Review Article

Emerging Technologies in Fruit By-Products Valorization: A Review

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Abstract

Fruit and vegetable wastes from the agri-food industry are produced in vast quantities and, due to their high moisture content and microbial load, can cause significant environmental contamination. The bioactive chemicals present in the leftovers can be employed as pharmaceutical excipients, food additives, or incorporated into pharmaceutical formulations or food matrices to produce nutraceutical and functional foods. As a next eco-conscious step of waste valorization the advances in food packaging technology may be an efficient solution to reduce the amount of food waste through the utilization of waste and by-product derived natural materials in the food packaging industry. By doing so, global pollution by microplastics could be reduced. The present review emphasises on the promising alternatives for the valorization of certain fruit by-products. Furthermore, more environmentally sustainable food systems can be created, and food security and nutrition can be improved through waste reduction by implementing some emerged technologies in fruit by-product valorization.

Keywords: Bioactive compounds; valorization; vegetable wastes

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Introduction

The term "valorization" refers to repurposing food waste into food or feed products, as well as converting or extracting food or feed ingredients. It is a sustainable method of converting food waste into value-added goods, reducing food waste disposal in landfills and reducing greenhouse gas emissions. It is a practical method for dealing with trash management. Food safety and efficient waste management are two of the most pressing issues facing the twenty-first century, and they intersect in the agri-food sector. Food waste is one of the most abundant residues in the world. According to the FAO, around one-third of edible components from food sources destined for human consumption are rejected and wasted worldwide (about 1.3 billion tonnes per year) [1]. Within the European Union, more than 88 million tonnes per year are produced (statistics for the EU-28 in 2012), or to 173 kg per person [2]. Furthermore, it is anticipated that this value would rise by up to 40% in the future years [3]. Fruit and vegetable waste (FVW) generation takes place at all stages of the food supply chain, although the share of FVW generated in each stage varies significantly from one country to another, depending on the level of development of the regions where crops are cultivated. In developing countries, harvesting and processing are the most important stages contributing to FVW generation. In a recent survey by FAO in developing countries, around 50% of fruits produced are lost in supply chain between their harvest and consumption. The processing industries, on the other hand, are the chief sources of by-products and waste generation in huge amounts [4]. This has made fruit safety and management the major concern, globally. Since these materials are prone to microbial spoilage it may cause high level of environmental contamination. Hence, different management techniques are required to be explored to resolve this problem [5]. A promising alternative to overcome this issue is the valorization of fruit by-products into high-value-added compounds. Consequently, by-products of processed fruits such as peels, unused flesh, and seeds are used for the production of functional food products of high nutritional value with several health benefits. This makes it applicable in different industries like agriculture, nutraceutical, cosmetic, pharmaceutical, etc [6]. Keeping in view these aspects, this review is written with the pretext to discuss different by-products of fruits, the emerging technologies to extract valuable compounds from them and their potential applications.

Fruit By-Products

Fruit by-products are unused or unconsumed pieces of fruit that occur as a result of incorrect treatment or disposal. Fruit by-products vary in number and type depending on the commodities and morphological components, which include seeds, pomace, pulp, skin, leaves, tuber, and so on [7]. Fruit peels, seeds, and other non-consumable components are found to be high in vital nutrients and phytochemicals [8]. **Figure 1** depicts a schematic illustration of the use of fruit waste and by-products in several industries.

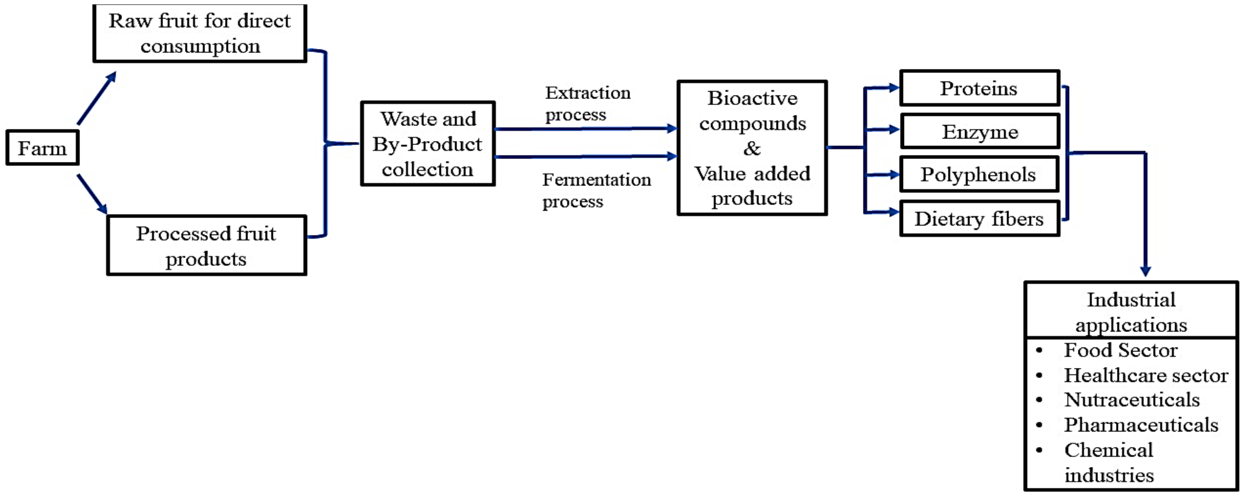

Figure 1 Schematic representation of fruit waste and by-products utilization

Difference between waste valorization and food waste valorization

Waste valorization, defined as the process of transforming waste into more usable products, is an effective way to deal with waste management. The term is most commonly used in industrial processes when waste from the creation or processing of one product is used as a raw material or energy source for another.

The conversion of food waste or by-products into higher-value items that contribute back to the food supply chain is known as food waste valorization. It is a sustainable method of converting food waste into value-added goods, reducing food waste disposal in landfills and reducing greenhouse gas emissions.

Difference between waste and by-product

Inefficient actions that do not add value to a product or service are classified as waste. It is items that are undesired or useless and have no commercial worth.

Municipal solid waste (home trash/refuse), hazardous waste, wastewater, radioactive waste, and other types of waste are examples.

A by product is a secondary product created by chance during the manufacturing of the primary product. It has some resale value, but it is usually far less than the primary product's value. Commercial value of by-products is minimal.

Buttermilk (a by-product) is produced alongside butter and cheese in the dairy industry, for example (main product).

Why valorization (Reasons for adapting valorization)

Food waste and the production of food by-products is a major issue that has negative environmental, economic, and social consequences. Food waste reduction is a common goal in global action programmes to reduce food waste. The EU and many other countries push measures to reduce food waste since they are well aware of the seriousness of the problem. The farm to fork strategy, the circular economy action plan, and EU trash regulations are just a few examples. Food waste reduction could be a key component of lowering production costs and resulting in more efficient food systems. Furthermore, waste reduction can help establish more environmentally sustainable food systems, as well as increase food security and nutrition.

Valuable components from food waste

Fruits and vegetables, which make up a substantial part of the food industry, generate a lot of trash every year. They are a good source of a variety of beneficial components (carotenoids, polyphenols, and so on), also known as bioactive compounds. Because of their antioxidant, anti-cancer, anti-inflammation, and anti-allergenic capabilities, these bioactive chemicals have a positive impact on human health, depending on the pathway and their bioavailability in the body. In this context, there is a lot of interest in valuing FVW by extracting high-value-added chemicals that might be used in a variety of industrial industries FVW extracts are high in bioactive chemicals including phenols and fibre, and they can be employed in a variety of products for the development of functional foods, nutraceuticals, and cosmetics. FVW can produce a wide range of platform chemicals, high-value-added compounds, and building blocks, as shown in **Figure 2**.

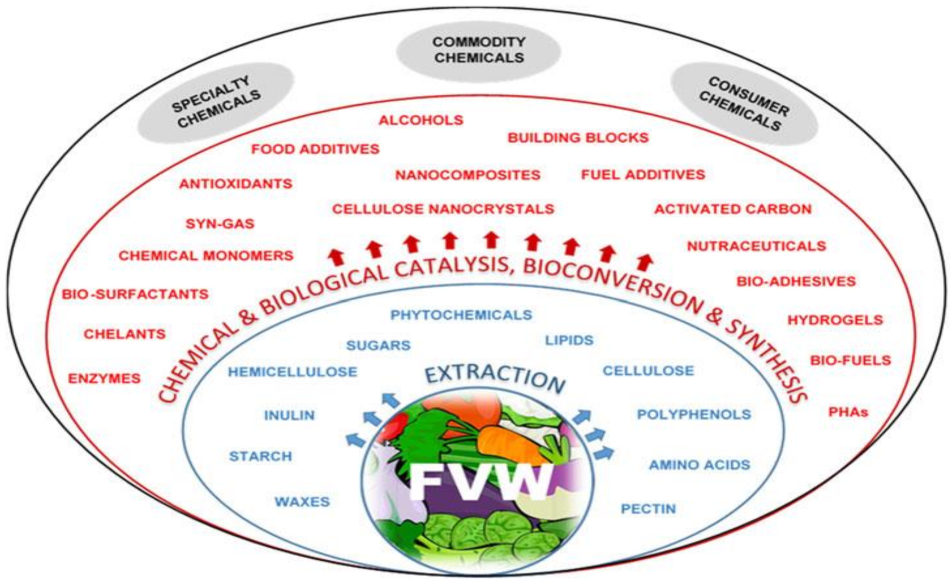

Figure 2 Overview of the different chemicals that can be obtained from FVW through valorization.

Because of their antioxidant, anti-cancer, anti-inflammation, and anti-allergenic capabilities, these bioactive chemicals have a positive impact on human health, depending on the pathway and their bioavailability in the body. These extracts are used in a variety of industries, including nutraceuticals, packaging materials, and preservation. Many industries use components extracted from fruit by-products for a variety of purposes Consumer demand for natural fragrances and flavours has prompted the use of vanillin (4-hydroxy-3-methoxy benzaldehyde) for vanilla flavouring in cosmetics, detergents, food, and other products. Pharmaceutical industries, Pineapple peels contain ferulic acid, a precursor to vanillic acid, which is utilised in the production of vanillin [9]. The peel of a pomegranate contains a lot of phenolic chemicals, including a lot of anthocyanin. Because of its high gelling property, pectin is another component that plays a vital part in the creation of food products such as jam, jellies, and sweets. It's found in fruit by-products including apple, orange, carrot, peach, and so on [10]. Polyphenols isolated from orange peel and flesh have been discovered to have medicinal properties. It protects human HepG2 cells from oxidative DNA damage caused by peroxyl radicals and leukocytes from oxidative DNA damage [11].

Main targets of government and the food sectors includes:

- The main action in waste valorization that contributes to the circular economy is the production of value-added goods from wastes such as fuels, materials, and chemicals.
- Food waste from industrial food processing can be valorized for a variety of economic, social, and environmental benefits, including the production of value-added goods such as organic fertilizers, animal feed, biofuels, and power.
- Many studies on the valorization of food wastes to produce food ingredients, functional
- foods, nutraceuticals, pharmaceuticals, and cosmeceuticals have been conducted because they contain many health-promoting bioactive compounds such as polyphenols, proteins, lipids, vitamins, and dietary fibre that may improve the nutritional, functional, and technological properties of food products.
- As a next eco-conscious step in waste valorization, innovations in food packaging technology could be an effective way to reduce the quantity of food waste and by-products in the food packaging sector by utilizing waste and by-product-derived natural materials.
- As useful packaging material becomes accessible, global pollution from microplastics could be decreased.
- Food products become safer and more resistant to spoiling processes when antioxidant compounds produced from food waste are incorporated into packing material.

Various emerging techniques in fruit by-product valorization

- Non-thermal concepts-based emerging technologies (i.e. pulsed electric fields promise to surpass most of the above challenges and optimise processing efficiency). These sophisticated technologies are now being proposed for use in a variety of food industry operations, and they might be simply adapted for the recovery of valuable chemicals from wastes downstream.
- Super critical fluid extraction
- Ultrasound-assisted extraction
- Microwave-assisted extraction
- Pulsed electric field
- Enzyme-assisted extraction
- High hydrostatic pressure
- Ultrasonication
- High pressure processing
- Vacuum processing

Supercritical fluid extraction

SFE (supercritical fluid extraction) is a sample preparation process that aims to eliminate the usage of organic solvents while increasing sample throughput. Temperature, pressure, sample volume, analyte collection, modifier (co-solvent) addition, flow and pressure control, and restrictors are all things to think about. For SFE, cylindrical extraction vessels are commonly utilised, and their performance is unquestionably good. Another crucial phase is the collection of the extracted analyte after SFE: considerable analyte loss might occur during this stage, leading the analyst to conclude that the efficiency was low. Carbon dioxide as an extracting fluid has numerous advantages. In addition to its good physical qualities, carbon dioxide is inexpensive, safe, and abundant it has a number of polarity restrictions. When extracting polar solutes and when strong analyte-matrix interactions are present, solvent polarity is critical. Because it is less expensive and more inert than carbon dioxide, argon is being used [12].

Applications

- Food and fragrance extraction are two applications for SFE.
- Samples from the environment.
- Natural products, essential oils, and polymers.

Ultrasound-assisted extraction

Another new technology is ultrasound-assisted extraction, which has industrial-scale processing equipment designs [13]. Vanillin extraction, almond oils, herbal extracts, and soy protein are all examples of food processing applications (with enhanced removal of flatulence-causing soluble sugars). Although the method is effective in particular situations, such as the extraction of ruwolfia root, its use on a broad scale is limited due to the high costs. It also provides a technique that decreases reliance on solvents like hexane while improving economics and efficiency. Benefits to the environment (owing to a larger yield of extracted components), increased extraction rate, shorter extraction time, and faster process throughput.

Applications

- Sonication can be used to make nanoparticles such nanoemulsions, nanocrystals, liposomes, and wax emulsions, as well as to purify wastewater.
- Extraction of plant oil.
- Production of biofuels.
- Polymer and epoxy processing, adhesive thinning, and a variety of additional procedures are all available.
- It's used in a variety of industries, including pharmaceuticals, cosmetics, water, food, ink, paint, coatings, wood treatment, metalworking, nanocomposite, pesticides, fuel, and wood products.
- Sonication can also be utilised to start crystallisation and even regulate polymorphic crystallisations.
- It is used to enhance mixing and separate tiny crystals in anti-solvent precipitations (crystallisation).

Microwave-assisted extraction (principle)

At the molecular level, this temperature effect is almost instantaneous, although it is limited to a tiny area and depth near the material's surface [14]. The dipole of polar and polarizable materials interacts with the microwave radion. Electric and magnetic component coupling forces rapidly change direction. Polar molecules strive to align themselves in the changing field direction, which causes them to become heated. Heating is low in non-polar solvents lacking polarizable groups (dielectric absorption only because of atomic and electronic polarization). Conduction heats the rest of the substance. As a result, huge particles or agglomerates of small particles cannot be heated uniformly, which is one of microwave heating's fundamental drawbacks. It may be feasible to increase penetration depth by using high-power sources. Once within a microwave absorbing substance, however, microwave radiation exhibits an exponential decrease.

Applications

- Isolation of important pharmaceutical compounds.
- Extraction of virtually all compounds from all matrices.
- Isolation and extraction of phytoconstituents from plant materials using a microwave aided extraction procedure.

Pulsed electric field-assisted extraction

In the food business, pulsed electric field-assisted extraction (pef) has been found to improve solid–liquid extraction procedures [15]. Pef had previously been used to extract anthocyanins and phenolics from red wine, sucrose, proteins, and inulin from chicory, betanine from beet, sugar beet, apple, and carrot juice, as well as maize germ and olive oils. Pef extraction methods' high extract yield, lower operating temperatures (preventing thermal degradation), high product quality and purity, high process efficiency, shorter extraction times, and lower energy cost are key advantages of this technique, heralding its potential for energy-efficient and environmentally friendly food processing.

Applications

- PEF has been used to make protein extraction easier, alter enzyme catalytic characteristics, and improve the physiological and nutritional qualities of bioactive proteins.
- PEF is a non-thermal extraction technology that uses short electrical impulses to inactivate bacteria.
- PEF's goal is to provide consumers with high-quality foods.

Aqueous two phase extraction

Aqueous two phase extraction for the purification and concentration of betalains, aqueous two-phase extraction was successfully used (a natural colourant from beetroot). One of the most important separation procedures in downstream processing is aqueous two-phase extraction [16]. ATP extraction is typically made up of a water solution containing two structurally unique hydrophilic polymers or a water solution containing one polymer and particular ions. As a result, the procedure is simpler and thus more environmentally friendly.

Application

- In terms of cost, downstream processing of proteins is a critical step in the purification and separation of biomolecules.
- Low molecular weight molecules are separated.
- They provide gentle conditions that do not injure or denature biomolecules that are unstable or liable.
- Antibodies, antigens, and their complexes are partitioned.
- The purification of pharmaceutical enzymes.
- The purification of antibiotics.
- The purification of other pharmaceuticals.

Enzyme-assisted aqueous extraction

Aqueous extraction with the help of enzymes this method has been used to extract oils from a variety of oil seeds and fruits [17]. The method's benefits stem from the fact that it processes at low temperatures and uses water as a solvent, providing better product quality while also being safe and environmentally benign. Oil output is improved by the presence of food-grade enzymes.

Application

- EAE is a more environmentally friendly alternative to traditional extraction technologies.
- Oil and protein extraction from oilseeds at the same time.
- Extraction of buffers and enzymes to allow for the manufacture of a variety of oils and proteins, despite the fact that the procedure is fraught with difficulties.

High pressure processing

It's a promising non-thermal technology that was created with the goal of producing microbiologically safe food [18]. Pascalization is another name for it. Food packets submerged in liquid are subjected to high pressures of up to 1000 MPa (often 400-600 MPa). High pressure is delivered in a"isostatic" way, ensuring that all areas of the meal are subjected to the same level of pressure.

Application

- Used for cold extraction of meat in crustaceans and the opening of molluscs.
- Pharmaceutical and cosmetic items, in addition to food and beverage applications, appear to be a lucrative area.

Conclusion and future prospective

Food processing has had tremendous growth over the previous decade and is now one of the world's fastest growing industries [19]. During the processing, however, a significant amount of waste is generated. According to studies, nearly 20% of the total 14 million metric tonnes (mmt) of waste is generated during the preparation, distribution, and retail of food and beverages. In contrast to other food processing businesses, the fruits and vegetables (f&vs) industry generates higher amounts of waste, equivalent to 25–30 percent, which includes peels, rinds, seeds, cores, rags, stones, pods, vine, shell, skin, pomace, and so on [20]. Every processing phase, including fruit & vegetables processing (5.5 mmt), canning and freezing (6 mmt), wine processing (5–9 mmt), and others, is anticipated to release roughly 55 mmt of waste. Philippines, China, India, and the United States are the top producers of these wastes. If these wastes are not properly disposed of or managed, they constitute a major threat to the environment due to the release of numerous greenhouse gases during decomposition. As a result, there is a need to valorize wastes into various value-added products or extract bioactive substances with varied functional benefits in order to avoid these concerns.

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Publication History

Received	21.02.2022
Revised	07.07.2022
Accepted	07.07.2022
Online	31.07.2022