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Potential of fruit and vegetable waste as a source of pectin

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Abstract
Fruit processing waste accounts for 16% of waste produced and is rich in bioactive molecules, especially pectin, which is a soluble dietary fibre. Modern diets made after processing of grains lack soluble dietary fibres and this creates an opportunity for their fortification and enrichment. Fruit waste contains 5-35% soluble dietary fibres in the form of pectin which can be extracted through chemical, physical, enzymatic methods or any combination thereof. The choice of extraction method depends on ease of extraction, quantity of pectin, quality of final product extracted and economic feasibility. Conventional extraction methods take longer time and aren't environmentally friendly whereas novel extraction techniques like microwave, ultrasound, and high pressure for extraction generally give higher pectin yield with superior quality of final product. Pectin thus extracted can be added to bakery products and have been shown to increase water holding capacity and functional properties of baked products. Drinks present another scope for their incorporation since they have very low to no soluble dietary fibre component. Valorisation of fruit waste is step towards sustainable technologies in circular economy producing zero waste.

Keywords: Potential, fruit and vegetable, pectin

1. Introduction

Fruit processing industries have seen a major growth in the last few decades due to changing lifestyles and demand of on-the-go fresh food. 124.5 MMT (million metric tons) apples, 82 MMT oranges, 0.404 MMT papaya, 55.59 MMT mangoes, mangosteens and guava, 6.73 MMT carrots and turnips, 69.25 MMT potatoes, and 39.84 MMT tomatoes were produced in 2017 (FAO, 2019) [13]. More than 4112 MMT of fresh fruits and vegetables were produced in the world in 2017 (FAO, 2019) [13]. FAO (2019) [13] estimates that 13.4% of the food produced annually is wasted or lost. Central and southern Asian region lost most food at 20.7% whereas least food loss is in Australia and New Zealand (5.8%). Fruit and vegetable waste accounts for 21.6% of all food waste, highest among all food types of foods. Fruit waste alone accounted for 16% of total food waste in 2013 and contributed to 6% of total greenhouse emission through anaerobic respiration (FAO, 2013) [12]. Losses can occur at any stage of food production, processing and transportation. Food loss occurs at all steps of post-harvest stages before food is consumed. Food waste whereas exist at consumer scale and food unfit for consumption but having lost its visual appeal is discarded (FAO, 2014) [14]. FAO (2014) [14] reported that post-harvest processing and consumption of fruits and vegetables in the developed parts of China, India, United States of America, and Philippines produce approximately 55 MMT of fruit and vegetable waste (FVW).

Fruit and vegetable waste not only represents loss of edible food but also loss of energy, labour, chemical fertilizers, land, water and bioactive compounds present in the fruits and vegetables. Horticultural by-products are potentially rich source phenols, antioxidants, pigments, dietary fibres, organic acids, minerals, pigments, and other valuable molecules (Sagar *et al*., 2018) [30]. Most of these bioactive compounds have health benefits and are known anti-tumour, anti-microbial properties (Yahia *et al*., 2017) [45]. These bioactive compounds thus have potential applications as nutraceuticals and food additives in food industry. This presents a unique opportunity for its economical and sustainable utilization. Losses from fruit and vegetable waste consists of seeds, unused part, roots, skin, stones, pomace, etc. The loss in fruits and vegetables can range anywhere between 10-70% (Gupta and Joshi, 2000; Almeida *et al*., 2015) [16, 1]. Many fruits and vegetables produce high amount of losses.

50% of fresh weight in citrus fruits is lost during its processing in the form of seeds, skin and peel (Gupta and Joshi, 2000; Macagnan *et al*., 2015; Chau and Huang, 2003) [16, 4, 21]. Mangosteens and jackfruit can have losses as high as 50-75% consisting of rind, seeds, and skin (Saxena *et al*., 2011; Chen *et al*., 2011) [32, 6].

Pectin for commercial food application is extracted mostly from cereal sources are consists of pure fractions only. However, pectin extracted from by-products will contain some amounts of antioxidants, colorants, proteins and other bioactive compounds. These bioactive compounds are set to have additional health benefits and will add to the nutraceutical properties of the dietary fibres (Chantaro *et al*., 2008; Xu *et al*., 2018) [3, 44]. By-products of fruits like apple, citrus fruits, papaya, watermelon and other tropical fruits are especially rich in pectin and have potential for commercial applications. With fruit and vegetable processing rising every year, the amount of this waste is set to rise each passing year and poses potential for extraction of soluble dietary fibres.

Traditional extraction methods involve using chemicals or solvents to lyse/disrupt the cell/tisses to extract bioactive compounds. Such methods include acid extraction, alkali extraction and solvent extraction. Most extraction methods for SDF require high temperature, use of strong acids/alkalis, long incubation time and tend to leave residues in the final product. Such methods also utilize large amounts of chemicals and are not environment friendly (Tiwari, 2015) [37].

Novel alternatives for SDF extraction are Ultrasound assisted extraction (UAE), microwave assisted extraction (MAE), accelerated solvent extraction (ASE), pulse electric field (PEF), high pressure processing and colloidal gas aphrons (CGAs), Ultrasound/microwave assisted extraction (UMAE) and subcritical and supercritical fluid extraction (SFE). These techniques can either be used individually or as pre-treatment or as combined treatment to get maximum yield at minimum cost.

Table 1: Nature of loss and waste from some fruits and vegetables

Crop	Nature of waste	% waste	% TDF	% IDF	% SDF	Reference
Apple	Peel	11	0.91	0.46	0.46	Gupta and Joshi, 2000; Renard and Thibault (1999) [16]
	Pomace		88.5	69.9	69.9	
Banana	Peel	35	50	42.66	7.34	Gupta and Joshi, 2000; Wachirasiri *et al*., 2009 [16, 40]
Citrus	Rag, peel, seeds	50	54.82	29.65	25.17	Gupta and Joshi, 2000; Macagnan *et al*., 2015 [16, 21]
Orange	Rag, peel, seed	50	57	47.6	9.41	Gupta and Joshi, 2000; Chau and Huang, 2003 [16, 4]
Peach	Seed, skin	-	54.5	35.4	19.1	Pagan and Ibarz (1999) [24]
Grapes	Skin, stem, seed	20	77.9	68.4	9.5	Gupta and Joshi, 2000 [16]; Valiente *et al*., 1995 [39]
Guava	Peel, core, seeds	10	48.6	-	-	Gupta and Joshi, 2000 [16]; Sanchez-Zapata *et al*., 2009 [31]
Mango	Peel, stone	45	51.2	32.3	19	Gupta and Joshi, 2000; [16]
Passion fruit	Skin, seeds	45-50	62.65	43.43	19.22	Almeida *et al*., 2015 [1]; Macagnan *et al*., 2015 [21]
Papaya	Rind, seeds	10-20	44.6	-	-	Pavithra *et al*., 2017 [25]
Carrot	Pomace	30-40	63.6	50.1	13.5	Chau *et al*., 2004 [5]; Schieber *et al*., 2001 [33]
Pea	Hulls	-	91.5	87.4	4.1	Ralet *et al*., 1993 [28]
Tomato	Pomace	3-7%	50	25	25	Del Valle *et al*., 2006 [10]; Schieber *et al*., 2001 [33]

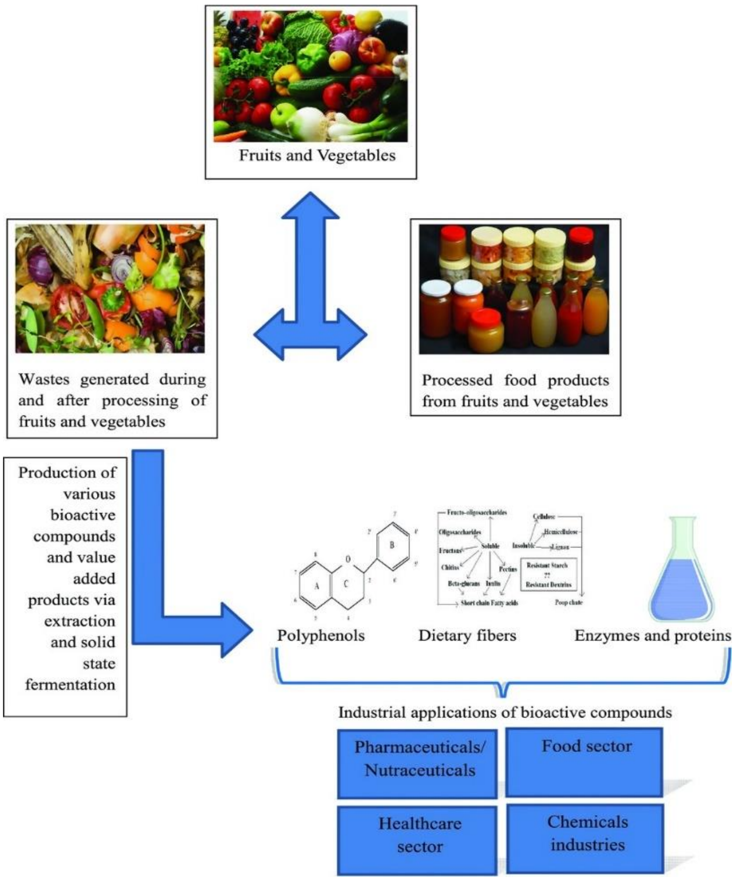

Fig 1: Graphical illustration of fruit and vegetable waste (Sagar *et al*., 2018) [30].

2. Dietary fibres and pectin

Dietary fibres are defined as non-digestible carbohydrates and lignin that are components of plant including the non-digestible carbohydrates that have a beneficial effect on human body (CAC, 2009). The soluble portion of the dietary fibre, SDF consisting of pectins, gums and mucilage have functional properties and therefore can be added in food products to enhance their functional and sensory properties. Pectic substances are a complex group of polysaccharides with repeating D-galacturonic acid units. They are found in intercellular spaces and are structural component of plant cell walls. Pectins are water soluble, form gels, and are metabolized by intestinal microflora. They have hypoglycemic properties since they decrease the rate of gastric emptying and decrease the small intestinal time (Jenkins *et al*., 1978) [18]. D-galacturonic acid, an isomer of D-galacuronic acid, is present in three polymeric forms in pectin, ie., homogalacturonan, rhamnogalacturnan-I and rhamnogalacturnan-II. Homogalacturonan, is the linear chain polymer of α-1-4 linked galacturonic acid and is most abundant pectic polysaccharide in plant cell walls.

The technological functionality of pectin depends on its physiochemical parameters. Degree of methyl esterification refers to the percentage of methylated C-6 atoms of galacturonic acid in its main chain (Wang *et al*., 2015) [43]. Pectin can be divided into 2 categories based on degree of esterification, high methoxyl pectin with 50% or more degree of esterification and low methoxyl pectin with less than 50% degree of esterification. Degree of esterification is also related to water holding capacity and oil holding capacity and sorption properties of pectin (Bochek *et al*., 2001) [2]. Galacturonic acid content indicates the purity of pectin and its commercial quality (Pereira *et al*., 2016) [26]. Molecular weight and size of pectin influences its viscosity (Polanco-Lugo *et al*., 2019) [27]. All physiochemical properties of pectin in turn are influences by the methods of extraction (Li *et al*., 2014) [20].

3. Extraction of soluble dietary fibres from fruit waste

Complex molecules like pectin are generally embedded in the cell matrix and rely on cell rupture for their successful extraction. The objective of extraction method is to purify and maximize the yield of target compound without causing contamination or effecting the compound’s properties. Conventional extraction method utilise mineral acids for extraction of pectin. These acids are cost-effective but not environmentally friendly and can degrade compounds being extraction. They also cause loss of volatile compounds (Marić *et al*., 2018) [22]. Organic acids are an alternative to mineral acids. Xu *et al*. (2018) [44] employed various organic and mineral acids in maintaining the pH during conventional heating extraction. The acids used were hydrochloric acid, nitric acid, sulphuric acid, lactic acid, citric acid and tartaric acid. Citric acid was most effective in getting the highest yield of pectin (17.9%) as compare to hydrochloric acid (17.2%), lactic acid (12%), nitric acid (11.8%), sulphuric acid (10.22%) and tartaric acid (9.76%). Citric acid has lower degradation effect on the pectin being extracted since it is less hydrolysing and has a less dissociation constant. Additionally, it is environmentally friendly and easier to remove from the final product.

Among novel extraction methods of pectin, microwave assisted extraction and ultrasound assisted extraction are the most popular. Microwave energy is transferred to the water in the sample by the means of dipole rotation and ionic conduction. The radiation frequency corresponds to the spin leading to energy re-distribution among molecules. This causes the cell contents to heat up and cell lysis, releasing its contents (Wang and Weller, 2006) [42]. Ultrasound on the other hand rely on high frequency acoustic waves to rupture the cell. Ultrasound waves, when propagated through medium, causes compressions and rarefactions leading to pressure changes. Pressure changes leads to formation of cavity bubble and finally cell rupture (Tiwari, 2015) [37]. Both these techniques are energy efficient when compared to conventional methods of extraction. They also lead to higher yield of final product, reduce the extraction time and don’t contaminate the environment or the final product (Li *et al*., 2014; di Oliviera *et al*., 2016a) [20, 8]. Enzymatic extraction is another non-toxic approach for pectin extraction. Enzymatic reactions degrade the plant cell walls to release cell components and increase cell permeability (Marić *et al*., 2018) [22]. Enzymatic extraction depends on extraction time, pH, temperature and enzyme concentration.

Li *et al*. (2014) [20] compared acid assisted extraction (AAE), microwave assisted extraction (MAE), ultrasound assisted extraction (UAE), and enzymatic extraction (EE) (cellulase from *Aspergillus niger*). The pectin yield was 10.3% from AAE, 16.4% from UAE, 14.9% from MAE and 18.7% from EE. The time taken for extraction was however drastically improved by MAE (2 min irradiation) as compared to UAE (40 min sonication) and EE (3 hrs of enzymatic treatment). Pectin extracted using EE had the highest water holding capacity, oil holding capacity and swelling power followed by UAE, MAE and AAE. di Oliviera *et al*. (2016a) [8] used ultrasound assisted extraction (UAE) to extract pectin from passion fruit peel and compared the process with conventional heating extraction. Conventional heating extraction gave a yield of 7.92% whereas the yield by UAE was12.67%. UAE extracted pectin also had higher degree of esterification (60.36%) and higher galacturonic acid content (66.65%). Polanco-Lugo *et al*. (2019) [27] extracted pectin from tangerine and grapefruit peel powder using CHE and UAE. UAE gave higher yield of pectin (24.08 to 26.05% for tangerine and 10.06% to 13.46% for grapefruit) than CHE. However, pectin extracted using CHE had higher degree of esterification, galacturonic acid content and molecular for both grapefruit and tangerine pectin. CHE extracted pectin from both fruits also had higher water holding capacity, oil holding capacity and intrinsic viscosity than UAE extracted pectin.

Wang *et al*. (2015) [43] extracted pectin from grapefruit peel using conventional heating extraction (CHE) and UAE. The use of ultrasound for extraction provided 16.34% higher yield, lowered the required heating temperature by 13.33°C and 33.33% less time was required for extraction. The pectin extracted using UAE also had better colour, more loosen microstructure, lower viscosity, molecular weight and degree of esterification, and had higher degree of branching and purity than CHE extracted pectin. Su *et al*. (2019) [35] compared pectin extraction using CHE and MAE and surfactant-microwave assisted extraction (S-MAE). Using microwave shortened the extraction time from 3 hrs to 7 minutes. The pectin yield increased with increase in microwave power (from 160 to 400W). Between CHE and MAE, pectin yield was higher while using MAE (27.5% to 29.9%) and the pectin thus extracted has high degree of esterification with better product quality. Addition of tween-20 (8g/L) in S-MAE in the extraction medium further increased the pectin yield by 17% (32.8% pectin yield) and the pectin thus obtained had 69.8% degree of esterification with 78.1% galacturonic acid content and was of highest quality. Jiang *et al*. (2012) [19] extracted pectin from seeds watermelon peel using CHE and MAE. MAE resulted in higher pectin yield (17.6 to 19.6%) as compared to conventional heating extraction. The pectin extracted using MAE also had higher degree of esterification (44.3-48.7%), higher molecular weight (143400-154300) and lower content of galacturonic acid content (74.6-76.1%).

Xu *et al*. (2018) [44] employed a combined ultrasound-microwave assisted extraction (U-MAE) for extraction of pectin from jackfruit peel. Pectin was also extracted using the conventional heating methods for comparison. Citric acid was used instead of inorganic acids to maintain the pH to make the whole process sustainable with production of less toxic waste. U-MAE showed decreased extraction time (2 hrs to 30 min) and higher yield (21.55) than conventional extraction process (17.5%). The pectin extracted using U-MAE has higher antioxidant activity as well. Di Oliviera *et al*. (2016b) [9] evaluated the combined effect of high-pressure and conventional heating on pectin extraction. Extraction yield was doubled (7.4 to 13.34%) using high-pressure as pre-treatment. The process parameters were 20 minutes holding time at 50 °C, 2 pH, solid/liquid ratio of 1:30 and 300MPa pressure. The pectin thus extracted had 50% higher degree of esterification and 65% higher galacturonic acid content.

Table 2: Laboratory scale extraction methods for dietary fibres from waste

Sample	Kind of DF	Extraction method	Extraction parameters					Yield %	Reference
			pH	Temp (°C)	Time	Solvent	Solute/ solvent ratio		
Apple pomace	Pectin	Acid assisted extraction	2	80	4 hrs	Water	1:20	10.3	Li *et al*., 2014 [20]
		Microwave assisted extraction (550 W)	2	80	2 min	Water	1:20	14.9	
		Ultrasound assisted extraction (400W)	2	80±2	40 min	Water	1:20	16.4	
		Cellulase assisted extraction	4.5	50	3 hrs	Water	4% pomace	18.7	
Passion fruit peel	Pectin	Ultrasound assisted extraction (664W)	2	85	10 min	Water	1:30	12.67	di Oliviera *et al*., 2016a [8]
		Acid assisted extraction	2	85	10 min	Water	1:30	7.92	
Tangerine peel powder	Pectin	Ultrasound assisted extraction (130W, 20Khz)	2.5	80	30 min	Water	1:30	26.05	Polanco-Lugo *et al*., 2019 [27]
		Conventional heating extraction	2.5	80	90	Water	1:30	24.08	
Grapefruit peel powder		Ultrasound assisted extraction (130W, 20KHz)	2.5	80	15 min	Water	1:30	13.46	
		Conventional heating extraction	2.5	80	90	Water	1:30	10.06	
Grapefruit peel	Pectin	Ultrasound assisted heating extraction ($12.53W/cm^2$)	1.5	66.71	27.95 min	Water	1:50	27.34	Wang *et al*., 2015 [43]
		Conventional heating extraction	1.5	80.01	90 min	Water	1:50	11	
Orange peel powder	Pectin	Heating extraction	1.0	90	3 hrs	Water	30%	27.5	Su *et al*., 2019 [35]
		Microwave assisted extraction (400W)	1.5	-	7 min	Water	25%	29.9	
		Surfactant-microwave assisted extraction (400W; tween-20, 8g/L)	1.5	-	7 min	Water	25%	32.8	
Jackfruit peel	Pectin	Conventional heating extraction	2	90	2 hrs	Water	1:30	17.9	Xu *et al*., 2018 [44]
		Ultrasound-microwave assisted extraction	2	86	29 min	Water	1:48	21.5	
Seed watermelon peel	Pectin	Conventional heating extraction	1	90	2 hrs	Water	1:20	17.6	Jiang *et al*., 2012 [19]
		Microwave heating extraction (500W)	1.5	-	7 min	Water	1:20	19.6	

4. Addition in food products

Pectin as a dietary fibre have numerous health benefits as they increase satiety, control glycaemic index, reduce the risk of heart diseases, alleviates constipation and reduce the risk of metabolic syndromes and diabetes depending on the type of soluble fibre present in food (Dhingra *et al*., 2012) [11]. Therefore, addition of pectin in food will create functional foods. Beverages and foods can also be formulated for people with special needs like meal-replacement, weight-loss, Patients suffering from irritable bowel syndrome. The enrichment of pectin done with pure commercially fibres doesn't have all the health benefits of pectin due to their selective nature. Addition of crude and un-purified pectin from fruit and vegetable processing waste would thus overcome multiple challenges in creating a multi-beneficial functional drinks while tackling the problem of food processing waste.

Addition of pectin in foods can change their texture, consistency behaviour and sensory characteristics. They can also be a fat substitute in baked goods owing to their high oil holding capacity and thus the product contained less fat without loss of taste (Martin, 1999) [23]. Addition of soluble dietary fibres to pasta, biscuits, cakes, noodles and cookies have been reported to improve their quality characteristics without loss of taste and enhance nutritional aspects (Hou and Kruk 1998, Sudha *et al*., 2007, Tudorica *et al*., 2002) [17, 36, 38]. Pasta incorporated with dietary fibres exhibited anti-sticking property, was easily extruded and released more glucose on cooking (Tudorica *et al*., 2002) [38]. Soluble dietary fiber incorporated noodles were firmer and easier to rehydrate upon soaking and reheating (Hou and Kruk, 1998) [17] whereas pectin (extracted from apple pomace) incorporated exhibited superior functional characteristics (Sudha *et al*., 2007) [36]. Jam enriched with peach fruit dietary fibre had pseudoplastic behaviour and exhibited better viscosity than industrial pectin at the same concentration (Grigelmo-Miguel and Martina-Belloso, 1999) [23]. Beverages traditionally are deficient in dietary fibres and present a scope for enrichment with pectin. The soluble and dispersible nature of pectin in fruit juice beverages and water increased their viscosity and stability and improves flavour, mouth feel, aftertaste and overall acceptability. However, use of commercially available pure pectin and gums posed the challenge of high viscosity and thus unpalatability at higher levels (Wang and Troup, 1999; Stillman 2001) [41, 34].

5. Conclusion

Fruit processing waste generates huge amount of wastes and currently its use is limited. The major problems in its use are collection, sorting and technology needed for economical industrial use. Soluble dietary fibres like pectin have wide scope of application in food products as their addition led to superior quality food products. They improve the quality of bakery products, extruded products and drinks with respect to their texture, water holding capacity and increase their shelf-life. The extraction and utilisation of pectin from fruit waste can lead to generation of profits and also address hunger and malnutrition. Pectin extracted using novel extraction techniques (UAE, MAE, high-pressure extraction) is of commercial quality with respect to their degree of esterification and galacturonic acid content, water and oil holding capacity, swelling power and can generate profits. The way forward is to develop step by step biorefinery for extraction of pectin and different bioactives from wastes using green technologies. Valorisation of fruit waste is step towards sustainable and circular economy having zero-waste.

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