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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

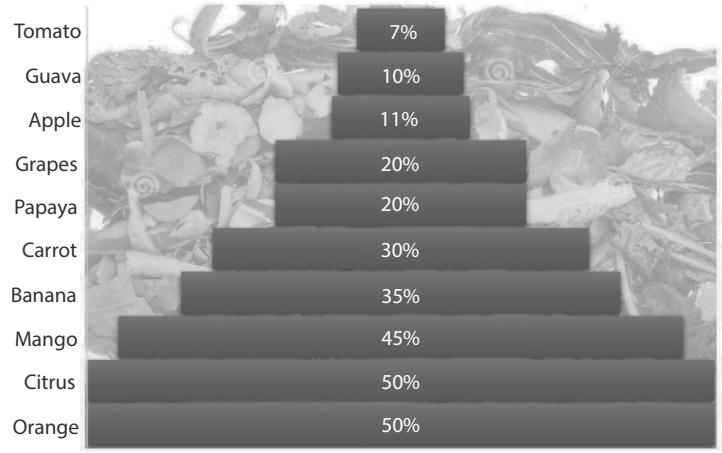

Figure 1.1 Waste generated from various fruits and vegetables (Modified from Dalal *et al*., 2020).

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,

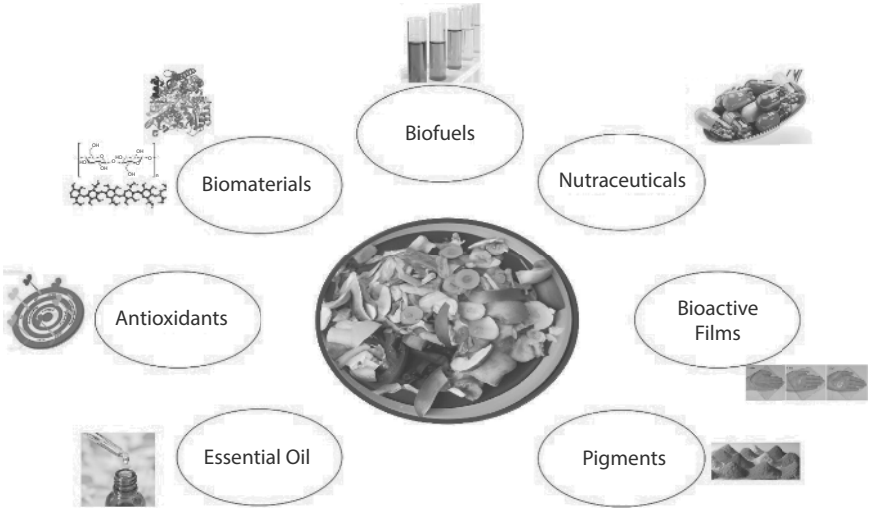

Figure 1.2 Valorisation of fruit and vegetable waste.

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

can be employed to produce lycopene from tomato paste production waste. The pre-treatment of 4 g of ground tomato waste (peels and seeds) mixed with 27.2 ml of distilled water, 0.8 ml (0.2 ml/g) of suitable enzyme mixture, i.e., cellulolytic and pectolytic enzymes at the enzyme to enzyme ratio of 1, incubated at 40°C for 5 h, followed by the extraction with ethyl acetate at the solvent to substrate ratio of 5 ml/g and extraction time of 1 h produced oleoresins with the highest lycopene (11.5 mg/g) concentration and red color intensity. These oleoresins also had the highest phenolic compound concentrations and antioxidant properties.

Betalains are a class of red and yellow pigments derived from tyrosine. These are abundantly found in beetroot. The ultrasound-assisted extraction method was used by Fernando *et al.* (2021) to extract betalains from red beetroot waste. A combination of ethanol/water-based solvent mixtures was used for extraction and was found to be better than individual solvent usage. The sample solution was sonicated at 44 kHz for 30 min at 30°C. The nominal power and energy density in the study was 35W and 252 J/mL. The amount of betalains so extracted was much more than from pomace (beetroot waste). Extraction of beetroot pomace from pomace powder was optimised by Kushwaha *et al.* (2017). A solid to liquid ratio of (1:15) was found to be suitable for extraction. Maximum yield was obtained at a temperature of 50°C for 10 minutes at a pH of 2.5. Microwave-assisted extraction was also used for extraction of pigments from beetroot peels. The microwave power of 224.61 MW, pH of 5.2 and time of 57 seconds were the optimised conditions obtained when citric acid was used as solvent. With ethanol as a solvent, the optimised conditions varied with microwave power being 384.25 MW, pH of 4.74 and time of 74.91 seconds (Singh *et al.* 2017). Hernández-Aguirre (2021) used deep eutectic solvents (magnesium chloride hexahydrate and urea in different proportions) to extract red and violet betalains form beetroot waste. A ratio of 2:1 (magnesium chloride hexahydrate: urea) was found best for extraction and recovery of betalains. The extracts such obtained were 75% more stable than aqueous beet extracts and were stable for a period of 150 days under visible light and 340 days in amber vessel storage. The aqueous extracts exhibited alteration from violet colour just after 5-7 days. Enzyme-assisted extraction can be also be used for recovery of betalains from beetroot waste. Lombardelli *et al.* (2021) used a mixture of cellulases (37%), xylanases (35%) and pectinases (28%) for extraction of betalains from unsold beetroot. A dosage of 25 U/g of enzyme mix, temperature of 25°C and processing time of 240 min was found to be suitable for pigment extraction. Thirugnanasambandham and Sivakumar (2017) extracted betalains from dragon fruit peel. The authors used microwave assisted extraction for the same. The experiment so

conducted was optimised using response surface methodology. The optimised conditions suitable for the extraction of betalains from 20 g dragon fruit peel were a temperature of 35°C and time of 8 minutes. Using these conditions, 9 mg/L of betalain was obtained. Utpott *et al.* (2020) tested the suitability of encapsulating betalains from red dragon fruit (Pitaya). Pitaya fruit peel was used for extraction of mucilage and mixed with maltodextrin for microencapsulation using spray drying. The yield from such matrix was obtained to be 16-25% owing to the low solid content. The incorporation from peel extracts enhanced betalain retention by 7%. Active packaging involving betalains extracted from waste have been studied. Rodríguez-Félix (2022) tested the suitability of ultrafiltered betalain extract obtained from beet baggase for use in preparation of active packaging. It was found that the average degradation temperature for all zein-betalain films was 313°C. With the increase in concentration of betalain, the hydrophobicity was enhanced. Smoother films were obtained by using ultrafiltered betalains in comparison to non-ultrafiltered betalains.

Anthocyanins were water soluble pigments found in the vacuole of plants exhibiting red, purple, blue or black colour depending upon the pH of the system. Anthocyanins were extracted from blueberry skin using various combinations of temperature, sulphur dioxide, citric acid and industrial juice processing enzymes. Enzyme application was least effective for anthocyanin recovery in this study (Lee and Wrolstad, 2004). Al-Shurait and Al-Ali (2022) optimised extraction conditions for solvent type, temperature, time, pH from the peels of eggplant, onion, red cabbage and pomegranate. Maximum extraction was obtained with acidified ethyl alcohol (5% citric acid) at pH 2 followed by acidified ethyl alcohol with hydrochloric acid. Optimum raw material: solvent ratio extraction from onion and eggplant was found to be 1:40 compared to 1:20 for extraction from cabbage leaves and pomegranate peels. Medium stability is an extremely important factor especially when it comes to bioactive compounds. Patras (2019) assessed the stability of anthocyanins obtained from cabbage waste in the presence of other food ingredients. The study included nineteen different compounds for assessment. Tartaric and citric acid influence the stability and colour to the maximum extent. In general, the authors concluded that the overall color changes are due to acids, calcium, magnesium and natrium. Ingredients like honey, glycine, xylitol, lactose and maltose induce smaller colour changes. Anthocyanins extracted from blackcurrant fruit waste was used as a renewable hair dye by Rose *et al.* (2018). The study utilised the fruit skins obtained as a waste from the fruit pressing industry for extraction of pigment using acidified water. Freundlich isotherm was followed for anthocyanin sorption onto

hair. The hair dye has stability even after multiple washes. Anthocyanins extracted from *Plinia cauliflora* and purple sweet potato peels were used for manufacturing colorimetric indicator films. These films were used to monitor meat freshness. The extraction was done using acidified water solution. Incorporation studies showed that the pigment enhanced molecular spacing in polymer chains indicating incorporation in the film (Capello *et al*., 2021).

1.2.5 Biofuels

In the changing world order and the current situation of conflict among various countries, biofuels are now not just an alternative to natural petroleum products but they have become the exclusive need of the energy-intensive developing countries. The reserves of petroleum-based fuels are finite and the depleting petroleum reserves also raise concern. It has now become essential to utilize non-conventional sources of energy. Agriculture-dominated economies like India generate a lot of waste from agriculture and food processing. This waste can be successfully used to produce biofuels and can lead to a sustainable energy system. This section discusses the studies carried out by various researchers to develop biofuels from different fruit and vegetable wastes. Oil can also be extracted from the seeds of fruit vegetables like sponge gourd (*Luffa cylindrical* (L.) ROEM), pumpkin (*Cucurbita moschata L.)*, bottle gourd, etc. Sponge gourd is widely cultivated in India and it is sown twice, i.e., mid-February to March and mid-May to July. The crop is usually harvested at the unripe mature stage and is ready for harvesting after 70-80 days of sowing. The average yield is 66-83 quintals/acre. Over-mature and ripe fruits are unfit for consumption and hence are wasted. The fully ripened dry fruits of the sponge gourd are rich in fibre and seeds. The fibre extracted from ripe fruit is used as bath sponge, cleansing agent and for making table mats and shoe soles, etc. (Apnikheti, 2022). The number of seeds in each fruit may vary from 203 to 734 (Khan *et al*., 2017). The seeds are rich in fat (39.11/100g) and protein (33.38 g/100g) and can be used for oil extraction and the residue can be used for the protein extraction. The oil extracted from its seeds is edible and is rich in unsaturated fatty acids especially linoleic acid (50.1%) (Elemo *et al*., 2011, Ogunsina *et al*., 2010) and can also be used for cooking purpose. Adetoyese *et al*. (2020) optimized the process of bioethanol production from sponge gourd using the Central Composite Design of Response Surface Methodology. The study was divided into two parts. In the first part, dried sponge gourd was milled and sieved (with a sieve having pore size of 1.0 mm) and the effect of various pre-treatments, i.e.,

alkaline treatment, steam explosion, combined alkaline and steam explosion, sodium sulphite treatment, and zinc chloride treatment was studied on glucose production. It was found that the treatment of 6 grams of dried, milled and sieved sponge gourd (DMSG) with 6% w/v sodium sulphite solution containing 0.5% NaOH as catalyst produced highest glucose yield (6.65 Kg m^{-3}). On the further optimization of the concentration of sodium sulphite (3-9%), temperature (60-100 °C) and reaction time (60-180 minutes) it was found that the glucose production (6.673 Kg m^{-3}) was optimal when dry milled sponge gourd was treated with 9% w/v sodium sulphite at 100 °C and 60 minutes. The highest ethanol concentration (6.84 kg m^{-3} was obtained with inoculum (*Saccharomyces cerevisiae*) size of 7.5 v/v and fermentation time of 24 h and utilizing ammonium sulphate as the nitrogen source.

Pumpkin (*Cucurbita moschata L.)* is another fruit vegetable that is widely cultivated in India. It is an annual climber that flowers from July to September and bears the humongous fruits that ripen from August to October. The fruits' size can vary from a few kilograms to up to 20 kg (Ahmad and Khan, 2019). Both the ripe and unripe fruits are edible and are used in the preparation of various dishes. A variety of waste in the form of peel (9-10%) and seeds (2.5-3%) is generated during its processing that accounts for about 13.42% losses (Singh *et al*., 2020). The seeds are rich in oil that exhibits various nutritional and medicinal properties. Kukeera *et al*. (2015) studied the extraction, quantification and characterization of oil from pumpkin seeds of three pumpkin varieties, namely Japanese type of *Curcrubita maxima* species, Green Kabocha and the butternut squash of the *Cucurbita moschanta* species. The oil was extracted using the Soxhlet extraction technique using petroleum ether as solvent. The mean recovery of oil in the three varieties was 35.67%, 30.12% and 34.76%, respectively. The acid value, iodine value, specific gravity and refractive index of the oil from three varieties ranged between 2.24-3.74 mg KOH/g, 25.3-26.61 mg I2/100 g, 0.9126-0.9131, and 1.469-1.471, respectively. The acidity and peroxide value of this oil has been reported to be 1.4±0.01 % as oleic acid and 8.66±0.21 meq. O2/Kg (Bardaa *et al*., 2016). The L, a*, and b* color scores for pumpkin oil are 13, 34 and 22, respectively. The oil is rich in essential fatty acids, vitamins, phytochemicals and phytosterols and possesses several health benefits. The level of poly unsaturated fatty acids is more than 50% of total fatty acids present. The major unsaturated fatty acids in the pumpkin seed oil are oleic acid (26%) and linoleic acid (51%). The tocopherol (280 mg/kg) content of pumpkin seed oil is more than olive oil that contains 125-250 mg/kg tocopherol. Tocopherol is an excellent antioxidant and is also known as a beauty and anti-sterility vitamin. The oil is also rich

in total sterols (2087 ppm) and the major sterol is β-sitosterol that accounts for about 44% of total sterols. β-sitosterol can reduce swelling in the prostate and other tissues. It has been also reported to reduce the cholesterol levels in the body. It is a strong antioxidant and the lipid peroxidation activity of pumpkin is higher than BHT. The oil also possesses strong antimicrobial activity and this activity is more effective against gram positive bacteria than gram negative bacteria. This can effectively control the growth of *Bacillus subtilis* and has a minimum inhibitory and minimum bactericidal concentration of 6.25 and 25. It has wound-healing properties and also helps in blood clotting by shortening the bleeding time (Bardaa *et al*., 2016).

Chouaibi *et al*. (2020) optimized the process for the production of bioethanol from pumpkin peel wastes. The peel waste was first washed with hot water at 50°C, air dried at 60°C for 48 h and ground to powder having a particle size of less than 200 μm. The bioethanol production was carried out in three steps, i.e., hydrolysis, saccharification and fermentation. Pumpkin waste was mixed with sterile ultra-pure-water in the ratios ranging from 10% to 20% and hydrolysis was carried out at pH 4.8 in a 50 mM acetate buffer solution. To this solution, α-amylase was added in the range of 100-140 IU/g and the mixture was stirred at 200 rpm for 130-150 minutes in a water bath maintained at 90°C. The liquefaction was carried at 70°C with amyloglucosidase (30-70 U/g). The hydrolysed mixture was cooled to 20°C and centrifuged for 5 minutes at 7000 rpm to remove the remaining biomass. To the hydrolysed pumpkin peel yeast extract, potassium dihydrogen phosphate (KH_2PO_4), magnesium sulfate ($MgSO_4.7H_2O$) and ammonium sulfate $(NH_4)_2SO_4$ was added at the rate of 0.50-2.5, 2, 1 and 1 g/L. This media was sterilized using an autoclave at 121°C for 25 minutes and the fermentation was carried out in batch mode at different temperatures, pH, shaking speeds and yeast concentrations, i.e., 30-50°C, 4-6, 50-250 rpm and 0.5-2.5 g/L, respectively. The hydrolysis and fermentation conditions were optimized using two modelling approaches, i.e., response surface methodology and artificial neural network. The estimation and prediction capabilities were superior in ANN and a hydrolysis time of 120 minutes, substrate loading of 17.5 g/L, α-amylase concentration of 7.5 U/g and amyloglucosidase concentration of 56.40 U/g was found to be best for hydrolysis. The fermentation temperature of 45°C, pH of 5.06, shaking speed of 188.5 rpm and yeast concentration of 1.95 g/L was found to be optimum for fermentation. This condition yielded 50.60 g/L of reducing sugar and 84.36 g/L of bioethanol. The waste from fruits and vegetables can also be used for the production of biofuel precursor molecules such as mono carboxylic acids (caproic, heptanoic and caprylic acids) and bihydrogen through an anaerobic fermentation process containing *Clostridium*

kluyveri and specially enriched anaerobic mixed bacterial culture. These bacteria can convert short-chain fatty acids like acetate, butyrate and valerate into medium-chain fatty acids through the chain elongation. Reddy and Chand (2021) converted the apple and pumpkin waste (pulp and skin waste separately) into a pulp and the anaerobic fermentations of all three pulps was carried out in separate anaerobic chambers using mixed bacterial cultures. This was converted to a leachate (liquid extract obtained from the paste). The incubation of apple waste with mixed bacterial culture produced significant amounts of butyric acid (7.2 g/L) and caproic acid (1.2 g/L). The production of butyric acid and caproic acid using pumpkin pulp and peel waste were 4.4 and 1.7 g/L and 6.1 and 2.5 g/L, respectively. Biohydrogen constituted 75% of the biogas. Similarly, research is going on for other fruits and vegetables as well.

1.2.6 Organic Acids

Organic acids are compounds which are acidic in nature. These include acids having carboxyl group, suphonic acid, thiol group, enol group, phenol group, etc. Examples of organic acids include lactic acid, acetic acid, citric acid, tartaric acid, etc. In food, organic acids are generally used as food preservatives as the undissociated forms can penetrate the bacterial cell wall and disrupt the functioning by creating pH gradient. Organic acids like benzoic acid and lactic acid prevent bacterial growth. Food waste contains good quantities of biodegradable carbohydrates which can be suitable for production of organic acids (Panda *et al*., 2016).

Citric acid is a hydroxyl weak acid and is naturally found in citrus fruits. It has a pH of less than 2 and is one of the widely used compounds in the food and pharmaceutical industry owing to its pleasant tart flavour. In the food industry, citric acid finds application as antioxidant, preservative, emulsifier, stabilizer, flavour enhancer, etc. The food industry consumes approximately 70% of the total produced globally, followed by pharmaceuticals (12%) (Vandenberghe *et al*., 2004). Biological synthesis of citric acid is preferred due to its economic advantage. Microbial species having the ability to synthesize citric acid include *Aspergillus niger, Mucor pyriformis, Penicillium lactum, Tricoderma viride* and Yeasts. Various fruit and vegetable waste has been utilized as substrate for the synthesis of citric acid. Examples of these include pineapple waste, banana peel, apple pomace, grape pomace, etc. Fermentation is the major biological method used for production of citric acid owing to its easiness, energy efficiency and steady operation. Citric acid can be produced by solid state, liquid surface and submerged fermentation. The process generally occurs in three phases.

The first phase is selection, preparation and inoculation of the substrate; the second phase is the actual fermentation process and the third phase is downstreaming (Merrylin *et al*., 2020).

Lactic acid is one of the highly used organic acids commercially and hence is always in demand. The demand of lactic acid is likely to rise from 1220 kilotonnes (2016) to 1960.1 kilotonnes in 2025 due to high demand of products like polylactic acid (Oliveira *et al*., 2018). Like citric acid, biological production of lactic acid is more sought after due to its superior and cost-effective nature. The cost of raw material is the major limiting factor in the biological method of production and accounts for approximately 35%. Food waste is rich in carbon and nitrogen and can act as a suitable substrate for fermentation to lactic acid. Lactic acid bacteria especially *Lactobacillus* is the preferred microorganism for lactic acid production as it can grow in a wide temperature and pH range (Mazzoli *et al*., 2014). Fruit and vegetables are rich in polysaccharides. Polysaccharides cannot be directly converted to lactic acid and need certain pretreatments for conversion. The raw materials derived from food waste are predominantly lignocellulosic in nature and hence require various pretreatments for separation of lignin, cellulose and hemicellulose. This makes the process expensive and cumbersome at large scale. Fungi *Rhizopus* can efficiently and directly convert starch to lactic acid. Lactic acid produced can be purified and stored. Jawad *et al*. (2013) optimized biofermentation conditions for production of lactic acid from mango peel. The conditions optimized for temperature, initial pH and time were 35°C, 10, and 6 days, respectively. These conditions gave a maximum yield of 17.484 g lactic acid per litre. Derabli *et al*. (2022) successfully attempted to produce lactic acid from *Opuntia ficus-indica* peel waste using *Lactobacillus plantarum* and obtained a yield of 0.46 g/g of hydrolysate. Maximum yield was obtained at temperature, time, and substrate loading of 120°C, 40 min and 5%, respectively. The granulation of the hydrolysate used was 350 micrometer. Idris and Suzana (2006) synthesized lactic acid from liquid pineapple waste using immobilized *Lactobacillus delbrueckii subsp. Delbrueckii ATCC9646. Lactobacillus delbrueckii subsp. Delbrueckii* was also used by de la Torre *et al*. (2020) from partially dried orange peel. For this, first saccharification was done in batches to produce carbohydrate hydrolysates (containing glucose, fructose, arabinose) having a concentration of more than 110 g/l. After saccharification, the substrate was fermented using *Lactobacillus delbrueckii subsp. Delbrueckii* to obtain lactic acid. Arekemase *et al*. (2020) attempted to compare the yield of lactic acid from peels of mango, banana and orange using *Lactobacillus plantarum* and *Lactobacillus casei*. Mango peels exhibited the highest production of

lactic acid in comparison to others. This was obtained with *L. casei*. Also, among microbes, comparatively higher production was obtained for *L. casei* than *L plantarum*. The authors observed that for all the peels, lactic acid production increased from day 1-6 (23.28% for mango peels, 12.9% for banana peel and 18.3% for orange peel on day 6) and decreased after that. Similar results were obtained by Rutuja *et al*. (2016) for vegetable waste. Mudaliyar *et al*. (2012) assessed the efficacy of lactic acid from five fruit and vegetable peels, namely, mango, potato, sweet corn, orange and green peas utilizing *Lactobacillus casei* and *L. delbruckii*. Amongst these as well, the highest amount of lactic acid was produced by mango peel (63.33g/L) with the help of L.casei. The highest yield using *L delbrukii* was obtained from orange peels (Mudaliyar *et al*., 2012). The fungal strain of *Rhizopus oryzae* MTCC8784 was used to produce lactic acid from the peels and other wastes of banana, sapota, corncob, potato and papaya. Sapota peel exhibited maximum production (3.6 g/g) of lactic acid. The concentration obtained was 72g/L. Hence, it is imperative to keep in mind the type of fruit/vegetable, waste part composition and micro-organism used for lactic acid production.

Acetic acid is another organic acid and is popularly used in the preparation of vinegar at commercial level which may have concentration of acetic acid anywhere between 4.1% and 12.3% depending upon the country. It can be produced industrially by microorganisms like *Clostridium*, *Acetobacterium*, *Acetobacter,* etc. (Sakauri *et al*., 2012). Raji *et al*. (2012) used pineapple peels as a substrate to produce acetic acid by a two-stage fermentation process using *Saccharomyces cerevisiae* and *Acetobacter aceti*. In the first stage, the substrate was converted to ethanol, and in the second stage, ethanol, the intermediate product, was then converted to acetic acid by *Acetobacter aceti*. An incubation period of nine days gave an acetic acid yield of 4.77%. The same microbes were used for production of ethanol from papaya peel (Vikas and Mridul, 2014). Vashisht *et al*. (2019) isolated mesophilic bacteria *Acetobacter pasteurianus* SKYAA25 for production of acetic acid from apple pomace. The bacterium so isolated was able to tolerate up to 14% ethanol and temperature of 42°C gave a yield of 52.4 g/100g dry matter of apple pomace. Perta *et al*. (2022) successfully produced acetic acid by dark fermentation under mesophilic conditions and got a yield of 7 mmol/g of vegetable substrate. Chalchisa and Dereje (2021) attempted production of vinegar using strains of *Propionic bacterium acidipropionici*, *Panteo agglomerans*, and *Pantea dispersa* from papaya peel. Optimum acetic acid production was observed for *Propionic bacterium acidipropionici* after 72 hours giving a yield of 6.15 g/L.

Volatile fatty acids including acetic acid, propionic acid, butyric acid are useful in the chemical industry owing to their functional groups. These are used for production of biopolymers and biofuels (Raganatia *et al*., 2014). Food waste generally contains high levels of organic matter, nitrogen and phosphorus which makes it a suitable substrate for microbes. Volatile fatty acids are produced by the process of anaerobic digestion involving three steps, viz., hydrolysis of complex matter into simple molecules, acidogenesis and methanogenesis involves fermentation into volatile fatty acids. Application of pretreatments like size reduction, exposure to acid, alkali, enzyme action can enhance the efficiency of the whole process. Eryildiz *et al*. (2020) used citrus waste as substrate for the production of volatile fatty acids. Volatile fatty acid yield was found to be 0.793 g volatile fatty acids per gram of substrate added at a pH of 6. Caproic acid and butyric acid were the major volatile fatty acids detected with a share of 21 and 15%, respectively. Acetic acid was also produced (32%). An important observation made by the authors was that the presence of D-Limonene and peel oil inhibited the process of acidification.

1.2.7 Enzymes

Enzymes majorly are proteins and act as biological catalysts useful in several biochemical processes/reactions. The valorisation of fruits and vegetable industry waste find application in the development of various products in industry like amylases and pectinases for the food industry. Cheaper substrates may well reduce the market cost of these. This section deals with the potential of valorisation of fruit and vegetable waste into useful enzymes.

Amylases are starch hydrolysing enzymes which hydrolyse complex carbohydrates into simpler ones. Exo and endo amylases are responsible for cleavage of the α 1-4 and 1-6 bonds. Fruit kernels have been used to produce α-amylases. Loquat and mango kernels have been used successfully to produce amylolytic enzymes using microorganisms like *Penicillium expansum* and *Fusarium solani* (Erdal and Taskin, 2010). Mouna imen and Mahmoud (2015) utilized citrus waste in the form of peels and produced α-amylase with the highest activity of 8.26 U/mL in submerged fermentation after five days of cultivation. Sharma *et al*. (2018) isolated starch hydrolysing bacteria from the waste of brinjal, cucumber, papaya, potato and snake gourd. Nine isolates were found to be amylase positive with the starch hydrolysing ratio in the range of 1.13-2.71. Irfan *et al*. (2017) utilised Bacillus subtilis K-18 (KX881940) for cellulase production from potato peel. At a 2% raw material concentration and same inoculum size, pH of 5

and incubation conditions of 50°C for 24 hours, an enzyme titre of 3.50 ± 0.11 IU/ml was attained.

Lipases can be produced from substrates like banana peel and potato peel using *Aspergillus* sp. An initial moisture content of 55%, temperature and time combination of 30.5 C for 30 hours for incubation was found suitable for production (Gerber *et al*., 2013). Other sources include lemon peel, fruit seeds, coffee husks, vegetable oil refining waste, etc (Kumar and Kanwar, 2012; Santis-Navarro *et al*., 2011).

Pectinases are enzymes that have the capability to hydrolyze pectin. It is used for various purposes in the food industry like juice and oil extraction, clarification, tea fermentation and wastewater treatment. In the fruit juice industry, it is used for the extraction and clarification of fruit juices, clarification in breweries, manufacture of fruit and vegetable concentrates, and extraction of pigments. Generally, microbial production of pectinase is a common method used for its synthesis. Pandey and Mishra (2021) screened twenty microbial strains from orange and banana waste strip squander tests. Two microorganisms, namely *Penicillium oxalate* and *Talaromyces aurantiacus,* were identified which exhibited pectinase movement. Hale *et al*. (2022) isolated pectinase-producing bacteria from avocado peel waste and assessed its efficacy in juice clarification. The study identified *Serratia marcescens* isolates for peel waste and successfully used pectinase derived from bacterium for clarification of apple, lemon and mango juices. Orange peel, wheat bran, corn cobs, sweet prayer plant peels and banana peels derived *Aspergillus niger* has also been successfully used for production of pectinases (Kumoro *et al*. 2022; Awan *et al*., 2022; Ametefe *et al*., 2022a). Ametefe *et al*., 2022b assessed the pectinase activity of flavedo and albedo portions of *Citrus sinensis* and compared it with the pectinase activity from the albedos of lemon and sweet prayer plant. The study concluded that the albedo portion of peel waste of sweet orange, lemon and sweet prayer plant is a superior substrate for pectinase production in comparison to flavedo.

Tannase has the ability to hydrolyse tannins to gallic acid and glucose. It is used in the food industry for reduction of tannin content, astringency, for clarification of juices, beer, for manufacturing dyes and instant tea (Sagar *et al*., 2018). Fungal strains of *Aspergillus niger*, *T. viridae* can be used for producing tannase from grape peel waste (Paranthaman *et al*., 2009). Highly stable, tannase was produced from agro-industrial waste using *Penicillium montanense* (Lima *et al*., 2014). Varadharajan *et al*. (2016) assessed various horticultural waste for the potential of tannase production and found that pomegranate rind extract gave a yield of approximately 138.12 IU/mL using *Aspergillus oryzae.* Pomegranate peel was utilized for tannase production

by Lekshmi *et al*. (2020). *Bacillus velezensis* TA3 under solid state fermentation was utilized for the fermentation of agrowaste like coffee husk, apple peel and pomegranate peel for production of tannase. Similar results were obtained by fermentation of potato peel from *Penicillium commune* HS2 (Mostafa 2022). Hence, fruit and vegetable waste can be successfully used for the production of tannase and other enzymes.

1.2.8 Bioactive Compounds

Bioactive compounds are those components which offer various health benefits and prevent degenerative diseases (Panghal *et al.*, 2022; Chhikara and Panghal, 2022). Fruit and vegetables are rich in bioactive compounds. Available literature evidence shows fruits and vegetables waste to be rich in bioactive compounds, sometimes richer than the fruit itself. Many secondary metabolites are present in the least palatable parts of fruit and vegetables and seeds. Various phytochemicals are found in fruit and vegetable waste, especially phenolic compounds and dietary fibers. For instance, pomegranate pomace after juice processing can have bioactives up to 10-50 g/kg dry weight (Renard, 2018). Polyphenols are among the biggest classes of phytochemicals and include classes like hydroxybenzoic and hydroxycinnamic acid, anthocyanins, flavonols, flavonoids, flavonones, phenolic acids, tannins, etc. These are plant secondary metabolites and contribute to the sensorial and health-enhancing aspects of food. The unconsumed parts of fruits and vegetables like rind, peel and seeds contain high quantities of polyphenols. High quantities of polyphenols were reported in Korean potato variety peel which contained higher chlorogenic acid and caffeic acid in comparison to cortex (Choi *et al.*, 2016). Date seed oil had the highest quantity of polyphenolic content in comparison to other tested seed oils. Peel, pomace and seeds of apple, avocado, grapes, mango, palm, and pomegranate are rich in polyphenolic compounds like epicatechin, catechin, chlorogenic acid, glycosides, cinnamic acids, coumaric acid, caffeic acid, vanillic acid, condensed tannins, etc., as reported in various studies. Carrot peel and tomato skin and pomace are rich in phenols and beta-carotene. Cucumber peel has been reported to contain appreciable quantities of chlorophyll, pheophytic, phellandrene, and caryophyllene, and peels of potato contain phenolic compounds like vallic, caffeic and vanillic acid (Kumar *et al.*, 2017). The phytochemicals obtained from various fruits and vegetables have been summarised in Table 1.1.

Different extraction methods are used for extraction of bioactive compounds from fruit and vegetable waste (Figure 1.3). Traditional methods

Table 1.1 Bioactive compounds reported in fruit and vegetable waste.

Name	Un-utilized parts	Phytochemicals identified	Content	References
jamun	Seeds	Tannic acid	3.89-188.5 mg/g	Kumar M, *et al.*, 2022 and Kaur N, *et al.*, 2022
		Epicatechin	0.05-2 mg/g	
		Gallic acid	$14.95x10^{-3}$-90.8 mg/g	
		Kaemferol	0.24 mg/g	
		Ellagic acid	$18.65x10^{-3}$-36 mg/g	
		Caffeic acid	$1.02x10^{-3}$-26.07 mg/g	
		p-coumaric acid	0.26-6 mg/g	
		Catechin	$5.36x10^{-3}$-9.05 mg/g	
		Quercetin	1.54 mg/g	
		Chlorogenic acid	0.89-6.80x10-3 mg/g	
		Ferulic acid	$1.5x10^{-3}$ -0.2 mg/g	
		Valoneic acid dilactone	9.37 ug/ml	
		Rubuphenol	28.14 ug/ml	
		3-hydroxy androstane [16,17-C](6'methyl, 2'-1-hydroxy-isopropene-1-yl) 4,5,6 H pyran	7.38%	
		Dodecamethyl-cyclohexasiloxane	0.80%	
		Tetra-decamethyl-cycloheptasiloxane	0.69%	
		Pyrazole [4,5-b] imidazole 1-formyl-3-ethyl-6-a-d-ribofuranosyl	1.63%	
		1-monolinoleoylglycerol trimethylsilyl ether	1.45%	
	Pomace	Total anthocyanins	2.78-5.87 mg CE/g	

(*Continued*)

Table 1.1 Bioactive compounds reported in fruit and vegetable waste. (*Continued*)

Name	Un-utilized parts	Phytochemicals identified	Content	References
		Total phenols	11.95-26.05 mg GAE/g	
		Flavonoids	5.46-11.17 mg QE/g	
Jackfruit	Peels	Phenolics	6.38-48.04 mg/g	Zhang L, *et al*., 2017; Brahma and Ray, 2022; Adnan *et al*., 2020
		Flavonoids	2.79-28.55 mg/g	
		Tannins	5.83-5.96 mg/g	
	Fiber	Phenolics	13.91-23.28 mg/g	
		Flavonoids	14.72-35.4 mg/g	
		Tannins	5.83-12.27 mg/g	
	Core	Phenolics	13.91-15.68 mg/g	
		Flavonoids	12.27-24.15 mg/g	
		Tannins	4.61-9.69 mg/g	
	Seed	Phenolics	9.71 mg GAE/g	
		Flavonoids	1.62 mg QE/g	
Papaya	Seed	Flavonoids	23.50-38.68 mg/g	Dotto J M, Abihudi S A, 2021; Martial-Didier A K, *et al*., 2017; Kanadi M A, *et al*., 2019
		Alkaloids	16.20-27.62 mg/g	
		Anthraquinones	21.50%	
		Carotenoids	19.75%	
		Glycosides	0.84-2.18 mg/g	
		Oxalates	2.33%	
		Tannins	0.03-0.91 mg/g	
		Saponins	23.50-36.76 mg/g	
	Peel	Total polyphenols	65.48 mg GAE/100g	
		Flavonoids	5.58 mg QE/100g	
		Tannins	10.51 mg TAE/100g	

(*Continued*)

Table 1.1 Bioactive compounds reported in fruit and vegetable waste. (*Continued*)

Name	Un-utilized parts	Phytochemicals identified	Content	References
Banana	Peel	Total phenolic content	0.15-55.5 mg/g	Zaini H M, *et al.*, 2022
		Flavanols		
		Kaemferol	9.30-28.80 ug/ml	
		Isoquercetin	10.47-14.54 ug/ml	
		Rutin	973.08 mg/100g Dry extract	
		Myricetin	11.52 mg/100g Dry extract	
		Naringenin	8.47 mg/100g Dry extract	
		Hydroxycinnamic acid:		
		Ferulic acid	1.63-60 mg/100g	
		Cinnamic acid	1.93 ng/g	
		Alpha-hydroxycinnamic acid	40.66 ng/g	
		Sinapic acid	10.29 ng/g	
		p-coumaric acid	8.05 ng/g	
		Total dietary fibre	50%	Gupta and Joshi, 2000
Mango	Peel	Flavonoids	29.04-37.18 g/100 g	Onuh J O, *et al.*, 2017; Alañóna M E, *et al.*, 2021
		Tannin	15.91-24.27 g/100g	
		Alkaloids	0.25-0.29 g/100g	
		Saponins	2.64-3.94 g/100g	
		Total phenols	237.13-436.44 mg/100g	
		Dihydroxybenzoic acid glucoside	1.13-29.78 mg/100g	
		p-Hydroxybenzoic acid glucoside	6.06-16.27 mg/100g	

(*Continued*)

Table 1.1 Bioactive compounds reported in fruit and vegetable waste. (*Continued*)

Name	Un-utilized parts	Phytochemicals identified	Content	References
		Vanillic acid glucoside	6.75-17.47mg/100g	
		Coumaric acid glucoside	1.51-4.36 mg/100g	
		Ferulic acid glucoside	1.71-8.32 mg/100g	
		Syringic acid	0.51-2.64 mg/100g	
		Ellagic acid	1.13-13.67 mg/100g	
		Catechin	3.28-50.23 mg/100g	
		7-O-galloyl tricetilflavan	4.90-34.77 mg/100g	
		Quercetin glucoside	0.76-3.43 mg/100g	
		Gallic acid	8.96-21.51 mg/100g	
		Galloyl glucose	52.00-254.33 mg/100g	
		Galloyl diglucoside	6.12-30.04 mg/100g	
		5-Galloyl quinic acid	7.04-86.51 mg/100g	
		3-galloylquinic acid	0.86-8.28 mg/100g	
		Methylgallate	387.08-650.25 mg/100g	
		Digallic acid	0.61-7.33 mg/100g	
		Digalloyl glucose	0.23-8.25 mg/100g	
		Trigalloyl glucose	0.12-4.59 mg/100g	
		Tetragalloyl glucose	23.21-77.61 mg/100g	
		Pentagalloyl glucose	113.98-180.24 mg/100g	
		Hexagalloyl glucose	112.40-211.54 mg/100g	

(*Continued*)

Table 1.1 Bioactive compounds reported in fruit and vegetable waste. (*Continued*)

Name	Un-utilized parts	Phytochemicals identified	Content	References
		Heptagalloyl glucose	4.11-30.72 mg/100g	
		Mangiferin	41.77-148.12 mg/100g	
Orange	Peel	Total phenols	3.64-27.14 mg GAE/g	Oikeh EI, *et al.*, 2020; Liew SS, *et al.*, 2018; Emojorho EE and Akubor PI, 2016; Romelle FD, *et al.*, 2016
		Flavonoids	59.94-86.82 mg QE/g	
		Total tannins	8.00-28.50 mg TE/g	
		Alkaloids	5.44%	
		Oxalates	99.78 mg %	
		Phytates	2.34%	
		Phenolic acids		
		Gallic acid	18.80-43.43 ug/g	
		Protocatechuic acid	24.40-140.25 ug/g	
		4-hydroxybenzoic acid	24.07-81.74 ug/g	
		Caffeic acid	69.58-411	
		Ferulic acid	108.79-917.88 ug/g	
		Flavonoids		
		Catechin	123.99-679.32 ug/g	
		Epigallocatechin	178.07-621.84 ug/g	
		Vitexin	69.61-225.52 ug/g	
		Rutin	15.08-30.63 ug/g	
		Luteolin	227.97-539.49 ug/g	
		Apigenin	141.24-313.08 ug/g	
	Seed	Alkaloids	6.95%	
		Flavonoids	29.17%	
		Tannins	10.74 mg/100g	

(*Continued*)

Table 1.1 Bioactive compounds reported in fruit and vegetable waste. (*Continued*)

Name	Un-utilized parts	Phytochemicals identified	Content	References
Pomegranate	Peel	Total phenolics	16.397-468.3 mg GAE/g	El-Hamamsy, *et al.*, 2020; Singh B, *et al.*, 2018; Romelle FD, *et al.*, 2016
		Total flavonoids	49.22-70.65 mg Rutin/g	
		Alkaloids	1085.2 mg QE/ 100 g	
		Oxalate	6.50%	
		Phenolic compounds	2283.77 mg%	
		Protocatechuic acid	10.26 mg/ml	
		p-coumaric acid	18.43 mg/ml	
		Caffeic acid	9.55 mg/ml	
		Ellagic acid	8.14 mg/ml	
		Cinnamic acid	33.08 mg/ml	
		Quinic acid	20.0 mg/ml	
Pine-apple	Peel	Alkaloids	11.1-12.24 mg/g	Dabesor A P, *et al.*, 2017; Nurdalilah O, *et al.*, 2018
		Oxalate	5.31-5.46 mg/g	
		Tannins	2.11-3.16 mg/g	
		Phytate	0.53-0.63 mg/g	
		Glycosides	1.16-1.25 mg/g	
		Total phenols	1.62 g GAE/mg	
Custard apple	Peel	Total phenols	763.49 mg GAE/100g	Nguyen V T, *et al.*, 2020; Chel-Guerrero L D, *et al.*, 2018; Ethiraj S Sridar V, 2018
		Chlorogenic acid	1.11 ppm	
		Total flavonoid content	13.97 mg QE/g	

(*Continued*)

Table 1.1 Bioactive compounds reported in fruit and vegetable waste. (*Continued*)

Name	Un-utilized parts	Phytochemicals identified	Content	References
	Seeds	Polyphenol	113.89-234.17 mg GAE/100g	
		Flavonoids	84.90-189.15 mg QE/100g	
		Total phenols	216.29-230.47 mg GAE/100g	
Watermelon	Peel	Oxalates	128.40 mg %	Romelle F D, *et al.*, 2016; Dieng S I M, *et al.*, 2017
		Alkaloids	10.09%	
		Phytates	0.70%	
		Total phenolics	0.91%	
		Polyphenols	63.33 mg TAE/g	
		Flavonoids	1.105 mg RE/g	
	Seeds	Alkaloids	47.2 mg/g	
		Cardiac glycosides	10.07 mg/g	
		Flavonoids	3.51 mg QE/g	
		Total phenols	8.40 mg GAE/g	
		Phytate	66 mg/g	
		Saponin	32.48 mg/g	
	Whole meal	Alkaloids	95.8 mg/g	
		Cardiac glycosides	14.35 mg/g	
		Flavonoids	7.76 mg QE/g	
		Total phenols	5.36 mg GAE/g	
		Phytate	16.4 mg/g	
		Saponin	11.62 mg/g	

(*Continued*)

Table 1.1 Bioactive compounds reported in fruit and vegetable waste. (*Continued*)

Name	Un-utilized parts	Phytochemicals identified	Content	References
Avocado	Peel	Total phenols	140-5158 mg GAE/100g	Ramos-Aguilar A.l., *et al.*, 2021; Oliveira C.S., *et al.*, 2022; S. Mpai and D. Sivakumar, 2020; M. Kamaraj, *et al.*, 2019; P. Jimenez, *et al.*, 2020; G.G. da Silva, *et al.*, 2022
		Total flavonoid content	131-1563 mg QE/100g	
		Total polyphenol content	430->30000 mg GAE/100g	
		Procyanidins	28.9-29,080 mg/100g	
	Seed	Total phenols	3215-3248 mg GAE/100g	
		Total flavonoid content	146-1,19,904 mg QE/100g	
		Total polyphenol content	25.35->30000 mg GAE/100 g	
		Procyanidins	152-5,560 mg/100g	
Peach	Peel	**Hydroxycinnamates**		Zhao X, *et al.*, 2015; Marija R. Koprivica, *et al.*, 2018
		Neochlorogenic acid	5.77-342.75 mg/kg	
		Chlorogenic acid	52.20-1264.42 mg/kg	
		Flavan-3-ol		
		Procyanidin B1	54.76-539.22 mg/kg	
		Catechin	60.14-1030.06 mg/kg	
		Anthocyanin		
		Cyanidin-3-O glucoside	9.33-1030.06 mg/kg	
		Flavonols		
		Quercetin-3-O galactoside	8.45-396.49 mg/kg	

(*Continued*)

Table 1.1 Bioactive compounds reported in fruit and vegetable waste. (*Continued*)

Name	Un-utilized parts	Phytochemicals identified	Content	References
		Quercetin-3-O-glucoside	2.45-581.21 mg/kg	
		Quercetin-3-O-rutinoside	59.15-172.73 mg/kg	
		Kaemferol-3-O-rutinoside	16.91-110.86 mg/kg	
	Kernels	Protocatechuic acid	1.5-5.36 mg/kg	
		p-hydroxybenzoic acid	1.38-38.12 mg/kg	
		p-hydroxyphenylacetic acid	1.95-14.12 mg/kg	
		Chlorogenic acid	0.47-23.73 mg/kg	
		p-coumaric acid	0.97-9.10 mg/kg	
		Ferulic acid	2.29-29.43 mg/kg	
		Catechin	0.59-44.09 mg/kg	
Apple	Peel	Total dietary fibre	0.91%	Gupta and Joshi, 2000
Potato	Peels	Total phenols	12.57-122.03 mg GAE/100g	Rowayshed G, *et al.*, 2015
		Gallic acid	7.56 mg/100g	
		Caffeic acid	20.96 mg/100g	
		Chlorogenic acid	11.46 mg/100g	
		Isoferulic acid	13.77 mg/100g	
		Vanillic acid	13.52 mg/100g	
		Isovanillic acid	11.88 mg/100g	
Cauliflower	Leaves	Total phenol content	4.40 mg GAE/g	Drabinska N, *et al.*, 2021
		Total flavonoid content	0.64 mg RUT/g	
		Total glucosinolates	225.2 mmol/g	
	Stem	Total phenol content	4.40 mg GAE/g	
		Total flavonoid content	0.64 mg RUT/g	
		Total glucosinolates	225.2 mmol/g	

(*Continued*)

Table 1.1 Bioactive compounds reported in fruit and vegetable waste. (*Continued*)

Name	Un-utilized parts	Phytochemicals identified	Content	References
Pumpkin	Peel	Total phenol content	2.65 mg GAE/g	Singh A and Kumar V, 2021; Hussain A, *et al*., 2020
		Total flavonoid content	0.22 mg RUT/g	
		Total glucosinolates	125.05 mmol/g	
	Seed	Total phenolic contents	93.40 mg GAE/100g	
		Total flavonoids contents	45.0 mg CE/100g	
		Total carotenoids	23.7 mg/100g	
		Total phenol content	35.66 mg GAE/g	
		Total flavonoid content	23.65 mg QE/g	
		a tocopherol	3.76-5.65 mg/100g	
		b+y tocopherol	35.83-47.69 mg/100g	
		B-Sitosterol	29.11-35.81 mg/100g	
		Stigmasterol	8.89-13.28 mg/100g	
		Squalene	82.19-86.91 mg/100g	
		Total carotenoids	8.2 mg/100 g	
	Kernel	Total phenol content	31.39 mg GAE/g	
		Total flavonoid content	20.11 mg QE/g	
		a tocopherol	2.39-4.51 mg/100g	
		b+y tocopherol	28.82-33.37 mg/100g	
		B Sitosterol	23.03-28.31 mg/100g	
		Stigmasterol	5.88-7.55 mg/100g	
		Squalene	69.94-77.42 mg/100g	

(*Continued*)

Table 1.1 Bioactive compounds reported in fruit and vegetable waste. (*Continued*)

Name	Un-utilized parts	Phytochemicals identified	Content	References
Plantain (unripe)	Peels	Alkaloids	3.53 g/100g	Uzairu SM, *et al.*, 2021
		Flavonoids	0.116 g/100g	
		Tannins	2.18 g/100g	
		Terpenoids	1.88 g/100g	
Onion	Peel	Total phenolics	19.7-68.2 mg GAE/g	Manoj Kumar, *et al.*, 2022; Irtiqa Shabir, *et al.*, 2022
		Total flavonoids	19.5-55.27 mg QE/g	
		Total flavanols	7.89-19.27 mg/g	
		Total polyphenolic content	97.28 mg GAE/g	
		P-coumaric acid	583.2 ug/g dm	
		Vanillic acid	245.0 ug/g dm	
		Epicatechin	275 ug/g dm	
		Morin	158.7 ug/g dm	
		Quercetin 3-40-diglucoside	100-331.93 mg/100g	
		Quercetin 40 monoglucoside	140.43-298.87 mg/100g	
		Quercetin aglcone	60.51-70.10 mg/100g	
Beetroot	Peel	Betacyanin	55.36 mg/g	Sharma, *et al.*, 2020

like solvent extraction, Maceration, decoction, infusion, percolation, use of supercritical fluids, and enzymatic pretreatments can be used for extraction of bioactive compounds. Maceration has been used for extraction of polyphenols and flavonoids from kinnow and mango peels using solvents like ethanol, methanol and ethyl acetate (Safdar *et al.*, 2017). Decoction and infusion have been successfully used for extraction of polyphenols from pomegranate peels at 70C-100C in the time range between 10-60 min. Total phenolic content was found to be 148-237 mg gallic acid equivalent/g dry weight (Turrini *et al.*, 2020; Ghosh *et al.*, 2019). Percolation and soxhlet

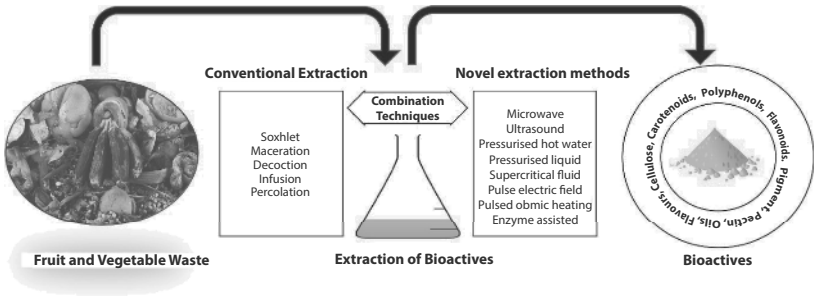

Figure 1.3 Techniques for the extraction of bioactive compounds from fruit and vegetable waste.

extraction was used for grape peel and sweet orange peel. Percolation is a continuous technique but has low yield rate and long extraction time in comparison to maceration. Soxhlet is the preferable but time-consuming method for extraction of polyphenolic compounds. Maceration is an effective and easy technique for extraction of polyphenols and flavonoids (Rifna *et al.*, 2021). Due to unsustainable/noneconomical nature, low solvent purity, poor extraction yield, long extraction time, loss of heat sensitive compounds, and health risks involved, conventional techniques are getting replaced by novel strategies recently.

Novel strategies like non-thermal processing, pressurized liquid extraction, negative pressure cavitation, and high-pressure homogenisation are used to facilitate the release of bioactive from the matrix (Jiménez-Moreno *et al.*, 2020). Microwaves and ultrasound-assisted extraction have been successfully used coupled with other extraction techniques (Renard, 2018, Kumar *et al.*, 2021). These methods generally work at low temperature and are more cost effective. Currently various studies are being conducted on green extraction techniques which minimize the use of solvents (Rodriguez Garcia and Raghavan, 2022). Microwave and ultrasound extraction is used for extraction from banana, mango, eggplant, pomegranate, and citrus peels (Vu *et al.*, 2019, Sommano *et al.*, 2018, Ferarsa *et al.*, 2018, Zivkovic *et al.*, 2018, Wang *et al.*, 2016). Various combination techniques are also being used these days for better efficiency like microwave-assisted enzymatic extraction, ultrasound-assisted enzymatic extraction, microwave-ultrasonic–assisted extraction. Tang *et al.* (2016) used ultrasound-assisted enzymatic extraction for extraction of lycopene from tomato peels.

Dietary fibre is another component present in fruit and vegetable waste which has various health benefits and is extremely good for the gastrointestinal tract. Although onion has dietary fibre in all the layers, the content was

much higher (68% dm) in the skin in comparison to the inner (11.6% dm) core (Jamie *et al*., 2002). Different types of processing treatment had variations in the bioactive composition of the produce. For instance, pasteurization of onion peel was found suitable for dietary fibre and fructans, whereas sterilization treatment could give products like alkenyl cysteine sulfoxide. Potato solid waste including potato peel was also found to be a good source of fibre (Sharoba *et al*., 2013). On similar grounds, the non-starch polysaccharide content of cauliflower waste was found to be much higher than florets. Similar reports were obtained from carrot pomace and peels; apple peels, grape pomace, mango waste products like skin, seed and pomace, etc. (Sagar *et al*., 2018). Orange and lemon peels contained good quantities of both soluble and insoluble dietary fibre. In studies conducted worldwide, the components identified in various wastes included soluble and insoluble fibre, hemicellulose, lignin, cellulose, pectin, galactose, arabinose, and glucose. Ultrasound-assisted enzymatic extraction increased extraction yield of dietary fibre by 4.67% (Tang *et al*., 2016). Microwave-assisted enzymtic extraction was used for extraction of soluble dietary fibre from grapefruit peel. Use of enzyme (cellulase) at the rate of 3000U/g along with microwaves enhanced the structural and functional ability of dietary fibre obtained. The extracted fibre had improved oil, water and nitrite ion binding ability (Gan *et al*., 2020). Bagherian *et al*., (2011) applied ultrasound followed by microwave subsequently for pectin extraction from grape peels. First, the peel sample was subjected to intermittent irradiation for 1800 sec followed by acidification and microwave power of 450 Watt for a time period of 600 sec. This technique improved pectin yield by 32% approximately.

1.2.9 Others

Verma and Kumar (2020) reported that the dried, ground and sieved (850 μm mesh size) peel powder of bottle gourd enriched with the whey and starch hydrolysates can be effectively used for the production of cellulose using the fungus *Trichoderma reesei* and *Neurospora crassa*. The most optimal results for both the fungal strains were obtained at incubation temperature of 30°C and inoculum dosage of 0.56 g/L. Solid state fermentation has been used to extract colors, aromas, alcohol and other ingredients from fruit and vegetable waste. Fermentation and enzymatic treatment is reportedly used in various studies for production of vanillin precursors from waste, viz., pineapple peel contains ferulic acid (Lun *et al*., 2014). Fruit and vegetable waste also contain precursors that can be used for the synthesis of flavors like rhamnose from citrus peel that can be used to synthesise furaneol; ethyl butyrate from apple pomace; δ-decalactone from olive press

cake (Sagar *et al*., 2018). Mulberry, blueberry, chokeberry residues, and purple sweet potato peel powder (high anthocyanin), have been used to produce pH-sensitive colorimetric films incorporated in corn starch or cassava starch base. Addition of pomegranate, papaya and jackfruit peel into bilayer films helps to enhance the thickness, opacity and moisture content of packaging films. Fibre/cellulose have been successfully extracted from carrot waste, durian skin, orange peel, banana peel. etc, (Mohd Basri *et al*., 2021).

1.3 Conclusion

Fruit and vegetable waste accounts for enormous loss of valuable components. This is not just the spoiled waste but also the by-products which are simply discarded as waste from various fruit and vegetable industries and have various types of bioactive substances having strong potential for being converted into something useful. These components have been successfully used for synthesis of useful substances like biofuel, enzymes, organic acids, etc., which find application not just in the food industry but elsewhere as well. By-products like peels, seeds and pomace also contain oils and phytochemicals which can potentially be utilized in different formulations after extraction. This book deals with the nutraceutical potential of wastes obtained from various individual fruits and vegetables, which will be discussed through the following chapters.

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