Handbook of Fruit Wastes and By-Products

Chemistry, Processing Technology, and Utilization

Edited by
Khalid Muzaffar • Sajad Ahmad Sofi
Shabir Ahmad Mir

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Handbook of Fruit Wastes and By-Products

Handbook of Fruit Wastes and By-Products: Chemistry, Processing Technology, and Utilization addresses the chemistry and valorization of wastes and by-products generated during the processing of fruits. It provides an overview of the recovery of bio-functional components from fruit processing residues and their utilization. Besides, this book is a valuable resource for scientists, researchers, professionals, and enterprises that aspire in the management of fruit processing wastes and by-products, and their utilization.

Key features

- Provides comprehensive information about the chemistry of wastes and by-products obtained during fruit processing
- Provides in-depth information about the bioactive potential of fruit processing wastes and by-products
- Explores new strategies used for the proper valorization of fruit processing residues
- Describes the utilization of nutraceutical components derived from fruit processing residues in the fabrication of novel functional foods

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Preface

Processing of fruits produces large volumes of wastes and by-products, which can create environmental problems. However, these fruit processing residues have amazing nutritional composition, containing good amounts of sugars, vitamins, minerals, and health-promoting bioactive components (polyphenols, carotenoids, dietary fibers, peptides, ω-fatty acids, and so on). Due to the presence of bioactive components, these can be used for a number of purposes in the food, pharmaceutical, and cosmetic industries. The present aim is to efficiently utilize these fruit wastes and by-products and minimize their impact on the environment. Proper utilization of fruit processing wastes and by-products will not only be a source of profit to the fruit processing industry, but will also help lessen environmental pollution.

Handbook of Fruit Wastes and By-Products: Chemistry, Processing Technology, and Utilization is the first book devoted to fruit processing wastes and by-products, exploring a wide range of important fruits including tropical, subtropical, and temperate fruits. This book provides in-depth information about fruit processing wastes and by-products, their nutritional composition, biochemistry, processing technology of by-products, and the utilization of these residues in various food applications. This book will deal with the transformation of fruit processing residues into value-added products. This book also offers in-depth information about the potential of these fruit processing residues as a source of bioactive ingredients and their utilization in the development of novel functional foods. In addition, the various novel technologies useful in the extraction of functional components from these fruit processing residues are discussed.

Although there are some general books on by-products of the food processing industry, they are limited in context, discussing only some particular fruits. The unique quality of this book is that it provides a full-length study of the different developments, from the basic technologies involved in the management of fruit wastes and by-products to the recent advancements and future areas of research to be done on this subject. This book includes the valorization of fruit processing wastes and by-products of important fruits grown in different climatic conditions of the world. The book comprises 22 chapters, with each chapter providing a detailed study of the nutritional profile, biochemical composition, nutraceutical potential, and utilization of wastes and by-products of a particular fruit.

The book will be of interest in almost all regions of the world, with considerable market appeal. This book is a comprehensive reference written for teachers, scientists, researchers, students, and others who have an interest in the management of fruit processing wastes and by-products, and their utilization. This book is a firsthand resource to policy developers and personnel working in the food industry regarding the valorization of fruit processing residues generated in the food industry.

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CHAPTER 1

Fruit Processing Wastes and By-Products

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CONTENTS

1.1 INTRODUCTION TO FRUIT PROCESSING BY-PRODUCTS AND WASTES

Fruits are considered to be widely used food items from horticultural produce that are consumed either fresh or processed into different products. With changes in dietary habits and increasing population size, the production and processing of fruits has increased exponentially to meet consumer demands (Sagar et al., 2018). As a consequence, high volumes of waste and by-products are generated during production and processing of fruits. The increasing popularity of processed fruit products such as juices, nectars, and minimally processed fruit products has amplified the production of fruit-based wastes and by-products. Many fruits, such as oranges, pineapples, apples, peaches, and pomegranates are utilized for juice extraction, jams, and frozen pulp, and produce significant amounts of waste and by-products. Fruit waste and by-products include pomace, peels, rind, seeds, stones, and trimmings (Rodriguez et al., 2006; Torres-Leon et al., 2018). Many fruits generate about 25% to 30% of their fresh weight as waste, which is not subsequently used (Ajila et al., 2007, 2010). During slicing of apple, 10.91% of the fruit is lost as seed waste, leaving 89.09% of final product. Processing of pineapple yields waste materials such as peel (14%), core (9%), pulp (15%), and top (15%), with a total final product of 48%. Mangos upon processing yield about 11% peel, 13.5% seed, 18% unusable pulp, and 58% of finished product (Ayala-Zavala et al., 2010; Joshi et al., 2012). Waste

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streams of 8.5% peel, 6.5% seed, and 32% unusable pulp leaves a final product of 53% during dicing of papaya. In addition, about 5.5 million metric tonnes of pomace waste is produced during juice production from fruits and vegetables (Sagar et al., 2018).

By-products and waste obtained during the processing of fruits can have a bad impact on the environment due to its high biodegradability. These residues contribute to emission of greenhouse gases to the atmosphere (Girotto et al., 2015). As most of these biomaterials are currently not utilized, they find their way into municipal landfills where they create serious environmental issues because of microbial decomposition to carbon dioxide and methane and production of leachate. The cost of handling and disposing of these fruit residues has an adverse impact on the economy, while the management of large amounts of residues poses an environmental challenge (Torres-Leon et al., 2018). The European Union (EU) action plan for the circular economy could be an effective strategy to reduce the level of waste and by-products generated during fruit processing. This plan is based on the reduction, reuse, recovery, and recycling of materials and energy, so as to enhance the value and consequently the useful life of products, materials, and resources in the economy. The utilization of agro-industrial wastes and by-products can represent a renewable source for food additives already used in the food system or even the generation of new additives with enhanced functional properties to be used in the development of novel, functional food products (Faustino et al., 2019). Currently, the food industries are concerned with innovations to achieve zero waste, where the residual wastes generated are used as raw material for the development of new products. Such types of action have a direct impact on the Millennium Development Goals, the forthcoming goals of sustainable development, and the Zero Hunger Challenge.

The wastes and by-products of fruit processing are a rich source of valuable bioactive compounds that can potentially be used in the food industry as economical sources of food additives. Although horticultural waste and by-products have not been taken seriously as very valuable materials in the past, the scenario has now changed. These fruit processing residues are potential sources of phenolic compounds, dietary fibers, pigments, sugar derivatives, minerals, organic acids, and other components. Most of these biomolecules possess various health benefits including antiviral, antibacterial, antimutagenic, anti-inflammatory, antitumor, gastroprotective, immunomodulatory, antioxidative, and cardioprotective activities. Fruit residues can be used to extract and isolate valuable biomolecules that can be used in the food, cosmetics, pharmaceutical, and textile industries (Dilas et al., 2009; Yahia, 2017). Extraction of bioactive compounds from fruit residues is the most critical step. The type and quantity of bioactive components that can be derived from fruit processing wastes and by-products depend on the extraction method adopted. Furthermore, the extraction method may vary with respect to the targeted bioactive molecules. Extraction process parameters such as the type and quantity of solvent, temperature, extraction time, and method of extraction could have a detrimental effect on the extraction of bioactive compounds (Sagar et al., 2018).

Therefore, although wastes and by-products generated during the processing of fruits can be considered to be unavoidable, the proper utilization of these residual materials generated from horticultural produce may provide an initiative for sustainable development to reduce the environmental issues. Human health can be improved through novel foods enriched with functional components derived from these residues. The derived functional ingredients may be regarded as nutraceutical ingredients, allowing for the fabrication of products with enhanced nutritional value, potential health benefits, longer shelf-life, and acceptable sensory properties. Thus, appropriate utilization of these fruit residues could generate economic gains for the industry, help to reduce nutritional problems, provide beneficial health effects, and lessen the environmental implications.

1.2 MANAGEMENT OF FRUIT PROCESSING WASTES AND BY-PRODUCTS

Large amounts of wastes and by-products are generated from fruits during processing and thus constitute a matter of great concern (Banerjee et al., 2017). Because of high moisture content and microbial load, these fruit residues are highly biodegradable and may cause high levels of environmental problems. The anaerobic biological decomposition of organic matter is considered to be the third largest anthropogenic source of atmospheric methane emissions (Breeze, 2018). Waste derived from fruits and vegetables takes place throughout the food supply chain, although the amount of residual waste generated at each stage differs significantly from one country to another, depending on the postharvest technologies adopted in the areas where crops are cultivated. Processing techniques adopted in developing countries are not up to the mark and contribute to waste generation during fruit processing. Reduction in the amount of these residues during processing is complicated and requires substantial investment (Jiménez-Moreno et al., 2020). Meanwhile, in today's world, food security is a growing problem due to the exhaustion of natural food resources combined with increasing demand from growing populations, creating a gap between the production of food and its consumption. It is thus of the greatest importance that the food material produced and its by-products are used efficiently with minimal generation of food waste (Villacís-Chiriboga et al., 2020). To cope with the nutritional challenges of today's society, we require more sustainable nutritional sources. In this regard, fruit wastes and by-products are of paramount importance due to the presence of valuable quantities of starch, proteins, lipids, bioactive compounds, micronutrients, and dietary fibers in these processing residues.

Waste management is defined as the collection, transport, recovery, and disposal of waste, along with the supervision of such operations, and the waste management system consists of the whole set of activities related to handling, disposing, or recycling of waste materials (Plazzotta et al., 2017). To counterbalance the waste problem, managing environmental sustainability and overcoming the economic development model of "take, make, and dispose", the circular economy approach has been presented to utilize the waste and by-products, using sustainable and profitable technologies (Maina et al., 2017). Transforming food waste and by-products into a resource provides a major opportunity to shift from a linear to a closed loop economic system. In addition, it is one of the most important strategies to understand the concept of circular economy. In this modern approach, food waste management involves the valorization of wastes and by-products by recapturing their functional components and/or developing novel products with a market value (Otles et al., 2015). Nowadays, food industries have realized the efficient use of by-products and waste so as to minimize the effect of these residues on the environment (Villacís-Chiriboga et al., 2020) A holistic concept of food production was introduced by Laufenberg et al. (2003), which includes the interactions between the different goals pursued by food production: maximum product quality and safety, maximum production efficiency, and protection of the environment. This concept is meant for reduction of waste generation and recycling of valuable components in the short term, to add value to food by-products in the medium term, and to apply environmentally friendly manufacturing processes and the development of novel food products in the long term (Jiménez-Moreno et al., 2020).

1.3 PROCESSING OF FRUIT WASTES AND BY-PRODUCTS

Wastes and by-products generated during fruit processing can present very interesting chemical compositions which act as a driving force for the design of various biorefinery processes for their valorization. These fruit residues can be processed into a number of valuable components and have a potential role in the food industry. Dietary fibers, protein, pectin, starch, oils, phenolic compounds, organic acids, pigments, flavors, enzymes, etc. can be derived from these fruit processing residues (Sagar et al., 2018). Bioactive components, such as phenolic compounds, dietary fiber, proteins, etc., have health benefits and can be used in the development of functional foods and in the preparation of pharmaceuticals. Bioactivity of these functional components depends on the source, the nature of the compound, and the extraction method (Azmir et al., 2013; Pagano et al., 2021).

Fruit processing by-products and wastes obtained from grapes, mangos, bananas, citrus fruits, avocados, apples, pears, oranges, and dates are important sources of dietary fiber. Residues of these fruits are used as dietary fiber supplements (gelling and thickening agents) in refined foods (Wadhwa et al., 2015). Apple peel has a dietary fiber content of 0.91% fresh weight (FW) consisting of 0.46% FW insoluble and 0.45% FW soluble (Gorinstein et al., 2001). Apple pomace also contains substantial amounts of dietary fiber (Li et al., 2014). Grape pomace is a rich source of dietary fibers consisting of cellulose, hemicelluloses, and small amounts of pectins (Kammerer et al., 2005). Mango peel and kernel have been shown to possess appreciable amounts of dietary fibers. Total dietary fiber of mango peel is 51.2% of dry matter (DM), of which 32% DM consists of insoluble fibers while 19% DM is soluble fibers (Ajila et al., 2007, 2008). Mango peel fiber shows high hydration capacities and is considered to have great potential in the preparation of dietary fiber-rich foods (Wadhwa et al., 2015). Mango kernel has about 3.96% DM of crude fiber although less than that of peel. Lemon peel was reported to have a dietary fiber content of 14% DM consisting of about 9.04% DM insoluble and 4.93% DM soluble fiber (Sagar et al., 2018). Peel of "Liucheng" oranges was found to contain 57% DM total dietary fiber, of which the soluble portion was 9.41% DM and the insoluble portion was 47.6% DM. Cellulose and pectin were observed to be the main components of the fibers (Chau and Huang, 2003). Date pits obtained during processing of dates could be used as a potential source of dietary fiber. Date pit fiber is used for the production of high-fiber biscuits, cakes, and bread. Compared with wheat bran, it provides similar sensory properties and thus could be used as an alternative to wheat bran (Wadhwa et al., 2015)

Pectin is another biomolecule that can be obtained from fruit wastes and by-products, which play a role as a polymeric matrix for active packaging. Pectin extraction from fruit processing residues mostly involves the microwave-assisted extraction (MAE) technique. This kind of technique has the potential to extract high-quality pectin from peel of oranges, mangos, citrus fruits, and bananas, and from apple pomace. Pectin content of about 5% can be extracted from pineapple, musk melon, and papaya peel. (Basri et al., 2021). About 10–15% and 20–30% pectin are present in apple pomace and citrus peel, respectively (Baiano, 2014), whereas 10–20% pectin is found in mango peel (Rehman et al., 2004).

Considerable starch content is also present in fruit processing wastes and by-products that can be further explored. These starches have unique properties and can find potential applications in industry. Fruit processing residues obtained from mangos, kiwifruits, litchis, longans, pineapples, tamarinds, apples, jackfruits, loquats, bananas, and avocados, act as new, non-conventional, sustainable sources of starch (Kringel et al., 2020).

Wastes and by-products of several fruits have been reported to act as a potential source of protein. Appreciable protein contents are found in the peel of papayas, kiwifruits, and avocados (Chitturi et al., 2013). Protein contents of 2.5% to 9.0% has been found in citrus peels (Mamma and Christakopoulos, 2014). Fruit residues, including apple pomace, and peel of mangos, mosambis, oranges, bananas, and pineapples, were found to have protein contents of 4.45, 9.5, 5.4, 5.97, 6.02, and 8.7%, respectively (Sagar et al., 2018).

Citrus fruit-processing residues, mango and apricot kernels, and pomegranate seeds contain an appreciable amount of oil (10–50% by weight, dry basis) (Banerjee et al., 2017). Banana peel, blackcurrant, rambutan seed, passion fruit seed, and date pits are other good sources of oils rich in polyunsaturated fatty acids. Banana peel has an oil content of about 2.2–10.9%, which is rich in polyunsaturated fatty acids, primarily α-linolenic acid, and linoleic acid. Depending on the variety, rambutan (*Nephelium lappaceum*) seeds varies between 14 and 41% oil. Guava seeds contain about 5–13% oil, which is rich in essential fatty acids. Oil from passion fruit seed exhibits antioxidant activity and predominantly contains unsaturated fatty acids (87.6%), primarily oleic acid (13.8%) and linoleic acid (73.1%). Peach seed also acts as a good source of edible oil and contains palmitic acid, stearic acid, oleic acid, and linoleic acid as the main fatty acids (Wadhwa et al., 2015).

The rind, peel, and seeds of fruits contain high amounts of bioactive, phenolic compounds. Fruit peels (lemons, oranges, and grapes) and seeds (avocados, longans, jackfruits, and mangos) have a higher phenolic content than fruit pulp (Sagar et al., 2018). Citrus waste (particularly peel) is considered to be a rich source of phenolics and has a higher phenolic content than the edible part of the fruit (Balasundram et al., 2006). Peel of other fruits also has a higher phenolic content than the edible part of the fruit. The phenolic content of the peel of apples, pears, and peaches is twice that of the peeled fruits (Gorinstein et al., 2001). Banana (*Musa acuminata*) pulp has been found to contain 232 mg/100 g DM of phenolics, which is only about one-quarter that of the peel (Someya et al., 2002). Peel of pomegranate was reported to contain 249.4 mg phenolic compounds/g, while 24.4 mg/g was recorded for the fruit pulp (Li et al., 2006). Grape pomace also acts as a rich source of phenolic compounds, particularly proanthocyanidins (mono, oligo, and polymeric forms) (Torres and Bobet, 2001). Fruit seeds are considered to be nutrient-dense functional ingredients rich in phytochemicals (Pelegrini et al., 2006; Udenigwe and Aluko, 2012). Seeds contain polyphenols including phenolic acids, flavonoids, catechins, hydrolyzable tannins, xanthanoids, and other secondary metabolites (Ballesteros-Vivas et al., 2019; Torres-León et al., 2016). Phytochemicals are more highly concentrated in the seed coat part of fruit seeds (Villacís-Chiriboga et al., 2020). Bioactive phenolic compounds, including phenolic acids, flavanols, flavonols, anthocyanins, and dihydrochalcones, are also present in fruit pomace. Recovery of phenolic compounds from fruit residues depends on the extraction technique used. Several thermal (heating, radiofrequency, microwave, and infrared heating) and nonthermal methods (ultrasound, high hydrostatic pressure, irradiation, pulsed electric field, and pulsed light) are used for phenolic extraction (Sagar et al., 2018).

Wastes and by-products from fruits can serve as a source of flavors, aromas, organic acids, enzymes, pigments, and alcohols. Vanillin can be synthesized from pineapple peel waste, which contains a precursor for vanillic acid called ferulic acid. A three-step microbial biotransformation is used for the synthesis of vanillin from pineapple waste. Citrus fruit waste is used for commercial production of rhamnose which is the basic raw material for the synthesis of strawberry-flavored furaneol (2,5-dimethyl-4-hydroxy-3(2H)-furanone). Production of pineapple flavoring from apple pomace is carried out with the help of the fungus, *Ceratocystis fimbriata*. A number of volatile compounds like esters, alcohols, aldehydes, ketones, and acids have been extracted from pineapple residues left behind after extraction of juice from the fruit (Sagar et al., 2018). Fruit wastes and by-products are rich sources of natural pigments like anthocyanins, betalains, chlorophylls, and carotenoids. Extraction of pigments from these fruit processing residues can meet the demand of natural pigment production at an industrial scale which find a potential application in the food, cosmeceutical, or pharmaceutical industries. Various novel methods like pulsed electric field, high-pressure processing, pulsed light, and ionizing radiation could be used for the extraction of these natural colorants from fruit wastes and by-products (Jimenez-Moreno et al., 2020). Organic acids derived from fruit residues are regarded as important biomolecules with potential application in the food, chemical, or cosmetic industries. Citric acid can be produced by the fungus *Aspergillus niger* using apple pomace as a substrate material for the microbe (Dhillon et al., 2011). Wastes from other fruits such as pineapple, mandarins, and mixed-fruit wastes can also be used for the production of citric acid (Prabha and Rangaiah, 2014). Large amounts of citric acid can be produced from pineapple waste using *Yarrowia lipolytica* and *Aspergillus niger* as the fermenting microbes (Imandi et al., 2008). Lactic acid, an industrially important organic acid, which is used as an acidulant and preservative in food products, can be produced by several microbes using fruit by-products as the substrate (Rodriguez Couto, 2008). Microorganisms like *Lactobacillus casei, Lactobacillus plantarum*, and *Lactobacillus delbrueckii* have been used for production of lactic acid using mango and orange residue as substrates (Panda and Ray, 2015).

Various studies have also been carried out with regard to the production of bioethanol from fruit wastes and byproducts by yeast (*Saccharomyces cerevisiae*) fermentation. Fruit residues with high pectin, hemicellulose, and cellulose content can be used as suitable substrates for bioethanol production. Amongst the various fruit processing residues, apple pomace, banana peel, beet pomace, kinnow (a high-yield mandarin hybrid) and peach wastes have shown promising results with respect to bioethanol production. Several studies related to bioethanol production from fruit peel (sweet lime, pineapple, and orange), and avocado seed have also been carried out. *S. cerevisiae* has been used in the production of bioethanol from date waste (Wadhwa et al., 2015).

Many fruit residues are used as substrates for the production of enzymes. Wastes from bananas, dates, citrus fruits, loquats, and mangos are used for enzyme production. Orange waste can be used for the production of α-amylase under the action of *A. niger* (Djekrif-Dakhmouche et al., 2006). Enzyme filter-paperase (FPase) can be generated by *Trichoderma reesei* from kinnow waste (Oberoi et al., 2010). Banana solid waste and a mixed bacterial culture (*Bacillus megaterium*, *Cellulomonas carte*, *Pseudomonas putida*, and *Pseudomonas fluorescens*) was used to produce cellulase and β-D-glucosidase (Dabhi et al., 2014). Solid-state fermentation (SSF) of grape pomace can be used for the production of pectinase from the fungus *Aspergillus awamori* (Botella et al., 2005), while pineapple peel can be used as a substrate for the synthesis of pectinase by *Penicillium chrysogenum*. Peel of orange, lemon, and banana can be used for production of pectinase using *A. niger* (Mrudula and Anitharaj, 2011). Under the action of the fungus *Aspergillus foetidus*, wastes obtained during the processing of banana, grapes, cashew apple, and pineapple can be used for the production of pectinase (Venkatesh et al., 2009).

1.4 NUTRACEUTICAL POTENTIAL

Fruit wastes and by-products possess health benefits due to the presence of bioactive components. The processing industries of fruit with nutraceutical potential have started to exploit the bioactive ingredients in wastes and by-products in the preparation of innovative functional foods. The peel, pomace and seed are rich in polyphenols, dietary fiber, proteins, and secondary metabolites which showed various bioactive properties, such as antitumor, antioxidant, antimicrobial, anti-inflammatory, antiallergenic, and antithrombotic, as well as in the treatment of cardiovascular diseases (Coman et al., 2020). The applications of advanced technology for the isolation and purification of bioactive compounds from fruit wastes and by-products have focused on their utilization in nutraceutical foods to reduce the risk of chronic diseases (Kumar, 2020). Bioactive components isolated from fruit processing residues act as strong antioxidants and provide a defense system for the body against harmful reactive oxygen species (ROS) and can thus mitigate various diseases associated with elevated ROS levels. Citrus-based peel, pomace, and seeds are rich sources of antioxidant pigments with high antioxidant action (Rafiq et al., 2018). The fruit peel, pomace, and seeds from mangos, grapes, avocados, apples, melons, citrus, pineapples, plums, apricots, pears, and pomegranates are rich sources of polyphenols and exhibit high antioxidant potential (Suleria et al., 2020; Torres-León et al., 2016; Sójka et al., 2015). The bioactives present in fruit pomace compounds have strong ROS scavenging activity and protein glycation inhibitory properties, as well as anti-tumor activities (Fernández-Fernández et al., 2021; Coman et al., 2020; Shao et al., 2015). Several *in-vitro* and *in-vivo* studies have revealed that bioactive compounds present in fruit wastes and by-products exhibit activity against cancers such as breast cancer, prostate cancer, colorectal cancer, and leukemia (Panth et al., 2017). Bioactive compounds like naringin, hesperidin, bromalin, limonin, and anthocyanins present in fruit processing residues have anticancer properties (Gualdani et al., 2016). Klavins et al. (2018), Majerska et al. (2019), Villacís-Chiriboga et al. (2020), Sojka et al. (2015), Mahato et al. (2018) have reported the anticancer properties of berry pomace, banana peel, apple pomace, avocado seeds, plum pomace, and citrus pomace, respectively. The peel, pomace, and seed from different fruits (citrus, mangos, bananas, watermelons, berries, apples, and avocados) have been used as functional ingredients with nutraceutical potential against cardiovascular diseases, inflammation, atherosclerosis, allergy, and obesity (Baeeri et al., 2018; Ramdhonee and Jeetah, 2017; Chavan et al., 2018; Uchenna et al., 2017; Wen et al., 2019). Fruit peel contains bioactive compounds with potent antioxidant, antitumor, antiviral, and immunomodulatory activities (Lau et al., 2021). A protein, which was one of the ingredients present in fruit seeds, was reported to possess various bioactive properties including antihypertensive, anti-inflammatory, and antifungal properties (Udenigwe and Aluko, 2012). The oil from fruit seeds is rich in health-beneficial components, such as omega fatty acids and phytochemicals that exhibit health benefits like anticancer, anti-inflammatory, and antiallergenic activities (Banerjee et al., 2017).

1.5 EXTRACTION OF BIOACTIVE COMPONENTS

Extraction of bioactive materials from fruit processing wastes and by-products can be an effective approach for the valorization of these fruit processing residues. The most common extraction techniques for biologically active compounds are solid-liquid extraction *via* utilization of Soxhlet apparatus, maceration and hydro-distillation using different organic solvents as well as combinations of them with heating and mixing procedures (Azmir et al., 2013; Wen et al., 2020), although recently many green methods such as ultrasound-assisted extraction, enzyme-assisted extraction, microwave-assisted extraction, supercritical CO_2, subcritical water, gas-expanded liquids, use of deep eutectic solvents or ionic liquids, and others has been used for the isolation of bioactive compounds (Amran et al., 2021; Wen et al., 2020; Zuin and Ramin, 2018)

1.5.1 Conventional Extraction Method

Conventional methods of extraction have been used for a long time and are still considered for extraction of bioactive compounds from fruit wastes and by-products. Conventional methods are easy-to-operate and readily available techniques for the extraction and isolation of bioactive compounds. The details of the technique used depend upon the nature of the fruit matrix, solvent type, purity and concentration (Rifna et al., 2021). The conventional techniques used for extraction of bioactive compounds from fruit waste and by-products (peel, pomace, and seeds) are solid-liquid extraction, maceration, and hydro-distillation (Azmir et al., 2013; Wen et al., 2020). The use of particular conventional methods for extraction of bioactive compounds depends upon the fruit matrix properties and the target bioactive compound (Zuin and Ramin, 2018).

Solid-liquid or solvent extraction is a common conventional method used in the form of Soxhlet apparatus, maceration, decoction, infusion, and percolation (Rifna et al., 2021). The solvents used for solid-liquid extraction have different polarities (hexane, benzene, cyclohexane, acetone, and chloroform) for rupturing the fruit matrix and releasing targeted bioactive molecules (Adeoti and Hawboldt, 2014). The Soxhlet method of extraction is simple and has shown good reproducibility (Sagar et al., 2018). The solvent extraction method is generally applied for extraction of bioactive compounds which are lipophilic in nature (total phenolics, anthocyanins, antioxidants, and essential fatty acids) (Corona et al., 2015; Machado et al., 2015; Pereira et al., 2019b; Santos et al., 2021; Lucarini et al., 2021). Maceration has been extensively used for the extraction of thermolabile bioactive compounds from fruit wastes and by-products which are similar to those isolated by Soxhlet extraction (Rifna et al., 2021; Sagar et al., 2018). Maceration is an economical, widely used technique which does not require sophisticated equipment and is an efficient technique due to its continuous extraction nature (Rifna et al., 2021). The maceration process involves reduction of sample size, extraction with a solvent to achieve greater contact with the fruit matrix for extraction of bioactive compounds, and then fractionation to obtain the desired bioactive from solvent obtained (Azmir et al., 2013; Sagar et al., 2018). The maceration process can be associated with novel techniques (ultrasound, microwave, ohmic heating) to increase the yield and bioactivity of the extracted bioactive compounds (Safdar et al., 2017). Hydro-distillation is another conventional technique similar to solvent extraction for isolation of bioactive compounds without the use of organic solvents (Azmir et al., 2013; Sagar et al., 2018). Hydro-distillation methods used for extraction of bioactive compounds from fruit wastes and by-products uses different methods such as water and steam distillation, water distillation, and direct steam distillation (Azmir et al., 2013; Sagar et al., 2018). Hydro-distillation methods use hot water and steam as carrier for extraction of active agents with bioactive properties. Hydro-distillation is a simple and easy technique but it is not suitable for extraction of heat-labile, bioactive compounds which are degraded or oxidized (Sagar et al., 2018).

1.5.2 Green Extraction Methods

The bioactive compounds extracted by conventional methods are characterized by low yields, environmental problems, limitations in the use of different food matrixes, and low activities of the extracted bioactive compounds. Although conventional extraction techniques are well established and frequently used as standard methods of extraction, these limitations have encouraged industries to use novel methods of extraction. The limitations associated with conventional extraction methods are the costly use of organic reagents, as in the case of solvent extractions; prolonged processing time; low selectivity of targeted compounds; potential degradation or oxidation of biological substances, and the need for purification (Figure 1.1). These limitations have stimulated the use of emerging, innovative techniques for extraction of bioactive compounds, such as microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), deep eutectic solvent extraction (DES), supercritical fluid extraction (SFE), pulsed electric field extraction (PEF), and others.

Green extraction techniques use less hazardous chemicals by replacing them with safer, alternative solvents, with efficient energy consumption and reduced analysis time, using renewable feedstock, with low toxic residue production and being environment friendly (Azmir et al., 2013). In addition, replacing toxic or non-renewable organic solvents is a crucial approach when using greener extraction alternatives (Zuin and Ramin, 2018). Green extraction methods exhibit good reproducibility, high efficiency and high selectivity robustness, with efficient processes and the use of safer products without affecting the health (Zuin and Ramin, 2018).

1.5.2.1 Microwave-Assisted Extraction (MAE)

MAE is considered to be an advanced technique for the extraction of bioactive compounds using microwave energy, resulting in enhanced bioactivities and yields from fruit matrixes (Azmir et al., 2013; Sagar et al., 2018; Vinatoru et al., 2017). Microwaves (MW) are radiation on the

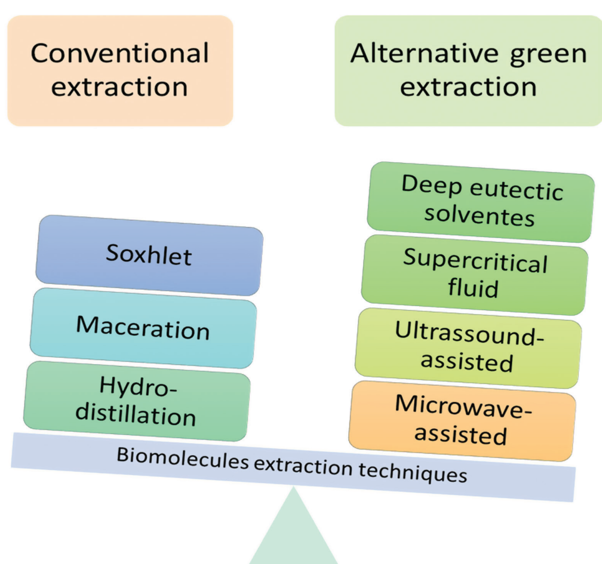

Figure 1.1 Graphical balance between conventional and green extraction methods for bioactive compounds.

electromagnetic spectrum that vary from 300 MHz (radio radiation) to 300 GHz (infrared radiation) in frequency (Vinatoru et al., 2017). MW extraction occurs due to the transfer of electromagnetic energy to heat, affecting molecules by dipole polarization and ionic conduction (Flórez et al., 2015). The dipole rotation occurs due to the alignment of dipolar molecules on the alternating electric field, making them oscillate and collide with each other and the surrounding molecules, releasing thermal energy (heat) (Flórez et al., 2015; Vinatoru et al., 2017). The MW used for extraction of bioactive compounds from fruit wastes and byproducts uses three types, based on solvent usage, namely microwave-assisted solvent extraction (MASE), solvent-free microwave extraction (SFME), and microwave extraction combining hydro-diffusion and gravity (MHG) (Rombaut et al., 2014). The extraction of bioactive compounds from fruit wastes and by-products occurs by mass transfer with increased yield, uniformity, and activities (Flórez et al., 2015). The MAE has potential application for extraction from fruit wastes and by-products of various bioactive compounds such as phenolic compounds, essential oils, aromas, pigments, antioxidants, and organic compounds (Rombaut et al., 2014; Vinatoru et al., 2017; Flórez et al., 2015; Rombaut et al., 2014; Zhang et al., 2011).

1.5.2.2 Ultrasound-Assisted Extraction (UAE)

UAE is one of the innovative and non-thermal methods for extraction of bioactive compounds with high yield, short processing time, high activity, and low solvent volumes as compared with conventional extraction methods (Alexandre et al., 2018). The UAE used for extraction of bioactive compounds from fruit matrixes is based upon hydrodynamic cavitations without affecting the extracted bioactive compounds (Vinatoru et al., 2017). The most used equipment for extraction of bioactive compounds are ultrasonic baths and ultrasound probes, depending on the nature of the fruit wastes and by-products (Rombaut et al., 2014). UAE has been extensively used in treatment of fruit wastes and by-products for extraction of various bioactive compounds, such as phenolic compounds, polysaccharides, volatile compounds, and enzymes with increased yield and reduced extraction time (Alexandre et al., 2018; Pan et al., 2012; Tabaraki et al., 2012; Rombaut et al., 2014; Chemat et al., 2017; Alexandre et al., 2018).

1.5.2.3 Supercritical Fluid Extraction (SFE)

SFE is a novel and modern method of extraction and used for the isolation of various bioactive compounds from diverse food matrixes. The SFE uses critical solvents, such as carbon dioxide, water, etc., in the supercritical state with gas and liquid properties, such as diffusion, viscosity, surface tension, and solvation power, with increased extraction rate and high mass transfer and bioactivities of extracted compounds (Azmir et al., 2013; Zuin and Ramin, 2018). SFE have been widely used as an environmentally friendly technique for the extraction of diverse bioactive compounds, such as plant lipids, free fatty acids, essential oils, phenolics (such as resveratrol), flavonoids, carotenoids, chlorophylls, and alkaloids from fruit wastes and by-products (Alexandre et al., 2018; Costa et al., 2016; Rai et al., 2016; Durante et al., 2014). Table 1.1 shows various extraction methods and the bioactive compounds which can be extracted from fruit wastes and byproducts.

1.5.2.4 Pressurized Liquid Extraction

Pressurized Liquid Extraction (PLE) involves the use of liquid solvents in their subcritical state under controlled conditions of temperature and pressure. PLE is an efficient technique for the extraction of bioactive phenolic compounds from plant materials in less time using solvents (organic or water) (Pereira et al., 2019a). Pressurized liquids have the ability to recover phenolic compounds faster than conventional extraction methods. The nature of the extract obtained after PLE is significantly affected by both the temperature and solvent system used. High temperatures recover more phenolics (Machado et al., 2015). Due to the involvement of high pressure, it is possible to reach higher

Table 1.1 Bioactive Components and Their Methods of Extraction

Extraction Methods	Fruit Wastes and By-Products	Target Compounds	Reference
Hydro-distillation	Pineapple fruit (*Ananas comosus*) processing residues	Volatile compounds	Barretto et al. (2013)
Subcritical water extraction	Papaya (*Carica papaya*) seeds agroindustrial residue	Phenolic substances	Rodrigues et al. (2019)
	Defatted orange peel	Flavanones	Lachos-Perez et al. (2018)
	Pomegranate (*Punica granatum*) seed residues	Phenolic substances	He et al. (2012)
Microwave-assisted extraction	Watermelon (*Citrullus lanatus*) fruit rinds wastes	Pectin	Prakash Maran et al. (2014)
	Sweet orange (*Citrus sinensis*) peel waste	Essential oil	Boukroufa et al. (2015)
Ultrasound extraction	Passion fruit (*Passiflora* ssp.) peel	Pectin	Oliveira et al. (2016)
	Jackfruit (*Artocarpus heterophyllus*) fruit peel waste	Pectin	Moorthy et al. (2017)
CO_2 supercritical fluid extraction	Sea almond (*Terminalia catappa*) fruits	Vegetable oil	Santos et al. (2021)
	Papaya (*Carica papaya* L.) agroindustrial waste	Phenolic substances	Castro-Vargas et al. (2019)
Pressurized liquid extraction	Blackberry (*Rubus fruticosus*) residues	Phenolic substances	Machado et al. (2015)
Deep eutectic solvent extraction	Bambangan (*Mangifera pajang*) fruit waste	Phenolic substances	Ling et al. (2020)
	Olive (*Olea europaea*) wastes from oil processing	Phenolic compounds	Bonacci et al. (2020)
	Citrus peel waste	Flavonoids	Xu et al. (2019)

temperatures than the normal boiling point of the solvent used. Due to this, processing times and volumes of solvent required are less as compared to conventional extraction techniques. Due to increase in temperature, the dielectric constant of the liquid solvent decreases thereby lowering its polarity up to the required values so as to extract the compounds of interest (Joana Gil-Chavez et al., 2013).

1.5.2.5 High Intensity Pulsed Electric Field Extraction

High Intensity Pulsed Electric Field (HIPEF) extraction is an emerging non-thermal extraction technology that has shown promising results in extracting bioactive phenolic compounds from agro food wastes. This extraction technique is considered a high efficiency technology and involves low temperatures for the extraction of natural bioactive ingredients. HIPEF extraction involves the application of high voltage pulses between 20–80 kV/cm on the material between two electrodes. HIPEF induces a synthetic effect which includes strong physical and chemical reactions. This increases cell membrane permeability causing inactivation of cells and increasing the release of intracellular compounds through cell membrane thus achieving higher efficiency and low extraction time (Yan et al., 2017). This technique has been effective in the extraction of various compounds like anthocyanins from blueberry by-products, b-carotene from carrot pomace, and polyphenols from fruit peels (for example, grape, orange, and plum peel) (Jimenez-Moreno et al., 2019).

1.6 FOOD APPLICATIONS OF FRUIT WASTES AND BY-PRODUCTS

Due to their amazing diversity of chemical composition, renewability, non-toxicity, versatility, biocompatibility, and biodegradability, fruit wastes and by-products have a wide range of food applications. The bioactive compounds extracted from fruit wastes and by-products have potential applications as functional ingredients due to their techno-functional and nutraceutical properties. Polysaccharides, especially cellulose, lignin, pectin, and hemicelluloses, present in fruit wastes and by-products are among the major natural polymers which act as dietary fibers (Rivas et al., 2021). In the food industries, dietary fiber from these fruit processing wastes is used for production of functional bread, pasta, biscuits, and extruded cereals (Duţa et al., 2018). Cellulose from fruit wastes and by-products is widely used in food products (Harini et al., 2018). Cellulose from fruit wastes and by-products has a versatile application in the food industry as a fat substitute, to design biodegradable composite packaging, and to encapsulate and deliver bioactive substances (Baghaei and Skrifvars, 2020; Rivas et al., 2021). Oils rich in bioactive compounds extracted from the processing residues of different fruit (apples, citrons, grapes, guavas, kumquats, mangos, melons, oranges, papaya, passion fruits, and strawberries) have wide applications in food products. These bioactive oils display good fatty acid profiles, indicating their potential as a source of essential fatty acids (da Silva and Jorge, 2017). Bioactive polyphenols derived from fruit residues can be used as natural preservative agents in food products, replacing synthetic additives. Fruits pomaces are used in the development of functional bakery products (biscuits and cereal bars) with good nutritional profiles (Ferreira et al., 2015). Food packaging obtained from fruit processing residues is of great interest due to its unique qualities. Fruit processing residues are used for preparation of edible films as potential food packaging for shelf-life extension of food products (Riaz et al., 2018). Packaging materials with added polyphenolic extracts from fruit wastes and byproducts have been prepared for development of antimicrobial packing materials (Goulas et al., 2019). When these wastes and by-products are used in food packaging systems, they offer several advantages, including increased antioxidant activity, improved mechanical properties and antimicrobial activity, and improved quality of protected food products (Bayram et al., 2021). Extracts obtained from fruit by-products and wastes are used in high-fat dairy foods like butter and cheese, in order to prevent lipid oxidation and enhance the microbial safety of these food products. Fruit beverages can also be enriched with these extracts to increase their phenolic content, with a subsequent increase in antioxidant potential. Utilization of extracts derived from fruit processing residues helps to delay lipid and/or protein oxidation of meat and meat products (Trigo et al., 2020). Fruit wastes and by-products (apple pomace, papaya peel, and watermelon rinds) are used in the development of low-glycemic index foods. Fruit pomace (particularly apple pomace) is utilized in the production of gluten-free food formulations (Kowalska et al., 2017).

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Avocado Wastes

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