



Review Article

Challenges and Opportunities in Managing Fruit and Vegetable Waste: A Comprehensive Review

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Abstract | This review examines fruit and vegetable (FV) production, characteristics, and waste types, focusing on the extraction of target bioactive compounds. The review highlights the substantial amount of waste generated throughout the FV supply chain, resulting from inadequate management practices in fields, harvesting, processing, transportation, storage, and distribution. This waste not only represents a loss of food but also leads to degradation of valuable components, including bioactive compounds, with significant implications for various industries and applications. Common and unconventional manufacturing processes for FV waste utilization are discussed, emphasizing the importance of adopting new technologies to achieve high recovery rates of substances that are bioactive. These extracted compounds hold potential applications in food, medicine, cosmetics, chemistry, and functional foods. Fruits and vegetables are highly valuable horticultural crops, offering health benefits and culinary versatility. However, substantial losses and waste pose significant challenges in the modern food industry and present major economic and environmental concerns. Notably, the Food and Agriculture Organization (FAO) reports that waste and losses are highest in FVs among all types of food, accounting for up to 60% of total losses. Most of this waste consists of seeds, husks, skins, and other components abundant in health-promoting bioactive substances, including oils, vitamins, dietary fibre, carotenoids, and polyphenols. Making use of FV waste to extract these bioactive compounds represents a crucial step towards sustainable development. This review covers various types of FV waste, extraction technologies, and potential applications of the obtained bioactive compounds, offering insights into strategies for waste reduction and resource optimization in the FV industry.

Received | May 11, 2024; **Accepted** | July 01, 2024; **Published** | August 12, 2024

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Citation | Nawaz, S., S.G. Khaskheli, A.H. Soomro, I. Rajper, S.A. Sheikh, A.A. Khaskheli and S. Soomro. 2024. Challenges and opportunities in managing fruit and vegetable waste: A comprehensive review. *Sarhad Journal of Agriculture*, 40(3): 955-971.

DOI | <https://dx.doi.org/10.17582/journal.sja/2024/40.3.955.971>

Keywords | Fruit and vegetable, Production, Bioactive compounds, Extraction techniques, Waste



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Introduction

Nutrition holds paramount importance for human sustenance and environmental equilibrium. The utilization of raw materials can yield consumable or processed goods of significant value. However, the escalating global populace and sporadic disruptions in supply chains have intensified apprehensions regarding burgeoning food wastage. Annually, globally almost 1.3 billion tonnes of food are lost or wasted, with a consistent upward trajectory (Du *et al.*, 2018). The proliferation of food waste and by-products across diverse sources designated for human consumption has emerged as a pervasive global concern. The management of voluminous biodegradable entities poses a formidable challenge. Owing to the associated costs of solid waste management and landfilling, a substantial proportion of these materials remain unrecovered, leading to their disposal, loss, sale, or consumption by pests. This practice precipitates significant environmental ramifications through microbial degradation and leachate generation (Torres-Leon *et al.*, 2017a). Consequently, this phenomenon engenders multifaceted environmental, societal, and economic quandaries, thereby representing a pressing challenge for contemporary civilization (Mirabella *et al.*, 2014). Harnessing these residual materials as a reservoir of natural food supplements harbors considerable promise in mitigating environmental degradation. Repurposing these by-products into high-value commodities offers a dual benefit of cost reduction and profit optimization for enterprises, thereby enhancing their operational efficacy. Consequently, this review endeavors to illuminate the prospective role of fruit and vegetable by-products as invaluable adjuncts to the food industry. Moreover, it delineates crucial lacunae in research domains and underscores the transformative potential of ameliorating waste management practices within fruit and vegetable processing, thereby elevating erstwhile overlooked resources into indispensable assets.

Citrus fruit wastes

Approximately 5 percent of all citrus varieties undergo industrial procedures (FAO, 2021). Mostly for the manufacturing of their fruit juices, which are the most popular fruit juices consumed globally and produce a significant quantity of processing waste annually—roughly 120 million tonnes. (Zema *et al.*, 2018; Chavan *et al.*, 2018), Nevertheless, only 45% of the entire fruit weight is utilised in this industrial pro-

cess; the remaining fruit weight is made up of disposal remnants including seeds (2%), pulp (endocarp and albedo; 26%), and peel (flavedo; 27%) (Leporini *et al.*, 2021). Furthermore, these numbers are increased by whole fruits that are thrown because they do not meet quality requirements. Concurrently, pruning is a common technique used to cut off tree branches or enhance the fruit's quality, suggesting the growth of a lot of leaves (Leporini *et al.*, 2021), a residue that adds to the substantial quantity of garbage citrus already produces. This is frequently tossed into rivers and landfills, especially in underdeveloped nations, polluting the environment and lowering the quantities of dissolved oxygen in water. Citrus waste contributes significantly to pollution since it is easily fermentable, abundant, complex chemically, and biodegradable, requiring a lot of oxygen to break down. Its pH is typically low (3–4), and it contains a lot of water (80–90%) and organic matter (95% of the residue overall) (Ruiz and Flotats, 2014). Another choice for getting rid of CF waste is to burn it in order to produce thermal energy (Siles *et al.*, 2016). A risky process that discharges significant amounts of carbon, nitrogen, and sulphur oxides into the atmosphere; as a result, it is no longer an appropriate method for disposing of CF waste. Therefore, a number of alternatives for better management of CF waste were put forth in an effort to lessen environmental pollution and generate revenue for the food, pharmaceutical, and cosmetic industries. These included the creation of fortified animal feeds, the use of fiber-rich ingredients in confectionery products, the extraction of macro- and micronutrients, as well as the production of organic fertilisers, biofuels, enzymes, and ethanol (Osorio *et al.*, 2021; Chavan *et al.* 2018; Muscat *et al.*, 2021). In fact, the establishment of waste biorefineries in developed nations may have a substantial positive impact on the environment and the economy. The former could include reduced greenhouse gas emissions, the preservation of natural resources like land, soil, and groundwater, energy, and the recovery of energy and value-added products, as well as savings on land, new business ventures that lead to the creation of jobs, and landfill costs (Nizami *et al.*, 2017). However, biorefineries frequently incur expenditures in handling CF waste. For instance, utilising 100,000 tonnes of garbage per year, the projected total cost to make ethanol is 0.91 USD/L, assuming 10 USD/ton for treatment and transportation to the biorefinery (Lohrasbi *et al.*, 2010). In any case, because of its heterogeneity, CF waste is regarded as a valuable, sustainable, and eco-

nomically advantageous source for the pharmaceutical, cosmetic, and health industries (i.e., for the manufacturing of nutraceuticals and functional foods, and for obtaining skin care products like soaps, lotions, body sprays, and essential oils) (Panwar *et al.*, 2021). Furthermore, by using these re-use tactics, the food industry may be able to lower waste generation and the expenses associated with disposing of it as organic matter, resulting in the creation of new commercial goods (such as food packaging, antimicrobials, encapsulating agents, additives, and prebiotics).

Apple pomace

Apple pomace which contains high contents of vitamins, dietary fibers and pectin, is a kind of byproduct produced in the apple processing industry (Yan and Kerr, 2013). With the development of apple processing industry, the total amount of apple pomace is increasing rapidly (Alvarez *et al.*, 2012). It was reported that apple pomace may cause serious environmental pollution without treatment (Sudha, 2011). In order to utilize the apple pomace comprehensively and reduce its negative effect on environment, apple pectin extraction and apple pomace fermentation industries have been developed (Alvarez *et al.*, 2012). The production of pectin from apple pomace presents a viable and sustainable approach, both economically and environmentally. In comparison to citrus pectins, apple-derived pectins exhibit favorable gelling characteristics. But the brown colour of apple pectins, which is caused by enzymatic browning, might constrain their utilization in high-fat diets (Endreß, 211). Using state-of-the-art technologies to effectively utilise these waste by-products will not only benefit humanity but also sustain the ecosystem. It is well knowledge that agricultural beneficial components like dietary fibre, carotenoids, phenolics, and micro- and macronutrients can be found in wastes. These waste materials can be used to make nutritious and healthful meals by mixing them with other food products as processed powders, extracts, and segregated bioactive (Hussain *et al.*, 2022; 2023a).

Grape pomace

20-30% of the grapes that are grown are wasted, with the remaining 75% going towards making wine (García-Lomillo *et al.*, 2017; Bender *et al.*, 2017). This waste, which is also known as grape pomace, is made up of the skins, leftover pulp, seeds, and stems (Balbinoti *et al.*, 2020) These byproducts are disposed of as waste, or they might be utilized to make wine

or alcohol, fertilizer, or animal feed (García-Lomillo *et al.*, 2017). Conversely, grape pomace has a high concentration of compounds that are thought to be health-promoting (Bender *et al.*, 2020; Bennato *et al.*, 2020). Dietary fibres, which can make up to 85% of the pomace depending on the variety of grape, and polyphenolic compounds, which mostly stay in the pomace after the winemaking process (approximately 70%), are the most prevalent in grape pomace (Acun and Gul, 2014; Beres *et al.*, 2017). Natural and healthful food components that can take the place of artificial antioxidants and food preservatives are in greater demand (Garrido *et al.*, 2011). Due to its biotechnological potential, grape pomace has been the subject of numerous research exploring its potential for use as a food fortification additive (Ianni *et al.*, 2019). In these investigations, grape pomace has raised the finished product's value and enhanced its nutritional profile. This research addressed a broad variety of goods, such as dairy, meat, fish, and plant-based food products. From just 0.06% used in pork burgers, (Garrido *et al.*, 2011), to 100% used in tea infusion (Bekhit *et al.*, 2011).

Peach and apricot

Processing apricots can result in the byproduct known as bitter apricot stones (*Prunus armeniaca* L., Rosaceae). In the past 20 years, peaches and apricots have also attracted the interest of scientists, farmers, and consumers due to their abundance of metabolites with nutraceutical qualities, including flavonoids, phenolic acids, carotenoids, and anthocyanins. It is commonly known that these secondary metabolites enhance food quality in general and have positive health benefits on people, including the prevention of cancer and age-related disorders (Wojdyło and Oszmianański, 2020). With their high concentrations of carbohydrates, fibres, proteins, minerals, and vitamins, apricots offer a significant nutritional and health profile (Moustafa and Cross, 2019) Peaches may have a significant antioxidant effect in mammalian cells due to their high phenolic component and vitamin (e.g., C) content.

Mango

Mango seed oil is recognized as a valuable source of edible oil, notable for its fatty acid composition and triglyceride structure closely resembling that of cocoa butter. Moreover, mango fruit serves as a reservoir of essential antioxidants, primarily identified as phenolic compounds and phospholipids (Suleman *et al.*, 2023).

Phenolic compounds in mangoes are comprised of gallic and ellagic acids, along with gallates. Another study has reported the presence of gallotannins and condensed tannins, akin to polyphenols found in mango fruit (Suleman *et al.*, 2023).

Guava

Guava is considered as superfruits because of their high phenol and other antioxidant levels (Lima *et al.*, 2018). International trade in fresh guava is restricted, but processed guava products—like drinks and preserves—are spreading throughout many nations (Todisco *et al.*, 2018). In the food business, guava is frequently used to make pulp, nectars, jams, jellies, and syrups (Narváez-cuenca *et al.*, 2020). Guava (*Psidium guajava* L., Myrtaceae) constitutes a source of low-methoxylated pectin, typically at around 50% methylation. Due to the limited utilization of guava waste, since makes up just 10% to 15% of the fruit, guava's availability for the synthesis of pectin is limited. Even though the seeds contain 5–13% oil that is rich in natural fatty acids, they are frequently thrown out during the juice and pulp preparation. Recent research has highlighted the potential productive utilization of guava peel and skin as a source of antioxidant dietary fiber (Hidalgo *et al.*, 2015). This underscores the multifaceted value of guava fruit beyond its traditional consumption, offering opportunities for the extraction of valuable components for various applications in the food and pharmaceutical industries.

Papaya

Papain is a stabiliser and proteolytic enzyme used in the preparation of meat. It is derived from the latex of papaya seeds (*Carica papaya* L., Caricaceae) for use in beer making. In addition, papaya seeds can be used to produce pectin. Naturally abundant in vitamins, macro and microminerals, bioactive compounds, and secondary metabolites, papaya fruits are a gift from nature. Alkaloids and flavonoids, which have antibacterial and therapeutic qualities, are abundant in leaves, stems, seeds, and other plant components in addition to fruits. Over time, several health benefits have been found for papayas, which makes them a plant with significant medicinal importance. The key industrial enzymes contained in papaya latex, endopeptidases, papain, caricain, and proteinase, are utilised in several commercial applications (Koul *et al.*, 2022).

Kiwifruit

Kiwi waste (*Actinidia chinensis* PLANCH., Actini-

diaceae)—sea litter kiwi fruit, which is less than 30% of the total kiwi, and when the production of juice from kiwi pulp (Sanz *et al.*, 2020). The chemical makeup, distinct taste, and increased anti-inflammatory and antioxidant qualities make it a super food. Traditional Chinese medicine has utilized kiwifruit waste. Kiwifruit's antioxidants strengthen the cardiovascular system and lessen oxidative stress. This fruit is a valuable part of a healthy diet and can also be used as a dietary supplement due to its low calorie content, abundance of vitamins, and high phenolic content, which provide protection against heart disease, cancer, diabetes, vascular diseases, and diseases of the central nervous system (Sanz *et al.*, 2020). Kiwifruit by-products can be valorized to yield biopolymers and promising components that can be used to make packaging that is biodegradable and contains bioactive elements to extend its shelf life.

Cranberry

The genus *Vaccinium* and family Ericaceae include the cranberry (*Vaccinium macrocarpon*). This berry fruit is high in sugar, fibre, vitamins, organic acids, and mineral salts. Cranberry fruits are also a rich source of bioactive substances such as carotenoids, terpenes, and polyphenols (Oszmiański *et al.*, 2017). Fruits are industrially processed to produce powders, concentrates, jellies, juice, and jams. By-products including peel, seeds, stem cells, *etc.*, however, continue to be a rich source of bioactive substances. Circular economy statements also assist the recovery of valuable molecules that have the potential to yield both financial and environmental advantages (Patra *et al.*, 2022). Whole pomaces can be utilised to make food with additional value that is enhanced with fruit byproducts (Mildner-Szkudlarz *et al.*, 2016). Because they have significant amounts of phenolic compounds and antioxidant activity, underutilized peels, pulp, seeds, and pruning remnants such as leaves and twinges would be an excellent source. These materials can be used in a variety of industrial industries. Oil derived from cranberry seeds is thought to be rich in beneficial components, which may justify the significance of sustainable cranberry seed oil acquisition. Looked into the polyphenol content of cranberry seed oil (Górnaś and Rudzińska, 2016). The sterol concentration of cranberry seed oil is higher than that of apple, gooseberry, pomegranate, and grape seed oil.

Sugar beet by-products

Figure 1, Illustrates the input and output processes

of a sugar mill or distillery, or any other biotechnological plant. Just 30% of the sugar produced worldwide is derived from sugar beet; the remaining sugar is produced from cane (Eurostat, 2017). Nevertheless, the process of extracting sugar from sugar beets produces a large amount of wastes annually, which is thought to be very important in terms of underutilized potential and generated levels (RedCorn *et al.*, 2018). When sugar beetroot wastes are harvested, they are often utilized as lignocellulosic material for the extraction of pectin and the production of ethanol (Maravić *et al.*, 2018). The possible application of many sugar beetroot by-products with distinct physico-chemical characteristics (pressed, ensiled, and dried pulp) as effective substitutes for pectin after it has been extracted using an acid or an enzyme. Similarly, rheological characterisation of the isolated pectins is used to explore their potential as thickening or gelling agents. The sugar beet sector produces a large amount of byproducts that have numerous potential uses. While molasses has historically been used primarily for the manufacturing of alcohol, animal feed, and as a medium for the generation of yeast biomass, by-products such as sugar beet pulp have historically been utilized as ingredients in animal feed (Duraisamy *et al.*, 2017). These applications include the synthesis of value-added chemicals and pharmaceutical intermediates (Cárdenas-Fernández *et al.*, 2017) and the utilization of sugar beetroot pulp to make bio-fuels via fermentation or thermochemical processes (Nicodème *et al.*, 2018). Among other things, sugar beet molasses can be utilized for ethanol production (Arshad *et al.*, 2017) or lactic fermentation (Tomaszewska *et al.*, 2018).

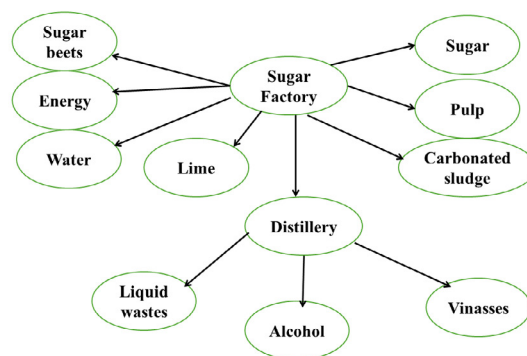


Figure 2: Flow in and out of the distillery/distillery (Kotzamanidis *et al.*, 2000; Vaccari *et al.*, 2005).

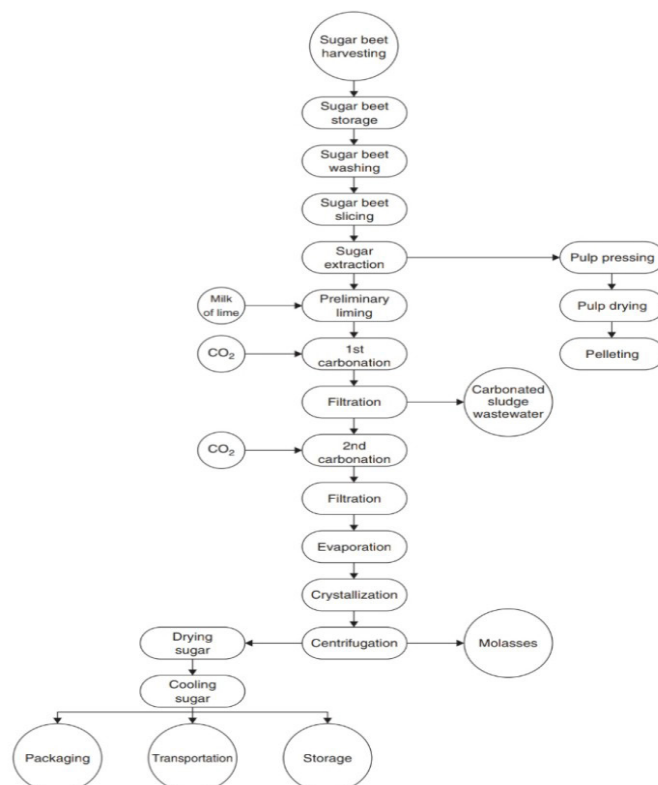


Figure 3: A simplified Flow diagram of the sugar industry (Kotzamanidis *et al.*, 2000; Vaccari *et al.*, 2005).

One of the many types of phytochemicals with properties and activities that promote health is phenolic compounds. Phenolic molecules, with their vast structures and functions, are categorized as secondary metabolites that are widely spread across the kingdom of plants. It is thought to be the most important and prevalent class of compounds in the kingdom of plants. Primary and secondary metabolic types are used to classify plant metabolism (Mohammed *et al.*, 2020). Lipids, carbohydrates, proteins, and nucleic acids are among the primary metabolites, along with all other necessary components needed for cell division and growth. Secondary metabolites are substances found in particular cells that are known to be crucial

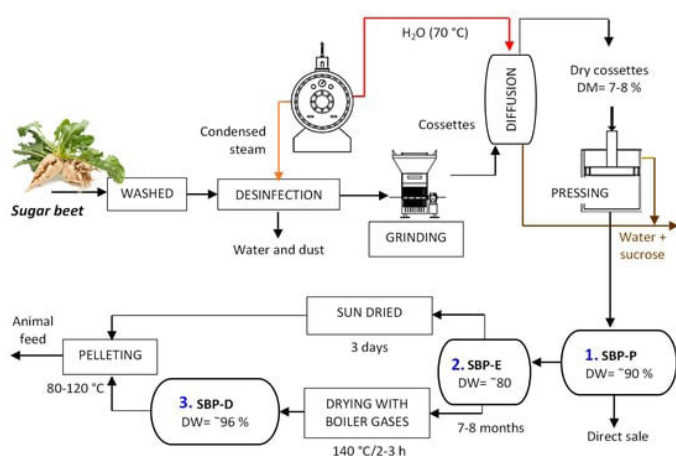


Figure 1: Industrial process of sugar extraction from sugar beet. By-products obtained: 1. SBP-P: sugar beet pulp pressed, 2. SBP-E: sugar beet pulp ensiled, 3. SBP-D: sugar beet pulp dried. DW: dry weight. (Pacheco *et al.*, 2019)

for a plant's life but are only tangentially necessary for basic respiration photosynthesis or metabolism. Fruit and vegetable seeds, peels, and skins harbor a significant number of phenolic compounds, with potato skin notably rich in these compounds (Choi *et al.*, 2016; Mohammed *et al.*, 2020). Fruits continue to be a good source of high-functioning phenolic chemicals, which are mainstays of our daily meals (Xu *et al.*, 2017). As primary sources of thiamine, vitamins, niacin, pyridoxine, minerals, folic acid, iron, dietary fibre, magnesium, malic acid, tartaric acid, calories, and citric acids, fruits and fruit products are important for human health and diet. Certain fruits and their byproducts have high levels of antioxidants found in their phytochemical components, or phytonutrients, which have the ability to change metabolic processes and the removal of carcinogens. They may even have an impact on the mechanisms that lead to cell tumours (Bozhuyuk *et al.*, 2016). Every fruit has a varied combination of phytochemicals, which causes variations in the fruit's antioxidant potential. Every fruit has a varied combination of phytochemicals, which causes variations in the fruit's antioxidant potential. As a result, increased consumption raises antioxidant capacity. The term for plant in Greek is phyto. As a result, it can be found in plants and their byproducts, such as fruits, nuts, seeds, vegetables, cereals, legumes, roots, and leaves. Fruits provide a range of tastes and are a good source of nutrients that have various benefits, such as helping maintain a healthy weight and promoting normal health development (Sheehan, 2019).

Bio compounds from fruit and vegetable wastes and domestic wastes

Residues from fruits and vegetables represent reservoirs of phytochemicals, which have been studied in relation to the extraction of dietary fibre, phenolic compounds, and other organic components. While only Research have shown that although most fruits and vegetables are eaten for their flesh or pulp, peels and other less commonly eaten parts harbor high levels of phytochemicals and essential nutrients (Rudra *et al.*, 2015). For instance, discarded parts such as cut lemons, grapes, oranges, mangoes, avocados, jackfruits, and longans have more than 15% more total phenol content compared to their pulp counterparts (Sagar *et al.*, 2018). It is crucial to note that fruit and vegetable waste (FVW) are susceptible to microbial spoilage, leading to malodors and environmental concerns. Disposal methods, whether thermal (including heating, microwave treatment, radio waves, infrared

heating, and sterilization) or non-thermal (such as high hydrostatic pressure, radiation, pulsed light, ultrasound, and pulsating electric field PEF), can impact the preservation of phytochemicals during waste management processes. Below are some important lifestyle factors that can affect biomolecules present in fruit and vegetable wastes.

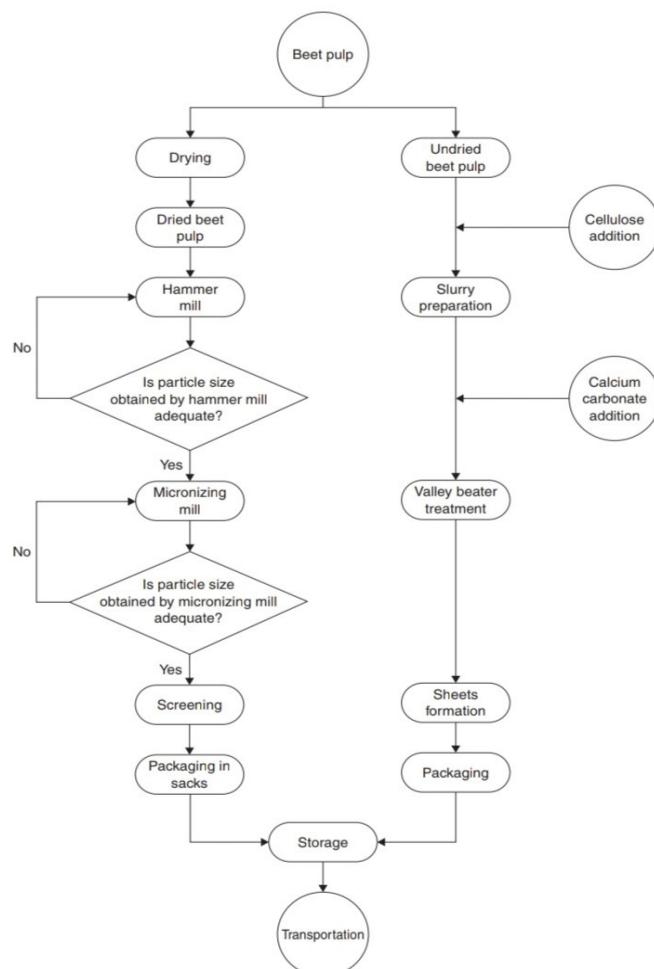


Figure 4: An approved solution for the use of non-dried sugar beet pulp in paper production (Vaccari *et al.*, 2005). Phenolic compounds

Extraction of bioactive compounds

One important source of bioactive materials with multiple applications is horticultural waste. Because FVWs can be utilized to extract extremely important biomolecules, horticulture by-products are finally being acknowledged as valuable resources. Horticultural by-products are rich in minerals, phenolic compounds, dietary fiber, organic acids, pigments, and sugar by-products. Some of these bioactive substances have characteristics that include cardio protective, antiviral, anticancer, antibacterial, and anti-mutagenic effects (Yahia, 2017). Fruits and vegetables that are utilized for juice or pulp extraction, jams,

Table 1: Phenolic compounds are found in some fruit and vegetable residues.

Commodity	Waste part	Phenolic compounds	References
Banana	Bract	Analogues of cyanidin, such as malvidin, pelargonidin, peonidin, and petunidin	Telesom and Wojdyło 2015)
Bilberry	Leaves	The compounds quercetin-3-O-rutinoside, epicatechin, neochlorogenic acid, caffeic acid, and myricetin-3-O-galactoside	(Teleszko and Wojdyło 2015)
Chokeberry	Leaves	Quercetin-3-O-galactoside and robinobioside	(Teleszko and Wojdyło 2015)
Citrus fruits	Peel and solid residues	Hesperidin, naringin, epicatechin, procyanidin B1, myricetin-3-, and eriocitrin	(Matharu <i>et al.</i> , 2016)
Cranberry	Leaves	xylopiranoside, methoxyquercetin-pentoside, dimethoxymyricetin-hexoside, and quercetin-3-O-galactoside	(Teleszko and Wojdyło 2015)
Kiwifruit	Peel	Protocatechuic acid, p-coumaric acid, and caffeineic acid	Moo-huchin <i>et al.</i> , 2015
Mango	Seed kernel	Gallic acid, ellagic acid, gallates, and gallotannins	Benzarti <i>et al.</i> , 2015,
Mango	Peel	of flavonoids	Teleszko and Wojdyło 2015)
Purple star apple	Peel	Myricetin, ellagic, gallic, caffeic, furulic, and sinapic	Procyanidin B1, procyanidin C1, kaempferol-3-O-glucoside, kaempferol-3-O-rutinoside, quercetin-3-O-galactoside, 4-O-caffeoylquinic acid,
Quince	Leaves		
Red cashew	Peel	Three-O-rutinoside quercetin	(Moo-Huchin <i>et al.</i> , 2015),
Olive	Oil	Gallic ellagic, myricetin, ferulic, sinapic, caffeic, and Hydroxytyrosol and oleuropein derivatives	
Wastewater	Vegetables		
Garlic	Husk	Caffeic acid-O-glucoside, hydroxybenzoic acid, p-coumaric acid, coumaric acid-O-glucoside, and caffeoylputrescine	(Kallel <i>et al.</i> , 2014)

frozen pulp, and other applications include oranges, pineapples, peaches, apples, potatoes, carrots, green peas, onions, artichokes, and asparagus. This leads to a significant amount of trash (Bermudez, 2019). The loss of bio-compounds as a result of inadequate processing in conventional extraction methods (maceration, shaking, Soxhlet, among others) is another technological advancement (Alirezalu *et al.*, 2020). Conventional extraction methods lyse or disturb the cells or tissues with chemicals or solvents in order to extract bioactive compounds. These processes include solvent extraction, alkali extraction, and acid extraction. Most methods for extracting soluble dietary fibre (SDF) need high temperatures, strong acids or alkalis, long incubation times, and residues in the final product. These processes are also not particularly ecologically friendly and involve a lot of chemicals (Garcia-Vaquero *et al.*, 2020). High pressure processing, colloidal gas aphrons (CGAs), pulse electric field (PEF), accelerated solvent extraction (ASE), microwave assisted extraction (MAE), ultrasound assisted extraction (UAE), ultrasound microwave assisted extraction (UMAE), and subcritical and supercritical fluid extraction are some of the newer SDF extraction methods. These procedures can be used separately, as a pre-treatment, or in combination to provide the highest yield at the lowest cost. Thermolabile chemi-

cals like polyphenols have been successfully extracted using ultrasound assisted extraction (UAE) (Montenegro-Landívar *et al.*, 2021). The UAE improves heat and mass transmission while facilitating the release of extractable bio-compounds, making it a repeatable, selective, productive, and environmentally friendly method (Mármol *et al.*, 2021).

A comparative analysis of different extraction methods and their respective advantages is summarized in Table 2.

Conventional extraction techniques

It is considered as the traditional method because it has been used for a long time. Based on this basic process of solvent and high-temperature extraction or mixing thereof. It is one of the main traditional methods (1) Soxhlet extraction, (2) liquid evaporation and (3) precipitation (Khoddami *et al.*, 2013). It is the most effective technique for the continuous extraction of a solid by a heated solvent and is named for the German agricultural chemist Franz Ritter von Soxhlet (Mohammed, 2018). Soxhlet device is a specialized glass refluxing apparatus primarily utilized for the extraction of organic solvents. With the exception of the extraction of compounds that are thermolabile in some restricted domains of application,

Table 2: Compare the advantages and limitations of different methods in the extraction of bioactive compounds.

Technique	Advantages	Limitations	Recommended Compounds	References
Soxhlet	Often employed as a classical approach Fundamental model technique for contrasting other techniques	• Time-consuming; • Requires a lot of chemicals and is not ecologically friendly	Lipid/fat extraction	(Azmir <i>et al.</i> , 2013)
Hydro- distillation	The earliest and most basic method for obtaining essential oils from plants Ideal for small-scale businesses offers a variety of alternatives based on preference, including direct steam distillation, hydro-diffusion, steam and water distillation, and hydro-distillation.	Heat-labile chemicals should not be used since they could be lost or destroyed at high temperatures. a laborious and slow procedure	Bioactive substances and oil	(Azmir <i>et al.</i> , 2013)
Solid-phase extraction	The pace of separation is quicker than LLE. Simple to operate and requires little manual labour greater repeatability compared to LLE	more costly than LLE Particularly for molecules that are more polar Because to evaporative losses, unsuitable for volatile analytes	Ideal for phytochemicals found in therapeutic plants	(Vuckovic 2013, Abd-Talib <i>et al.</i> , 2014)
Supercritical fluid extraction (SFE)	Better mass transfer is achieved with a lower viscosity and a higher diffusion coefficient compared to liquid solvent extraction. Because less sample and organic solvent are needed, the process is both environmentally benign and time-saving. Minimal waste because supercritical fluid may be recycled and reused Because it is done at room temperature, it is appropriate for volatile chemicals.	Not recommended for most drugs; 10000 kg/h extraction rate is quick, and yield is increased. Assistance with pure extract (grinding, reducing), lower energy costs and a smaller environmental impact than with traditional extraction.	Pharmaceutical specimens It is impossible to dissolve polar molecules. Expensive thermodynamic system complexity	
Pressurized liquid extraction (PLE)	Suitable for isolating biomolecules from solid samples Supercritical fluid extraction is not as effective for polar chemicals; it takes more time and requires less solvent.			
Pulsed electric field (PEF)	Can to be used continuously for up to	Increased expense of equipment Unfit for samples with extremely low targeted	Utilizing agro-industrial waste items to extract phytochemicals Ideal for different polyphenols and phytosterols	(Pue'rtolas <i>et al.</i> , 2012, Barba <i>et al.</i> 2015)
Enzyme-assisted extraction (EAE)	Environmentally beneficial since it substitutes water for organic compounds as a solvent. remarkably appropriate for extracting bound chemicals high rate of extraction	High enzyme costs for large-scale sample oil extraction and bounded		
Ultra-sound-assisted extraction (UAE)	More affordable than the solvent extraction method Easily manipulated and financially viable as compared to supercritical fluid extraction a shorter extraction time than when using ultrasonic assistance Reduced use of energy and power Reduced chemical usage, quicker processing times, and increased product yield	extraction aided by ultrasonic less environmentally friendly since organic solvents are used inadequate yield of extraction for nonpolar chemicals Not suitable for heat-sensitive biomolecules, For the highest yield, proper optimisation of the ultrasonic frequency, nominal power of the device, cycle propagation, input power, and system geometry is necessary.	Carotenoids, phenolic compounds, lipids, and chlorophyll	(Azmir <i>et al.</i> , 2013, Barba <i>et al.</i> , 2015)

High-voltage electrical discharge (HVED)	Less energy needed to extract biomolecules when compared to other recently developed technologies (PEF, UAE, MAE, and soon.) Reduced time and solvent consumption Requires a low diffusion temperature	Less discerning in contrast to PEF At the industrial or pilot level, viability is uncertain.	Polyphenols	(Barba <i>et al.</i> ,2015)
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Soxhlet extraction is a widely used and proven technology that outperforms other traditional extraction methods in terms of performance. The soxhlet apparatus is filled with the powdered solid material using a filter paper-filled thimble. The device is attached to a reflux condenser and a round-bottomed (RB) flask holding the solvent. The vapor from the gradually boiling solvent in the RB flask rises via the side tube, condenses in the condenser, and then descends into the thimble that holds the substance, filling the soxhlet gradually. The solvent extracts the portion of the substance it has extracted by syphoning into the flask once it reaches the top of the connected tube. Until total extraction is accomplished, the procedure is repeated (Mohammed, 2018).

Advantages:

A significant volume of plant material can be harvested at once.

Able to use solvent repeatedly.

Filtration is not necessary with this approach after extraction.

The type of matrix has no bearing on this procedure. This technique is quite basic.

The process of continuously bringing new solvent into contact with the solid matrix, which shifts the transfer equilibrium.

Disadvantages:

Since the samples are heated to a high temperature for a considerable amount of time, it is not possible to rule out the possibility that some compounds may be thermally destroyed if the plant material contains heat-labile chemicals.

The procedure requires a lot of labour and takes a long time to complete.

The procedure permits the modification of certain variables.

The Soxhlet extraction method has been widely criticized due to its length and high solvent required (Mohammed, 2018).

Novel technologies

New approaches are emerging because of the inefficiencies of traditional approaches.

Traditional methods of extraction difficult to get high purity, expensive to utilize solvents, long extraction times, degradation of heat-resistant compounds and low selective extraction (Selvamuthukumar and Shi, 2017). New techniques have been developed to overcome these limitations. Lots of new people and new people technology are currently used in the extraction process. Key new and emerging technologies are described below.

Microwave extraction

In an irradiated material, microwave heating results in the dissipation of electromagnetic waves, which is determined by the average local time of the electric field intensity and the dielectric characteristics. The transfer of heat from the heating system to the medium occurs in the case of conventional heating, whereas the dissipation of heat in an irradiated medium occurs in the case of microwave heating. This is the fundamental difference between the two types of heating mechanisms (Pérez-Martínez *et al.*, 2020). In contrast to traditional heating, heat transfer in a microwave heating mechanism is limited to thermal convection or conduction currents. Therefore, it appears from above that a rapid rise in temperature is possible. Furthermore, the only factor that influences the rate at which heat is lost and power is applied is the highest temperature that can be reached by heating the material in a microwave. The first time in 1986, how microwave energy might be utilized to extract numerous food components. Over the past ten years, there has been an increasing need for innovative items. Automation-ready procedures are quite intriguing, as are a number of other unique characteristics like shorter extraction times and reduced need for organic solvents to prevent contamination and lower sample preparation expenses. Two methods—microwave hydro-diffusion and gravity (MHG) and microwave-assisted distillation (MAD)—have been developed in response to these priorities in green microwave extraction mechanisms. Completely repeatable food procedures need very less energy and much less time than traditional processes that need to be heated by radiation or conduction. They can be fin-

ished with great reproducibility in a matter of seconds or minutes. Greater end product purity was achieved and wastewater post-treatment was eliminated thanks to lower manufacturing costs, easier handling, and work-up. The ensuing advantages for food manufacturing can include quicker heating of packaged food, more yield, smaller equipment footprints, and fewer process steps. Microwave-assisted extraction has been considered a valuable alternative to traditional methods for the extraction of numerous biologically active compounds from unprocessed plants and animals. The two main advantages of MAE are: (1) higher extraction yield; and (2) shorter extraction times. Water is typically used as a solvent in place of traditional organic solvents, which streamlines the procedure. As a result, bioactive chemicals are extracted from a variety of animal and plant sources using the MAE approach (Saini and Keum, 2018).

Pulsed electric field

PEF, also known as electro-permeabilization or electroporation, is a non-thermal process in which a bio cell is exposed to an external electrical field for a short amount of time (milliseconds or nanoseconds) (Usman *et al.*, 2022). Although the exact mechanism of membrane permeabilization is unknown, electroporation is known to occur in four separate phases, which are as follows: (i) PEF post-treatment stage with internal compound leakage and external compound input (such as reversible electroporation, membrane integrity recovery, and irreversible electroporation or pore resealing). (ii) Altering the quantity or size of the pores that are created (during the PEF treatment), (iv) If a threshold of trans-membrane possibility extends to 0.2–1.0 V, the production of small metastable hydrophilic holes; (iii) Increase the trans-membrane probability of the cytoplasmic membrane by applying the external electric field that charges the cell membrane. PEF's described cell membrane of expanded permeability phenomena or electroporation interference opens up a wide range of possibilities in food processing. Depending on the strength (external electric field) and (particular energy field), the application can be categorized. PEF has gained a lot of traction in this field since it makes the solid-liquid extraction crucial speed possible. PEF application makes extraction technologies in many agro-industries more selective and energy-efficient, (Usman *et al.*, 2022). PEF application offers great potential to replace or control traditional thermal technology (e.g., sugar extraction from sugar beets). Through PEF combina-

tion procedures, compounds contained in plant cells, such as colorants like carotenoids and chlorophylls, sucrose-containing polyphenols, and other secondary metabolites, can be expedited (Usman *et al.*, 2022). Increased sucrose content, improved juice filterability, and decreased colloidal contaminant concentration and coloration are the outcomes of PEF Pretreatment-assisted extraction. PEF pretreatment can be used to make wine before the maceration fermentation stage. This optimizes polyphenol extraction, and the resulting wine has unique organoleptic qualities. The same pretreatment improvement in anthocyanin (colorant extraction) selectivity is also observed for traditional wine-making wastes. Moreover, mechanical expressions applied after moderate PEF treatments, fruit juices, and vegetable oils lead to a significant rise in yields. Apple juice that has undergone electrical treatment becomes slightly hazy, significantly odorous, and contains more polyphenols. However, this treatment does not result in unpleasant tastes or flavours (Usman *et al.*, 2022).

Enzyme-assisted extraction

Enzymes are added to the extraction medium in a novel approach called Enzyme-assisted Extraction (EAE), which enhances the recovery method (Nadar *et al.*, 2018). The primary role of enzymes in the extraction of plant components is to degrade or soften the cell walls. This gives the active compounds access to the solvent. With standard solvent extraction, bound phytochemicals—those found inside cells or on cell walls—are difficult to remove. The surrounding elements were broken down by enzymes to help these components stand out. For polyphenols attached to protein or carbohydrate extraction, however, EAE is thought to be advantageous (within or on cell walls). Commonly used enzymes for enzymatic extraction include lipase, α -amylase, pectinase, amyloglucosidase, laccase, and protease (Gligor *et al.*, 2019). The key control variables for optimising the polyphenol yield are the particle size and the enzyme percentage to the sample. The sample (enzyme and solvent mixture) is incubated at low temperatures (35–50°C) with apH adjustment in the enzymatic hydrolysis extraction procedure. In low-temperature extraction, less energy is needed to avoid degradation because hydrolysis stops when enzymes deactivate at 80–90°C. The fact that the EAE is an environmentally friendly procedure has made it famous. Water is utilised either as a chemical substitute or as an organic solvent because the enzyme functions best in an

acidic medium. The primary disadvantage of EAE is its extended extraction time, which can range from 3 to 48 hours ([Malik and Mandal, 2022](#)).

Liquid-liquid extraction

It is well known by another popular name, solvent extraction, it consists of two immiscible liquid phases. There are two phases: the aqueous phase and the organic phase. For the extraction to be successful, the analytical must dissolve in the organic phase. In a separator funnel, the organic and aqueous phases are combined with a plant or other material from which the desired component is to be extracted. Shaking causes the liquid to separate into two different layers. In liquid-liquid extraction of the targeted analytic molecule, the analytic splits between the two immiscible liquids based on how soluble it is in each solvent (Yahya *et al.*, 2018). The liquid-liquid extraction method eliminates the requirement for distillation and is perfect for isotropic mixtures and temperature-sensitive materials ([Conde-Hernández *et al.*, 2021](#)). Many disadvantages of this technology have been identified including the need for a significant volume of organic solvents, emulsion formation, automation challenges, labor-intensive nature, *etc.*

Solid-liquid extraction

One of the traditional and traditional extraction methods for obtaining the polyphenols and polysaccharides found in the vegetative cell wall of agricultural leftovers is this one. The solid-liquid extraction method is based on hot water extraction or the effectiveness of various solvents ([Maran *et al.*, 2016](#)). The study conducted by ([Sirohi *et al.*, 2020](#)). Examined the effectiveness of six solvents in extracting phenolics, using varying concentrations of 80% MeOH, 80% EtOH, EtOAc, acetone, and acidified 50% and 80% MeOH. Of these, ethanol (EtOAc) has demonstrated the best performance in the extraction of triterpenoid and polyphenolic chemicals, including coumarins, stilbenes, flavonones, and flavanols. In the past, this process involved soxhlet extraction using ethanolic or methanolic solutions for maceration or hydro-distillation, together with mechanical agitation ([Sirohi *et al.*, 2020](#)). Enzymes, microwaves, and ultrasonography are used in conjunction with several traditional solid-liquid extraction techniques to help break down the cell wall structure of vegetable raw materials. In a study to extract soluble dietary fibre from grape pomace, the optimum solvent was determined to be hydrochloric acid. Although this method

has many benefits, it also has some drawbacks, such as a poor extraction yield, a lengthy extraction time, a greater solvent cost, and the destruction of volatile chemicals. For these reasons, it is not as appealing or “green.”

Conclusions and Recommendations

This review highlights fruit and vegetable production, characteristics, and waste categories managing, valorization has been presented. Furthermore, it considers the target bioactive substances found in FVW, including dietary fibers, phenolic compounds, scents, enzymes, and organic acids. It shows a lot of garbage and waste, not only a large amount of non-food items, but the quantity lost and lost due to lack of proper management e.g. due to insufficient field management, harvesting, processing, shipping, and storage (humidity and temperature) and distribution in the industrial sector. These things are not only loss of food, but degrades the products' components, including bioactive compounds has great advantages for various companies and applications. It is important to use new technologies to achieve high recovery of waste bioactive substances. The substances that were collected can be utilized in food, medication, cosmetics, and chemistry, as well as in food science and the manufacture of functional foods. One possible approach for achieving this goal is through the implementation. This review study has delivered evidence in the context of food waste management offers significant opportunities for the development.

Novelty Statement

The novelty of the present review is to distinguish between traditional fruit and vegetable waste management techniques and innovative strategies. Waste is an important source of bioactive molecules and waste streams have been underexplored for sustainable conversion.

Author's Contribution

Sana Nawaz: Wrote original draft

Shahzor Gul Khaskheli: Wrote original draft and supervised the work

Aijaz Hussain Soomro: Provided the facility

Inayatullah Rajper: Contributed with modification of the manuscript

Saghir Ahmed Sheikh: Correction the manuscript

Ashfaqe Ahmed Khaskheli and Shaista Soomro:

Collected the material for the review.

Sana Nawaz and Shahzor Gul Khaskheli contributed equally to this article.

Supplementary material

There is supplementary material associated with this review article will be available on request.

Conflict of interest

The authors have declared that there is no conflict of interest

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