BIOPROCESSING IN FOOD SCIENCE

NUTRACEUTICALS FROM FRUIT AND VEGETABLE WASTE

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Bioprocessing in Food Science

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Scope: Bioprocessing in Food Science will comprise a series of volumes covering the entirety of food science, unit operations in food processing, nutrition, food chemistry, microbiology, biotechnology, physics and engineering during harvesting, processing, packaging, food safety, and storage and supply chain of food. The main objectives of this series are to disseminate knowledge pertaining to recent technologies developed in the field of food science and food process engineering to students, researchers and industry people. This will enable them to make crucial decisions regarding adoption, implementation, economics and constraints of the different technologies. Bioprocessing has revolutionised the food industry by allowing for more efficient and sustainable production methods. This comprehensive series will be focused on microbial fermentation, enzyme technology, genetic engineering, microbial transformations, and bioreactor design. As we continue to face challenges such as population growth and climate change, bioprocessing will play an increasingly important role in ensuring a sustainable food supply for future generations.

Manufacturers are looking for new opportunities to take a significant position in a food market that is continually changing as demand for healthy food rises in the current global environment. In the current scenario, academia, researchers and food industries are working in a scattered manner and different technologies developed at each level are not implemented for the benefits of different stake holders. Compiled reports and knowledge on bioprocessing and food products is a must for industry people. However, the advancements in bioprocesses are required at all levels for betterment of food industries and consumers.

The volumes in this series will be comprehensive compilations of all the research that has been carried out so far, their practical applications and the future scope of research and development in the food bioprocessing industry. The novel technologies employed for processing different types of foods, encompassing the background, principles, classification, applications, equipment, effect on foods, legislative issue, technology implementation, constraints, and food and human safety concerns will be covered in this series in an orderly fashion. These volumes will comprehensively meet the knowledge requirements for the curriculum of undergraduate, postgraduate and research students for learning the concepts of bioprocessing in food engineering. Undergraduate, post graduate students and academicians, researchers in academics and in the industry, large- and small-scale manufacturers, national research laboratories, all working in the field of food science, agri-processing and food biotechnology will benefit.

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Preface

Fruits and vegetables are inherent components of healthy dietaries. However, in the span of production to consumption, these generate huge quantities of waste. As per estimates by various agencies, approximately 20 – 40 percent of the total production of fruits and vegetables is wasted. Significant losses and waste in the fresh fruit and processing industries are becoming a serious nutritional, economical, and environmental concern. The inherent nature of perishability is the major factor attributed for this loss. However, they manner in which most fruits and vegetables are consumed itself generates waste, wherein the edible part is sometimes even less than half of the total weight of the fruit. Enhanced fruit and vegetable production has made it as one of the highest wastes generating sector (approximately 42 percent). During processing and consumption, by products in the form of seeds, peels, pomace, stones, rind, pods etc. are generated. These parts abode nutrients in abundance, in some cases more than the fruit itself. There is an urgent need to recover value from this waste rather than to commit it to handful of other disposal methods. Long-term disposal of these remnants not only facilitates a breeding ground to microbes, insects, pests and mice but also incurs a huge cost to the environment by contributing significantly to greenhouse emissions. Valorisation of waste can be a key not only for better utilization but also for reducing environmental burden. The by-products obtained from the industry can be transformed into various useful end products like ethanol, enzymes, nutraceuticals etc.

One step for valorisation of fruit and vegetable waste can be through harnessing its nutraceutical potential. It has been identified through various studies that waste components are rich in potentially valuable bioactive compounds, such as carotenoids, polyphenols, dietary fibers, vitamins, enzymes, and oils, among others. These phytochemicals can be utilized in different industries including the food industry, for the development of functional or enriched foods, the health industry for medicines and pharmaceuticals, and the textile industry, among others. However, these

generally have not received much attention as antioxidant and nutrient source majorly due to lack of popularity and limited commercial applications.

This book is a comprehensive compilation which explores and conveys the key concepts for understanding the nutraceutical potential of fruit and vegetable waste for ensuring better utilization of these components in nutrition and health. It deals with the composition, methods of utilization and potential human health benefits of fruit waste.

The collection and compilation of fruit waste composition, utilization and health benefits will prove to be an important addition to the body of knowledge. We believe that this book will be interesting and useful to all concerned about the ever-growing volume of waste generated and for those who want to harness the hidden potential of the waste.

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Valorisation of Fruit and Vegetable Waste

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Abstract

The ever-increasing global population indicates that food demand will rise for at least another forty years, which will exert immense pressure on our limited natural resources. Hence, wise use of available resources, maximum utilization of available food and minimization of food waste is crucial. Due to their perishable nature, the highest wastage of food occurs in the fruit and vegetable sector, which is approximated to about 30-44%. The fruits contain various unused parts like peel, seed and pomace which sometimes may account for approximately half of the fruit, e.g., pineapple, mango. These components are rich in sugars, pectin, fats, cellulose, hemicelluloses, minerals, and vitamins, which in some cases are richer than the fruit itself. This can be bio-converted into useful products such as acids, alcohols (bioethanol), enzymes, fuels, and value-added products. The seeds and pits can also be used for the extraction of edible grade oils. This chapter introduces and summarises the methods by which fruit and vegetables have been valorised into useful products.

Keywords: Pigments, essential oil, nutraceuticals, bioactive compounds, phytochemicals

1.1 Introduction

With increasing population, the quantity of food required is also increasing, which exerts immense pressure on our natural production mechanisms

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(Panghal *et al.*, 2021). In addition, it also becomes a source of generation of additional food waste. Trends indicate food demand will rise for at least another forty years. Hence, wise use of available resources, maximum utilization of available food and minimization of food waste is crucial. As per the Food and Agriculture Organization, food loss is "a decrease in quality and quantity of food" (Diaconeasa *et al.*, 2023). Food waste can occur at any step of the supply chain. In the fruit and vegetable processing industries the major waste is generated through the left over and inedible parts of fruits and vegetables. This adds burden on the waste management systems, exacerbates food insecurity and is the biggest source of greenhouse emission. According to the Food Waste Index Report 2021, the food service industry produces 931 million tonnes of waste each year and a large chunk of this (570 million tonnes) is generated at the household level (United Nations Environment Programme, 2021). One-third of the total food produced is wasted and this is estimated to be worth one trillion USD. As per the reports of United Nations Environment Program Publications, the highest wastage of food occurs in the fruit and vegetable sector, which is approximated to about 30-44% (Barrera and Hertel, 2021; Cronjé *et al.*, 2018).

India is the second-largest producer of fruits and vegetables in the world and the food processing sector has been growing at an Average Annual Growth Rate (AAGR) of 10%. However, the postharvest losses are still high and almost 30-40% of fruits and vegetables in the country go to waste (*National Herald*, 2021). According to the Annual Report 2020-21, published by Ministry of Food Industries, the postharvest losses of major agricultural produce at national level was 92,651 crore Indian Rupees calculated using production data of 2012-13 at 2014 whole sale prices (MOFPI, 2021). The major waste generated from fruit and vegetables is in the form of peels, seeds and pits. For example, apples contain 10.9% as seed, pulp and peel as by-products. Minimal processing treatments like dicing produces only 53% of the fruit as final product and the rest is waste in the form of peel, seed and unusable pulp. Similarly, pineapple processing produces approximately 50% of waste in the form of peel, core, top and pulp (14, 9, 15, 15% respectively). In mango as well, only 58% of the fruit is utilised. Figure 1.1 summarises the waste generated from different fruits and vegetables. The fruit and vegetable juice industry produces around 5 MMT of solid waste and the canning and frozen food industry is responsible for almost an equal amount of waste generation (Sagar *et al.*, 2018). Waste is a big environmental burden.

Currently, fruit and vegetable waste is managed either by incineration or by landfill, owing to its biodegradable nature. The process of incineration results in gradual production and ejection of various primary and secondary compounds which may act as pollutants like gases, acids, etc. Inadequate

Figure 1.1 Waste generated from various fruits and vegetables (Modified from Dalal *et al.*, 2020).

landfill management leads to release of gases like methane, carbon dioxide, etc., which may impose not just environmental damage but also health risks (Sindhu *et al.*, 2019; Rifna *et al.*, 2021). In addition, this so-called waste is rich in sugars, pectin, fats, cellulose, hemicelluloses, minerals, and vitamins. This can be bio-converted into useful products such as acids, alcohols (bioethanol), enzymes, fuels, and value-added products (Verma and Kumar, 2020). The seeds and pits can also be used for the extraction of edible grade oils. This chapter introduces and summarises the methods by which fruit and vegetables have been valorised to something useful.

1.2 Valorisation of By-Products from Fruit and Vegetable Processing Industry

Valorisation of waste can be a key not only for better utilization but also for reducing the environmental burden. The by-products obtained from the industry can be transformed into various useful end products like ethanol, enzymes, nutraceuticals, etc. (Figure 1.2). This section deals with the products that fruit and vegetable waste and by-products can be transformed into.

1.2.1 Oil

The seeds of the fruits, especially the stone fruits like mango (*Mangifera indica*), peach, apricot, and avocado, etc., can be used for the extraction of oil. The yield of the oil varies with the particle size, volume of solvent,

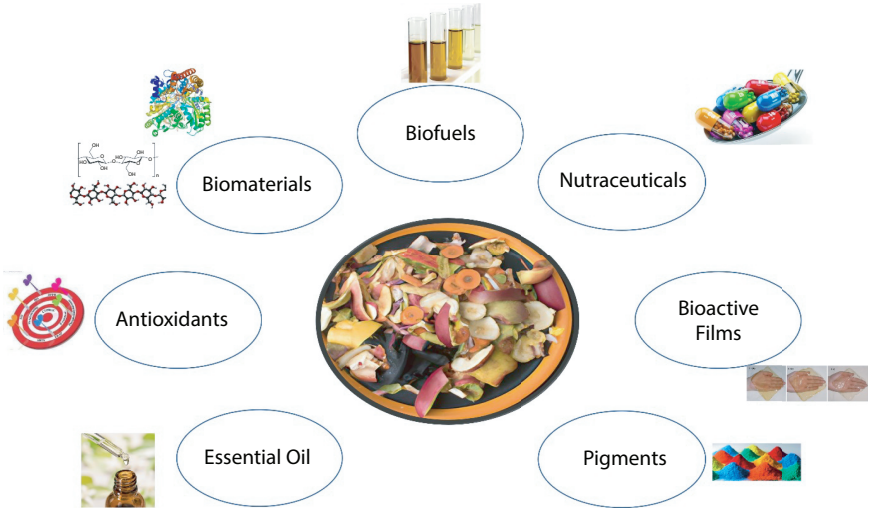

Figure 1.2 Valorisation of fruit and vegetable waste.

temperature and time of extraction. Yadav *et al.* (2017) reported that the highest yield (15.20%) of oil from the kernels of mango stone (25 g sample extracted with 250 ml n-hexane) can be obtained at a particle size of 1 mm and extraction time of 90 minutes. Karunannithi *et al.* (2015) optimized soxhlet solvent extraction process for the extraction of mango seed kernel oil using n-hexane. It was found in the study that minimum solvent requirement and time for the extraction of 20 g of mango seed kernel at 40-70 °C was 200 ml, and 3 hours, respectively. The extraction rate of the oil under these conditions was 12%. The composition of mango seed kernel oil is very similar to cocoa butter except the iodine value is higher in mango seed kernel oil than in cocoa butter. The specific gravity of oil is 0.912, refractive index is 1.46, saponification value is 187.7, iodine value is 49.4 and acid value is 1.93 (Moharram and Moustafa, 1982). The stearic acid, oleic acid, linoleic acid and palmitic acid content of mango seed kernel oil is 58.08%, 17.99%, 2.86%, and 1.33%, respectively. The oil is edible and has lower free fatty acids, carotenoid content and peroxidase value and is generally used without any processing. The melting point of oil is 32-36°C and is solid at room temperature. Mango kernel oil is also high in unsaponifiable matter and is extensively used in the cosmetic industry (Yadav *et al.*, 2017). Wu *et al.* (2011) optimized the extraction process of peach kernel oil using different solvents, i.e., petroleum ether, ethyl ether, chloroform and hexane. The oil extracted with hexane was found to have the highest overall acceptability. The oil is edible and has a high level of unsaturated fatty acids (91.27%). The major fatty acids in peach kernel

oil are oleic acid (61.87%), and linoleic acid (29.07%). The acid, peroxide, iodine and saponification values of oil were 0.895 mg KOH/g, 0.916 mg/g, 36.328 mg/g and 101.836 mg KOH/g, respectively. It was also found to have high phenolic compounds (4.1593 mg GAE/g).

Savic *et al*. (2020) optimized the soxhlet extraction process for the extraction of plum seed kernel oil using various solvents, i.e., n-hexane, n-heptane, ethyl acetate, acetone or a mixture of chloroform and ethanol (2:1 v/v). Among the various solvents, the highest oil yield was obtained for n-heptane (30.5%) and n-hexane (30%), while the lowest yield was obtained for ethyl acetate (23.5%). The obtained oil had a density varying from 0.50-1.10 g/mL (varied according to the solvent used), refractive index of 1.47, viscosity of 135.40-183.20 mPas, pH of 3.43-4.63, acid value of 1.41-2.81 mg KOH/g, saponification value of 180-198 mg KOH/g and peroxide value of 1.82-3.75. Plum kernel oil is also rich in unsaturated fatty acids (oleic acid, 52-66%, linoleic acid, 28-35%, α-linoleic acid, 0.2%) and the content of saturated fatty acids is very low (5.8-11.3%). This oil is also rich in phenolics and possesses good antioxidant properties. All these attributes make it a good fit for food applications and is also an excellent base for the development of cosmetic products and mature skin. Apricot seed yields about 22-38% kernels (Kate *et al*., 2014). The oil recovery can also be enhanced by the use of enzymes. Bisht *et al*. (2015) conducted a study examining the effect of enzymes (pectinase, cellulose, pectinase + cellulose) on the oil extraction efficiency from wild apricot. The enzymes were mixed with kernel powder and were kept at 50±2 °C for 2 hours before oil extraction using expeller. The enzymatic treatment enhanced the oil recovery by 9-14.22%. Maximum oil recovery was obtained at 0.3-0.4% enzyme concentration for both the enzymes individually, as well as in combination. The highest oil yield (47.33%) was obtained for the blend of enzymes used at a concentration of 0.3%. The oil recovery was increased by 14.22% by the enzymatic treatment in comparison to the control that had an oil yield of 33.11%. These were a few examples depicting the scope of application of kernel oils in various industries based on the physical and chemical properties they exhibit.

1.2.2 Essential Oils

Essential oils are concentrated hydrophobic liquids that are a mixture of many volatile aromatic compounds such as isoprenoids, monoterpenes, and sesquiterpenes and are responsible for the fragrance of many aromatic plants. Many other names like aromatic oils, fragrant oils, steam volatile oils and etheral oils are also prevalent for these (Fakayode and Abobi, 2018; Raseem *et al*., 2016). A number of methods like cold processing, reflux,

mechanical stirring, ultrasound-assisted extraction, microwave-assisted extraction and supercritical fluid extraction can be used for their extraction using both organic and green solvents. The organic solvents mostly used are ethanol, methanol, hexane, toluene, and petroleum ether, etc. The green solvents used are water, steam, supercritical CO_2 and ionic solvents, etc. Fakayode and Abobi (2018) optimized the effect of extraction temperatures (80-100°C) and extraction time (120-240 minutes) on the yield of essential oil using 2×5 factorial central composite rotatable design (CCRD) of response surface methodology. For the extraction of oil, the orange peels were pureed in a blender, dried and 5 g of dried puree was extracted in a Soxhlet extractor using n-hexane as solvent. The software generated 13 treatments and the yield of essential oils under these conditions varied from 0.57-3.24%. It was suggested that an essential oil yield of 3.38% can be obtained at the extraction temperature of 95.23°C and extraction time of 23.30 minutes. Ullah *et al*. (2017) studied the organic solvent (toluene, pentane, and hexane) and ionic liquids [1-butyl-3-methylidazolum bis (trifluoromethyl sulfonyl) [BMIM]NTf2, 1-butyl-3-methylimidazolium chloride [BMIM] Cl, 1-hexyl-3-methylimidazolium acetate [HMIM] Ac, 1-allyl-3-methylimidazolium acetate [AMIM] Ac, 1-butyl-3-methylimidazolium acetate [BMIM] Ac] extraction of essential oil from *polygonum minus* using four different extraction methods (microwave and ultrasound-assisted extraction, mechanical stirring and reflux extraction) and compared their results. In this study, the plant material was collected, washed thrice with distilled water, dried for 12 days at 45°C in an oven, ground to powder (60-80 mesh size) and extracted. For microwave-assisted extraction, the plant material was mixed with different organic and ionic solvents and the extraction was carried out at 400 W at different solid to liquid ratios at 60°C for 30, 40, 50, and 60 minutes with continuous stirring, with and without Clevenger apparatus in case of organic solvents and 60°C (except BMIM (Cl) where extraction was carried out at 80°C) for 15-25 minutes with Clevenger and 5, 6, 7, and 8 minutes in case of without Clevenger with ionic liquids. The ultrasound-assisted extraction was performed at 60°C [80°C for BMIM (Cl)] at amplitude of 70W for 15-30 minutes in the extraction using all the solvents. For mechanical extraction, the plant material was mixed with 40 ml of solvent and stirred for 60, 80, and 100 minutes at room temperature (25°C) using Ika RW 20 Model. In reflux extraction, the plant material was mixed with 40 ml of solvent in the reaction flask and heated at 60°C [80°C for BMIM (Cl)] for 60-90 minutes. The highest extraction efficiency of essential oil (9.61%) was obtained with the use of Clevenger apparatus in combination with the ionic liquids-based microwave-based extraction techniques using [AMIM] Ac ionic liquids. These oils are widely

used in perfumeries, incenses, aromatherapies, cosmetics, medicines and as food additives. They also exhibit antimicrobial properties (Fakayode and Abobi, 2018; Raseem *et al*., 2016).

1.2.3 Pectin

Pectin is a polymer of α-1,4 linked D-galacturonic acid that is present in the middle lamella of the higher plants. Orange peel and apple pomace contain 20-30% and 10-15% pectin, respectively, and most of the commercial pectin is extracted from these sources. The quality and purity of pectin vary depending upon the content of anhydrogalacturonic acid, degree of esterification and ash content. Pectin having high molecular weight, galacturonic acid content and low ash content is said to be of superior quality. A number of extraction methods such as solvent extraction method, microwave- and ultrasound-assisted extraction, subcritical water extractions and enzyme-assisted extractions can be employed for pectin extraction. The method of pectin extraction also affects the structure and functional properties of pectin. Based on the methylation of carboxylic acid groups the pectin can be further divided into high methoxy (HM) and low methoxy (LM) pectins. HM pectin has a degree of esterification in the range of 43-67%, while less than 40% is found in LM. Conventional methods of pectin extraction involves use of mineral or organic acids for facilitating its release from the matrix. In comparison to lactic acid, nitric acid, hydrochloric acid, sulphuric and tartaric acid, citric acid (17.9%) has been found to be most effective. In addition, citric acid exhibit low degradation of pectin owing to its less dissociation constant (Dalal *et al*., 2020; Xu *et al*., 2018).

The process of pectin extraction from orange peel was also optimized by Fakayode and Abobi (2018). For the pectin extraction, first the oil was removed and the pectin was further extracted with the acid hydrolysis technique. The effect of various extraction conditions, i.e., temperatures (80-100°C), time (120-240 minutes), and pH (1.0-3.0) was also studied using 3×5 factorial central composite rotatable design of response surface methodology. 25 g of de-oiled and dried sample was blended in 1000 ml of distilled water and the pH was adjusted by adding hydrochloric acid. The mixture was heated to the desired temperatures with intermittent stirring for the software generated time intervals. The pH was adjusted every 15 minutes and the lost water was replaced. The mixture was rapidly cooled at 40°C in an ice bath and filtered using Whatman filter paper under vacuum. The filtrate was coagulated using equal amount of 95% ethanol and left for different durations (60, 75, 90, 105 and 120 minutes) to allow the pectin to float on the surface. The optimum conditions for the extraction

of pectin were a temperature of 93.07°C, time of 117 minutes and pH of 1.60. Benassi *et al.* (2021) assessed the green extraction methods, i.e., hot water, rapid solid liquid dynamic (RSLD) and microwave-assisted methods for the extraction of pectin and evaluated the yield and quality of extracted pectin. Hot water–based methods were found to be more efficient to obtain high-quality pectin compared to other methods. The pectin yield was further increased (up to 21%) when hot water extraction was assisted by citric acid (pH 1.5). The use of citric acid in extraction also increased the degree of esterification (DE) and the pectin obtained by this method had a DE value of 82.5%. The authors suggested that acidic hot water extraction is the most suitable method to obtain high methoxy pectin, while low methoxy pectin can be obtained using microwave-assisted extraction directly on fresh orange peels. Ultrasound is effectively used for extracting pectin from passion fruit, tangerine and grapefruit peel (de Oliviera *et al.*, 2016, Polanco-Lugo *et al.*, 2019, Wang *et al.*, 2015). Pectin obtained by this method had a higher degree of esterification, higher galacturonic acid content, higher water and oil holding capacity. Use of ultrasound lowered the extraction temperature by approximately 13.3%. The study observed that pectin yield enhanced with increase in microwave power (160 to 400 Watt). Microwave-assisted extraction also yielded a higher degree of extraction in comparison to conventional method (Jiang *et al.*, 2012). In another study, combination of ultrasound followed by microwave extraction was used for pectin extraction from jackfruit peel, and the authors obtained 4% higher yield in comparison to conventional methods (Xu *et al.*, 2018). Ripoll and Hincapié-Llanos (2023) recently published a systematic literature review in which they adopted bibliometric methods for determining the best method for extracting pectin from fruit and vegetable waste. The study concluded that in the past twelve years, acid hydrolysis remains the most widely used method. Other methods like microwave-assisted, ultrasonic and enzymatic methods are also gaining momentum in terms of usage. The study pointed out that in future, use of radiofrequency, ohmic heating and aqueous two-phase extraction appears promising and can be further explored.

1.2.4 Pigments

The waste from fruits and vegetables such as peels, seeds, and pomace, etc., are rich in pigments like anthocyanins, betalins, carotenoids and cholorophylls, etc. These pigments can be extracted by solvent extraction methods or by green extraction methods. The traditional solvent extraction methods utilize a large volume of solvents and take a longer time. The consumption of solvents and extraction time can be decreased

by using the novel methods of extraction such as microwave-assisted extraction, ultrasound-assisted extraction, supercritical fluid extraction and enzymatic extraction, etc. These methods also increase the rate of pigment extraction and a 10% increase in yield has been reported for ultrasound-assisted extraction (Sharma and Bhat, 2021). Green solvents such as water, natural oils, ionic solvents, etc., can also be used for their extraction. This section discusses the scientific studies on the pigment extraction.

Sharma and Bhat (2021) extracted the carotenoids from the pulp and peel of two varieties of pumpkin, i.e., Gold Nugget and Amoro F1 of the species *Cucurbita maxima* using the conventional technique and innovative green extraction techniques, i.e., ultrasound-assisted extraction and microwave-assisted extraction. The pulp and peel of the samples was separated manually, cut into small pieces, freeze dried and ground to a fine powder. This was further extracted with the above-mentioned techniques. In the conventional extraction, 25 ml of mixed solvent containing hexane and iso-propanol in the ratio 60:40 was added to 5 g of pulp or peel sample and the extraction was repeated four times until no visible yellow color was obtained in extract. To achieve the phase separation and to eliminate the traces of isopropanol the extracts were washed with equal volumes of 0.1% NaCl. The extracts were placed in hot air oven (45°C) to evaporate the solvent to 50 ml. The extract was stored at -20°C for further estimations. For ultrasound-assisted extraction, 50 ml of corn oil was added to 5 g of sample and ultrasound probe of 13 mm was immersed in the sample at amplitude of 20% for 30 minutes. The pulse duration was adjusted to "on" (10 s) and "off" (5 s) mode during the extraction process. The extract was centrifuged at 4500 rpm for 45 minutes to separate the oil and residue and was further stored at -20°C. Microwave-assisted extraction was carried out using 5 g of pumpkin sample and 50 ml of corn oil at 130 W for 30 minutes. The extract was further centrifuged at 4500 rpm for 45 minutes to separate the residue and stored at -20°C. On the estimation of total carotenoids it was found that the highest carotenoid for peel (33.78-38.03 μg/g) and pulp (28.01-32.69 μg/g) in both the varieties was obtained for ultrasound-assisted extraction, followed by microwaves, i.e., 30.78-34.94 μg/g for peel and 26.98-31.067 μg/g for pulp. The level of carotenoids in the innovative green extraction methods was almost double that of conventional extraction, i.e., 16.21-19.21 μg/g for peel and 12.33-15.01 μg/g for pulp. El-Rahman *et al.* (2019) studied the β-carotene extraction from the orange peel. The orange peels were dehydrated at 50±1°C and ground to powder. The 500 g of dehydrated powder was macerated in 1 L of acetone in the presence of 0.1% ascorbic acid in a blender. The extract was filtered

and the residue was again extracted twice with the acetone. The collected crude extract was concentrated in a rotary vacuum drier at 40±1°C, the impurities like oil and chlorophyll was removed by saponification. The concentrated extract was added to a separating funnel and washed twice with 200 ml of methanolic potassium hydroxide solution (100g potassium hydroxide dissolved in 750 ml methanol) and 250 ml of water. Following this, a suitable amount of hexane was added to extract the carotenoids. The major carotenoid in the orange peel was β-carotene and its content was 14.51 mg/100g. These extracts can be used in various food preparations. Kumcuoglu *et al*. (2014) compared the ultrasound-assisted extraction of lycopene from tomato processing wastes with the conventional methods of extraction. Tomato waste (skins and seeds) was collected from a hot break tomato paste manufacturing plant, dried in a vacuum drier at 40°C for 24 h to moisture content of 4.9%, ground in a hammer mill and the particles having average size of 286.6 μm were used for lycopene extraction. For the conventional extraction 0.8, 1.14 and 2.0 g of dried samples containing 48.80% skin and 51.20% seeds were extracted with 40 ml mixture of solvent containing hexane, methanol and acetone in the ratios 2:1:1 v/v making the final liquid to solid ratios to be 50:1, 35:1 and 20:1. The suspension was agitated continuously in a shaking water bath at different temperatures (20, 40, and 60°C) and times (10, 20, 30, and 40 minutes). On the completion of the extraction, 15 ml cold distilled water was added to accelerate separation and the suspension was further agitated at 1000 rpm and 5°C. This was left undisturbed for 5 minutes and polar layer was separated and used for lycopene determination. In UAE, the solvent composition and liquid solid ratio was similar to the conventional system and for extraction a high-intensity probe system of 200W and 24 kHz, equipped with a H14 Sonotrode was used. The sample and the solvent was added to a 150 ml flask, the flask was put in the constant temperature (5°C) water bath and the ultrasonic probe was immersed in the flask by 7 cm from the top. The extraction was carried out at the ultrasound powers of 50, 65 and 90 W for 1, 2, 5, 10, 15, 20, and 30-minute runs. In the conventional method the highest yield (93.9±0.56 mg/kg) of lycopene was obtained when the extraction was carried out at 60°C for 40 minutes at a solvent to sample ratio of 50:1 v/w. In UAE, the highest lycopene concentration (89.9±0.87 mg/kg) was obtained when the extraction was carried out at 90 W and 30 minutes using 35:1 v/w of solvent to sample. The difference in the yield of lycopene was very small in both the extraction methods; however, UAE employed less time, less solvent and low temperature to reach the same rate of extraction. Catalkaya and Kahveci (2019) reported that an extraction process combining enzymatic and solvent extraction of the tomato waste