenoids

Important carotenoids include:β-carotene, lycopene, lutein, zeaxanthin

Examples:

Tomato processing waste → lycopene

Carrot residues → β-carotene

Leafy vegetable residues → lutein

Carotenoids can have antioxidant activity and some possess provitamin A activity.

Essential oils

Citrus peels are particularly important sources of essential oils.

Major compounds may include:limonene, linalool, citral.

These compounds have potential applications as natural flavouring and antimicrobial ingredients.

Pectin

Pectin is an important polysaccharide found particularly in fruit peels and pomace.

Citrus peel and apple pomace are important sources.

Pectin has applications as:gelling agent, thickener, stabilizer, dietary fibre ingredient, encapsulation material.

Review of Literature

In 2024, Mateus et al. published a study on the byproducts of fruits and vegetables, identifying a variety of phytochemicals that could have antioxidant, antibacterial, and other biological effects. In addition to helping establish circular-economy models, the writers stressed that the restoration of these chemicals may lead to sustainable food production.

Polysaccharides extracted from vegetable and fruit waste were examined by Ozcan et al. (2024), who found that they can provide functional polysaccharides that might be used in food systems. In addition to their ability to act as nutritional fiber, polysaccharides such as pectin can also serve as technological components due to their gelling, thickening, and stabilizing effects.

According to Teslić et al. (2024)'s comprehensive assessment of polyphenols in agri-food leftovers, fruit by-products made up a large portion of the information that was accessible in the database that was looked at. Additionally, the evaluation highlighted the necessity for further investigation into by-products obtained from vegetables, cereals, and other plants, stressing the significance of industrially applicable samples for effective valorization.

Mateus et al. (2024)'s latest study highlighted that by-products from fruits and vegetables are rich in a variety of phytochemicals that could be used in industry and have biological functions.

Ozcan et al. (2024) emphasized the possibility of using polysaccharides derived from fruit and vegetable waste in food applications and discovered that several of the polysaccharides retrieved have antimicrobial and antioxidant properties.

Recent studies have increasingly disputed the conventional understanding of food trash as having no additional worth. Peels, seeds, pomace, bran, pulp, leaves, and stems are examples of food-processing byproducts that can be rich in dietary fiber, proteins, lipids, vitamins, minerals, and phytochemicals. These compounds are thus being examined as possible sources of natural food additives, nutraceutical substances, and functional ingredients. Mateus and

colleagues (2024) revealed that leftovers from fruits and vegetables contain many different bioactive compounds and stressed how they might help with circular economy plans.

Tsegay and colleagues (2024) evaluated the nutritional properties and valorization of fruit and vegetable by-products and found that these materials may be transformed into dietary-fibre concentrates, nutraceutical goods, fermented drinks, natural colors, and edible packaging materials. The writers also pointed out that technological limitations are still preventing these resources from being used widely.

Tsegay et al. (2024) emphasized the significant nutritional and functional elements in fruit and vegetable byproducts, which include phenolic compounds, essential oils, pigments, other phytochemicals, dietary fiber, and proteins.

Teslić et al. (2024) highlighted the significance of polyphenols derived from agri-food by-products and examined current extraction and characterization methods. Such studies show a growing desire to transform polyphenol-rich leftovers into useful components.

Conclusion

Nutrients and bioactive chemicals are plentiful but underutilized in food waste. Significant amounts of dietary fibre, proteins, lipids, vitamins, minerals, polyphenols, carotenoids, flavonoids, pectin, and other functional substances may be present in cereal bran, oilseed cakes, vegetable leftovers, and dairy by-products, as well as fruit peels, seeds, and pomace. The opportunity to simultaneously address resource inefficiency, food waste, and the need for natural functional ingredients is presented by the valorization of these materials. The potential for recovering and utilizing these molecules is growing due to advancements in green extraction, biorefinery, encapsulation, and food-processing methods. However, the existence of a bioactive ingredient in a waste stream does not automatically ensure that it will be beneficial to one's health. Prior to commercialization, safety, bioavailability, dose, stability, sensory characteristics, regulatory standards, and financial viability must all be taken into account. Therefore, the future of food-waste valorization involves not only "using waste in food" but also scientifically describing waste streams, selectively retrieving valuable components, establishing their safety and bioavailability, and creating evidence-based food applications. This strategy has the potential to contribute to a food system that is more resource-efficient, circular, and sustainable.

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