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Review Paper

Effect of Pre-treatments on Extraction Yield and Quality of Fruit Pectin: A Review

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ABSTRACT

Fruit waste is an abundant and underutilized agricultural waste. It is a good source of pectin, a valuable polysaccharide with wide-ranging applications in the food, pharmaceutical, and industrial sectors. However, the complex structure of the plant cell wall and the existence of additional impurities make it difficult to extract pectin from fruit waste. Pre-treatment methods can be used to enhance pectin extraction by disrupting the cell wall and releasing the pectin molecules. Various pre-treatment methods have been investigated for pectin extraction from jackfruit waste. The maturity stages of fruit also affect the pectin yield. Therefore, this paper aims to provide a brief review of the pectin content present in various fruit parts, the effect of fruit maturity on the yield of pectin, and pre-treatment on parts of fruit given by various researchers, which helps to enhance the Quality and yield of pectin.

Keywords: Fruit parts, pectin, pre-treatment, yield

In 1825, a French scientist named Henry Braconnot identified and isolated pectin for the first time. D-galacturonic acid and α-(1-4) glycosidic links are the main components of pectin (Van Buren, 1991). Pectin is a complex mixture of homogalacturonic acid blocks termed "smooth regions" and blocks of homogalacturonic acid containing several neutral sugars, such as rhamnose, galactose, arabinose, and glucose, termed "hairy regions," that are found in the structure of plants (IPPA, 2001).

Pectin derived from by-products will include trace levels of proteins, colorants, antioxidants, and other bioactive substances. These bioactive substances are expected to have further health advantages and enhance the dietary fibers' nutraceutical qualities (Chantaro *et al.* 2008; Xu, *et al.* 2018). Fruit by-products with a high pectin content, such as apples, citrus fruits, papayas, watermelons, and other tropical fruits, may find use in industry. Fruit and vegetable processing produces an increasing amount of waste, which is expected to grow annually and present an opportunity for the extraction of soluble dietary fibers (Dalal *et al.* 2019).

Pectin is utilized in the production of preserves, jams, jellies, and other products. It can also be used as a

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texturizing agent in fruit-flavoured milk desserts and as a thickening ingredient for sauces, ketchups, and flavoured syrups. In addition, it has several uses in cosmetics, pastes, pharmacological preparations, etc. It can also be used to glaze candied fruit and boost the foaming strength of gasses in water. It is also employed as an emulsifying agent in the production of goods like cod liver oil, ice cream, etc. (GITCO, 1999). Pectin is produced commercially from sugar beet (less than 1%), apple pomace (14%), and citrus peels (85%) (Wang, 2018).

Sources of pectin

Although basically all plants contain pectin, citrus fruits like oranges, lemons, grapefruits, and apples are the commercial sources of the pectin (Rascón-Chu, 2009; Masmoudi, 2012). Soft fruits like cherries, grapes, and strawberries have far less pectin than fruits like quince, gooseberries, and plums. Pectin content in dried apple pulp is typically 15–20%, while pectin content in dried citrus peel is 30–35% (Nelson, 1977). According to Srivastava (2011), the normal levels of pectin in fruit such as carrots, apricots, cherries, and oranges are 1.4%, 0.4%, 0.5–3.5%, and 0.4%, respectively, based on fresh weight. The waste material from the processing of grains, fruits, and vegetables. Examples include sunflower head residues, mango waste, amaranth, olive pomace, and sugar beet pulp. Other examples include waste material from the potato starch industry, pumpkin pulp, peach pulp, linseed seeds, cocoa pod husk, papaya seed, nutmeg rind, mangosteen rind, banana peel, passion fruit peel, watermelon rind, etc. become a promising source of pectin (Madhav, 2001; Claudia Lara, 2018).

Industrial Application of Pectin

Pectin is mostly employed as a gelling agent in industry, although it can also be used as a thickener, water binder, and stabilizer. The traditional use is to give jams or marmalades which are normally sweet juices—a jelly-like consistency. Pectin can also be utilized as a fat alternative in baked goods and to stabilize acidic protein beverages like yogurt (Shrivastava, 2011). Pectin has commercial uses outside of the food sector. For example, it has been shown to be effective in gastrointestinal mucoadhesion (Sriamornsak, 2002). Pectin is used by pharmaceutical companies to treat diarrhoea and constipation. It is also used as a demulcent in throat lozenges. Pectin is also utilized in preparations for wound healing, particularly in adhesives employed in medical devices like colostomy kits (Shrivastava, 2011). According to ruminant nutritionists, pectin concentration in forages can improve digestibility and energy concentration (Helene, 2005). Pectin functions as a naturally occurring preventative agent for toxic cation poisoning. It has demonstrated efficacy in eliminating lead and mercury from the respiratory system and gastrointestinal system. Pectin is useful in reducing hemorrhage or local bleeding because it reduces the coagulation time of blood taken when given intravenously (Joseph, 1956). By lowering the fat and salt content, emulsified pectin oils function as a fat substitute to create goods with higher nutritional value. Low-fat mayonnaise, dairy goods, ice cream, and meat items are all made using it (Yang, 2018; Wicker, 2014).

Pectin Production

In 2019, the estimated value of the global pectin market was $1 billion USD (U.S. dollar). The pectin market is expected to develop at a compound yearly growth rate of 6.5% and reach USD 1.8 billion in 2026 (Nadar *et al.* 2022). Citrus peels, including those from lemons, limes, and oranges, account for over 85.5% of the world's current pectin output. Apple pomace comes in second place with 14%, while sugar beet pulp comes in third place with 0.5% (Ciriminna, 2015).

PECTIN CONTENT IN VARIOUS FRUIT PARTS

1. Fruit parts: Here are given pectin content of some fruits and vegetables. The pectin content in various fruits Lemon, sweet orange, apple, grapefruit, carrot, jackfruit, beal, papaya, banana, fig, cocoa, guava, pomegranate, cashew apple, draganfruit, plum, passion fruit, cubio, mangosteen,pineapple, nutmeg,pumello,okra, febabean, sunflower, tomato, linseed is presented in Table 1.

2. Effect of maturity on yield of pectin

Verma, (1965) studied effect of growth and maturity of two varieties of guava (Safeda Alahabad and Red flesh) on yield of pectin. They picked fruits at weekly interval from fruit set to slightly advance stage to maturity. The increase in the total pectin content in Safeda Allahabad range from 0.59% to 1.10% while in Red-Fleshed it ranged from 0.43% to 1.07% Further, there was an abrupt decrease in the total pectin content after attaining the peak. Safeda Allahabad showed higher percentage of pectin than Red-Fleshed.

Prasanna *et al.* (2003) studied the four stages of mango i.e. extreme raw (dark green), raw (light green), moderate ripening (yellowish green), ripe (yellow). They concluded that total pectin content of mango

Table 1: Pectin content in various parts of fruits, vegetables and oilseeds

Fruit/ Vegetables	Peel	Pulp	Pomace	Steam peel	Core	Rags	Leaf	Seed	Pod	Husk/ Hull	Head	Reference
Lemon	13.00 ± 1.06%	22.53 ± 1.95%	—	—	—	—	—	—	—	—	—	Marín *et al.* 2007
Sweet orange	23.02 ± 2.12%	12.07 ± 1.12%	—	—	—	—	—	—	—	—	—	Marín *et al.* 2007
Apple	1.21 – 14.50 %	—	33.50 %	—	—	—	—	—	—	—	—	Kumar *et al.* 2020; Morales-Contreras *et al.* 2020
Grapefruit	21.60 – 28.00%	—	—	—	—	—	—	—	—	—	—	Koubala *et al.* 2008
Carrot		8.7 – 9.10%	—	8.90 – 9.10%	—	—	—	—	—	—	—	Christiaens *et al.* 2015
Jackfruit	29.40 %	—	—	—	14.0 %	9.89% — 11.67%	—	—	—	—	—	Naik *et al.* (2020); Ahmmed *et al.* (2017); Sook Wah, *et al.* 2023; Kumar, *et al.* 2021
Beal	—	16.7%	—	—	—	—	3.4 g/100g	5.8g/ 100g	—	—	—	Maskey, *et al.* 2018; Singh, *et al.* 2012
Papaya	11.11— 49.83%	—	—	—	—	—	—	8.655%	—	—	—	Madhuvanthi, *et al.* 2022; Koubala *et al.* 2014
Banana	11.31%	18.1% – 22.65%	—	—	—	—	—	—	—	—	—	Girma, 2016; Mugampoza, *et al.* 2020
Fig	—	—	—	—	—	—	—	5.25 – 6.07%	—	—	—	Liang *et al.* 2012
Cocoa	42.3%	—	—	—	—	—	—	—	—	8 – 11%	—	Daniel Adomako, 1971; Sarah *et al.* 2018
Guava	—	—	16.59%	—	—	—	—	—	—	—	—	Kamal *et al.* 2023

Fruit/ Vegetables	Peel	Pulp	Pomace	Steam peel	Core	Rags	Leaf	Seed	Pod	Husk/ Hull	Head	Reference
Pomegranate	8.5%	—	—	—	—	—	—	—	—	—	—	Yang *et al.* 2018
Cashew apple	—	—	10.7% to 25.3%	—	—	—	—	—	—	—	—	Yapo *et al.* 2014
Dragon fruit	5.60—26.38%	—	—	—	—	—	—	—	—	—	—	Muhammad *et al.* 2014
Plum	—	—	3.80 – 21.30	—	—	—	—	—	—	—	—	Kosmala *et al.* 2013
Passion fruit	12.67 %	—	—	—	—	—	—	—	—	—	—	de Oliveira *et al.* 2016
Cubiu	14.3%	7.9%	—	—	—	—	—	—	—	—	—	Cristiane, 2017
Mangosteen	71.33%	—	—	—	—	—	—	—	—	—	—	Madhav, 2001.
Pineapple	47.00%	—	—	—	—	—	—	—	—	—	—	Madhav, 2001.
Nutmeg	82.0%	—	—	—	—	—	—	—	—	—	—	Madhav, 2001.
Pumello	49.67%	—	—	—	—	—	—	—	—	—	—	Madhav, 2001.
Okra	—	—	—	—	—	—	—	—	16.70%	—	—	Zhang *et al.*, 2021
Faba bean	—	—	—	—	—	—	—	—	—	15.75 %	—	Mohamed Korish
Sunflower	—	—	—	—	—	—	—	—	—	—	7.40 – 11.60%	Iglesias and Lozano,2004
Tomato	14.90 – 83.50%	—	—	—	—	—	—	—	—	—	—	Grassino *et al.*, 2016
Linseed	—	—	—	—	—	—	—	0.35 – 0.65%	—	—	—	Díaz-Rojas *et al.*, 2004

decreased from 2.0 to 0.7% fresh weight (FW) with progressive ripening.

In 2018, Ornelas-Paz *et al.* examined pectin during ripening and development. In this study, ripening and developmental phases of 'Golden Delicious' apples were harvested at 107, 122, 137, 152, and 167 days after full bloom (DAFB). The yield was gravimetrically calculated and expressed as % (dried weight basis).

The physical, chemical, and functional characteristics of pectin that were isolated from the edible parts of jackfruit at various stages of maturity were investigated by Nidhina *et al.* 2023. They discovered that when the fruit became older, the production of jackfruit pectin increased from 9.7% to 21.5%. The four stages of jackfruit-Stage I (0-3 weeks), Stage II (4-7 weeks), Stage III (7-12 weeks), and Stage IV (13-17 weeks)-were examined by Nidhina *et al.* 2023. They found that the functional properties of jackfruit pectin were similar or better than those reported for commercial apple pectin.

Azad *et al.* (2014) reported that yield of pectin decrease with increase in maturity stages of lemon. They were extracted pectin from lemon pomace at premature, mature and over ripen stage. Pectin extracted with distilled water showed high yield and low ash content as compared to other solvents. On the other hand, the premature stage of lemon gave the highest yield. The result shown that lemon pomace is good source of pectin at domestic as well as commercial level.

Yuliarti *et al.* (2014) extracted pectin from kiwifruit at two different maturity level i.e. early harvested fruit (12 week after pollination) and main harvested fruit (8 week less mature than main harvested fruit). Pectin was extracted from puree including seeds and skin. Fruit maturity and the extraction method had significant effects on the yield of pectin.

Extraction of pectin from different maturity level of peach fruit was done by Fishman *et al.* (1993). The peaches of two variety i.e., Suncling and Redskin were harvested at 20, 21, and 22 weeks after flowering (WAF), and extracted pectin into two form i.e., alkaline-soluble pectin (ASP) and chelate-soluble pectin (CSP). Result shown that markedly dropped in pectin content with increase in maturity of redskin variety of peach.

Agbenorhevi *et al.* (2020) extracted pectin from okra pods were harvested at different ages (5-19 days) after flowering (immature, intermediate and overgrown). The results showed that okra pod at 14-15 days after flowering produced the highest pectin yield and okra pod harvested after 18-19 days of maturity had the low yield of pectin. Thus, pectin yield increased from the early maturity, and highest at 14-15 days and then decreased after overgrown. Table 2 summarizes variations in the pectin yield of various fruits (Guava, Apple, Jackfruit, Lemon, Kiwi, Peach) and vegetable (okra) at different maturity level.

VARIOUS PRE-TREATMENT FOR PECTIN EXTRACTION:

1. Blanching

Blanching is a unit operation prior to freezing, canning, or drying in which fruits or vegetables are heated for the purpose of inactivating enzymes, modifying texture, preserving colour, flavour, and nutritional value and removing trapped air. Hot water blanching and steam blanching are the most commonly used methods, but microwave and hot gas blanching have also been studied. It also helps to cleanse the surface of food, brightens the colour, retard loss of vitamins, soften vegetables and make

Table 2: Pectin yield at various maturity level

Pectin Content in Different Fruit at Different Maturity Level

1. Guava

Duration	Variety	1st week	2nd week	3rd week	4th week	5th week	6th week	7th week	8th week	9th week	References
Pectin content %	Safeda Alahabad	0.59	0.64	0.68	0.77	0.71	1.09	1.04	1.10	0.69	Verma, 1965
	Red flesh	0.43	0.57	0.60	0.62	0.72	0.64	1.01	1.07	0.55	

2. Golden Apple

DAFB	107	122	137	152	167	References
Pectin content %	13.5±0.2	12.3 ± 0.2	13.2 ± 0.3	12.5 ± 0.2	8.8 ± 0.0	Ornelas-Paz, *et al.* 2018

3. Jackfruit

Maturity	Stage-I	Stage-II	Stage-III	Stage-IV	References
Pectin Content %	9.7 ± 0.2	16.1 ± 0.2	16.5 ± 0.2	21.5 ± 0.5	Nidhina *et al.* 2023

4. Lemon

Maturity	Pre-mature	Mature	Over ripen	References
Pectin Content %	13.13±0.17	10.83±0.02	10.33±0.15	Azad, *et al.* 2014

5. Kiwifruit

Maturity	Extraction Method	Yield%	References
Early harvested	Acid	1.43	Yuliarti, *et al.* 2015
	Water enzymes	1.01-2.14	
Main Harvested	Acid	3.27	
	Water enzymes	3.27-4.39	

6. Peach			
WAF Weeks after flowering	Pectin yield % **CSP** Chelate-soluble pectin	**ASP** Alkaline-soluble pectin	Fishman *et al.* 1993
Suncling			
20	11.0 ± 4.9	13.7 ± 2.3	
21	11.8 ± 5.0	13.8 ± 2.3	
22	11.5 ± 3.1	17.2 ± 4.6	
Redskin			
20	11.0 ±2.7	17.1 ± 2.5	
21	12.1 ± 3.2	14.1 ± 3.8	
22	6.9 ± 1.8	9.4 ± 2.5	

7. Okra				
Maturity	**Immature**	**Intermediate**	**Overgrown**	Agbenorhevi *et al.* 2020
Pectin yield %	16.82 ± 1.95	17.65 ± 3.33	8.97 ± 0.69	

them easier to pack (Praveena, 2015). In case of pectin extraction substantial losses in yield as well as Quality of pectin were observed during drying of pomace. However, these losses were reduced when drying was preceded by blanching. Since drying is necessary to facilitate raw material handling, blanching of pomace prior to drying was optimized as a pre-treatment before pectin extraction (Sharma *et al.* 2014). Blanching treatment before drying is an effective method for shortening the drying time (Wang *et al.* 2021). Blanching treatment is usually conducted using hot water at temperatures above 80 ◦C, and the primary objective is to inactivate enzymes that deteriorate products during processing and storage (Imaizumi *et al.* 2017). In addition, this treatment improves the drying time because the cell membranes break and the moisture-moving rate is enhanced (Ando *et al.* 2016; Arevalo-Pinedo & Murr, 2006). However, blanching treatment degrades pectin and changes the tissue structures in fruits. The tissue structure contributes to texture and is an important determinant of the Quality of dried fruits. Fig. 1 shows the effect of blanching on pectin extraction. According to Geerkens *et al.* (2015) Blanching is a vital step in recovering premium quality mango pectin because it makes it possible to remove all of the pulp from the peels, resulting in an increase in pulp production and pectin purity. LO *et al.* (2002) studied Blanching Effects on the Chemical Composition and the Cellular Distribution of Pectins in Carrots. After study they were concluded that During blanching, the right balance of time and temperature is essential. Blanching changed the chemical composition of pectic substances such as the galacturonicacid backbone, the side chains of neutral sugars, and the methylatedpectins.

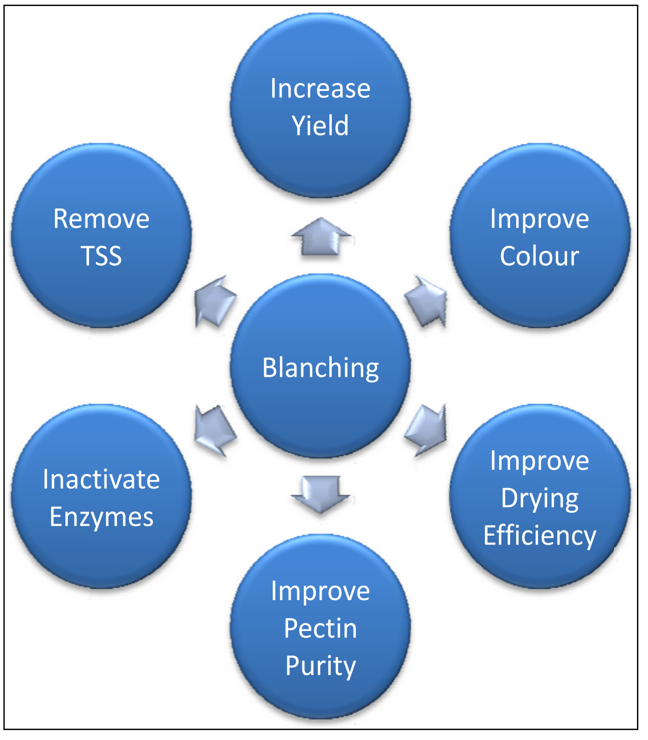

Fig. 1: Effect of Blanching for Pectin Extraction

Carrots subjected to high-temperature short-time (HTST) blanching were more similar in chemical composition to raw-carrots than Long time at low temperature (LTLT)-blanched carrots. The findings of this study support previous research showing that HTST is the best blanching treatment to preserve cell structure. Levi *et al.* (1988) stated that adequate blanching would improve some quality characteristics of the dry product, facilitating water removal and inactivating undesirable enzymes. They studied that with increase in blanching time from 0 to 5 min pectin yield increases 1780 to 2628 mg/100g dry matter. Sharma *et al.* (2014) optimised the method of pectin extraction from apple pomace, they concluded that Proper blanching would help remove water and inactivate unwanted enzymes, improving some of the dry product's quality attributes.

Drying

In pre-treatment of pectin extraction drying is a critical step which can affect the Quality of pectin. Many studies have reported the effects of different drying conditions on structural and functional properties of pectin (Huang *et al.* 2017). Few studies have examined the influence of drying pre-treatment methods on the properties of the extracted pectin. There are many methods of drying of raw material for extraction of pectin such as sun drying, solar drying, lyophilisation, subcritical dimethyl ether dewatering technology, convective hot air dryer. Table 3 shows the effect of drying method on yield of pectin which is given table 3.

3. Superfine grinding of the raw material

Raw material grinding is a common process before pectin extraction. The increased material surface effectively facilitated extraction yield of pectin in shortened time. Normal grinding usually produced the solid particles of 1–100 μm. In contrast, superfine grinding, as a clean physical processing, can crush materials to smaller particles of 0.1–1 μm (Zhao *et al.* 2009). Physic-chemical properties and bioactivity of polysaccharides can be affected by the superfine grinding treatment (Zhang *et al.* 2014). Jing Tan investigated that effect of superfine grinding of raw material on sunflower head pectin extraction. It was found that a high pectin yield (14.5 ± 0.36%) was achieved under mild conditions (25 °C, pH 5.0), with superfine grinding.

4. Microwave pre-treatment

Kratchanova *et al.* (1994) reported as The pre-treatment of fresh fruit waste using microwave heating ensured a better extraction of pectin, resulting in an increase in the yield of pectin from 10 to 50 %.

5. Ultrasonic pre-treatment

This non-thermal pre-treatment affects the cell wall of the raw material, and promotes the interaction between the substrate and the solvent by generating cavitation in the mixed solution (Zhang *et al.* 2020), finally increasing the mass transfer coefficient (Xu *et al.* 2015). The cavitation effect includes a high temperature and local pressure, turbulence in the fluid, high stress near the air bubble and micro jets near the solid surface, which affect the raw material and result in the facility of the extraction process (Gogate *et al.* 2011). The maximum yield of pectin (19.08%±0.5) was achieved using pre-treatment for 20 min and a power of 300Wbefore the microwave-assisted extraction (at 500 W for 5 min). Abou-Elseoud, *et al.* (2021) report that ultrasonic pre-treatment is highly effective for boosting the yield of isolated pectin (sugar beet pulp). An hour was all it took to complete the 84–92% increase in pectin output that comes from ultrasonic pre-treatment for 15–45 minutes. A

Table 3: Effect of drying methods on yield of pectin

Method of drying	Fresh fruit	Lyophilisation	Sun drying	Subcritical dimethyl ether dewatering technology	Reference
Yield %	6.09 ± 0.51	10.49 ± 0.23	7.59 ± 0.78	6.05 ± 0.42	Zhao *et al.* (2019)

2 hour enzymatic treatment combined with a 15–45 minute ultrasonic pre-treatment produced a 67-95% pectin yield. After a four-hour enzymatic treatment, a significant 15–45 minute ultrasonic pre-treatment produced a yield of 2–16% pectin. The Effect of Ultrasound Pre-treatment on Pectin Extraction from Watermelon Rind was researched by Forouhar, *et al.* in 2023. They discovered that, when using microwave-assisted extraction, microwave-assisted extraction with ultrasonic pre-treatment (MAUPE) can greatly boost the extraction yield and that, in comparison to ultrasonic power, pre-treatment time has a larger impact on pectin production. Before the microwave-assisted extraction (at 500 W for 5 min), a pre-treatment lasting 20 min at a power of 300 W produced the maximum yield of pectin (19.08%–0.5).

METHODS OF PECTIN EXTRACTION

1. Ultrasound assisted extraction

According to de Oliveira (2016), it is a novel, environmentally friendly, and clean extraction method for a variety of compounds and biomaterials, including 48 bioactive chemicals, proteins, peptides, essential oils, and polysaccharides. Target chemicals are extracted from different plant matrices using a technique called ultrasound-assisted extraction, which combines solvents and sonic energy. One of the advantages of this technique is the improvement of mass transfer due to the acoustic cavitation generated in a liquid media (Wang *et al.* 2015). As pectin is a soluble fiber found in plant cell walls, cavitation and cell rupture brought on by ultrasonic waves may improve the extraction of pectin by increasing mass transfer from the solid matrix to the solvent (de Oliveira 2016). The acoustic cavitation effect of ultrasound can increase the porosity and looseness of the matrix structure in a liquid system, hence enhancing the solvent-matrix surface contact. As a result, targeted chemicals are liberated from their matrices through the disruption of cellular tissues or increased solvent penetration into cellular components (Toma, 2001; Lott, 1963). Pectin is sticky, but unlike tiny molecular fragments, High viscosity is encouraged in some areas of the matrix by the improved swelling effect that coincides with the acoustic cavitation effect for pectin release.

2. Enzyme-assisted extraction (EAE)

Enzyme-assisted extraction is one technique regarded as the potential cure for the unintentional but necessary presence of trace chemical solvents in products from solvent-based extraction methods, among other benefits (Puri *et al.* 2012). In a manner that is not practical with acid-based hydrolysis, enzymes can catalyze processes like hydrolysis with a high degree of selectivity, which either lowers the amount of solvent or chemical required or increases yield for the same amount of solvent (Puri *et al.* 2012). The cellulose/xyloglucan network is implanted in a matrix of pectin along with a protein network. The plant cell wall is composed of an entangled network of polysaccharides, including cellulose, hemicellulose (like xyloglucan), pectin, and protein, with demonstrated interactions between them (Fissore *et al.* 2009; Panouille, Thibault, & Bonnin, 2006). A distinction is possible between two approaches to EAE of pectin, namely: (i) employing enzymes that break down pectin and aid in separating pectin fragments, such as galacturonic acid; and (ii) employing enzymes that have the ability to break down plant cell walls and separate pectin (Panouill *et al.* 2006). Although this latter method is more prevalent, there are also instances of the former in the research conducted by Zhao *et al.* (2015), who examined the de-esterification of commercial high-methoxyl pectin into low-methoxyl through the combined use of the enzyme pectin methyl esterase (PME) and high hydrostatic pressure (HHP). According to Zykwinska *et al.* (2008), low methoxyl pectin was produced from an otherwise high methoxyl pectin source when PME was directly added to the EAE process together with cellulases and proteases.In terms of energy usage and waste management, enzymatic pectin extraction appears to be more beneficial. The enzymatic process is often conducted at temperatures of approximately 50°C and a pH of 3-5, which is more advantageous for the environment and economy. Moreover, waste neutralization is not required because the process's pH is far higher than it would be with a conventional acid-based technique. Two researchers are working on the enzymatic pectin extraction procedure (Dominiak, 2014).

3. Subcritical water extraction (SWE)

Subcritical water is liquid at high pressure and can reach temperatures over its typical boiling point without changing phases. When such water is used as a solvent in extraction, the process is referred to as subcritical water extraction (SWE), which is also referred to as superheated water extraction (SHWE) and pressurized hot water extraction (PHWE) (Zakaria & Kamal, 2015). Many physical benefits, including high diffusion, low viscosity, low surface tension, enhanced vapor pressures, and a higher mass transfer rate, are brought about by the increasing temperature of water. Additionally, under these circumstances, the physicochemical characteristics of subcritical water, such as its dielectric and solubility, are substantially altered (Azmir *et al.* 2013; Zakaria & Kamal, 2015). It is feasible to extract both ionic and non-ionic chemicals from water because of its dielectric constant, which is around 79 at 25 ºC, 43 at 160 ºC, and 33 at 200 ºC (Brunner, 2009; Chen, Fu, & Luo, 2015; Ueno, Tanaka, Hosino, Sasaki, & Goto, 2008). This method can convert the batch pectin extraction process into a continuous or semi-continuous one because a SWE system's subcritical water has a flow rate. In a SWE module, flow rates between 2.1 and 7.0 ml/min were examined. It was discovered that a haphazard flow regime was caused by reduced vessel pressure (Ueno *et al.* 2008). Yet SWE of pectin is also done in batches, in which case the S/L ratio becomes important (Wang, Chen, & Lu, 2014) Some studies have recently begun to develop SWE procedures for pectin derived from different plant matrices. To extract pectin from Citrus junos flavedo, Ueno *et al.*, (2008) compared SWE with the traditional hot hydrochloric acid extraction method. The enhanced solubility of pectin in water was discovered to be caused by the high temperature, which resulted in a decreased dielectric constant of the solvent.

4. Microwave-assisted extraction (MAE)

Microwaves are electromagnetic waves that have frequencies between 300 MHz and 300 GHz (Basak *et al.* 2013). According to Menendez *et al.* (2015), the alternating magnetic field that makes up the microwave field causes molecules' polarity to shift from their initial random thermal motion in accordance with the direction in which the electric field is oriented. Due to its fast heating rates, more uniform heating, shorter cooking times, convenience of use, safe handling, and low maintenance requirements, microwave heating has become more and more popular in the food processing industry (Salazar-Gonzalez *et al.* 2011; Zhang *et al.* 2006). Furthermore, when compared to conventional heating during the cooking or reheating process, microwave heating minimizes changes in food's flavor and nutritional quality (Vadivambal and Jayas, 2010). According to Shrivastava and Malviya (2011), the most popular techniques for extracting pectin are direct boiling and microwave extraction. Direct boiling is the traditional process, and it takes at least two hours to get a good yield.

In comparison, microwave extraction takes around 15 minutes and produces a superior yield. According to Srivastava and Malviya's (2011) review of pectin sources, extraction, and applications in the pharmaceutical industry, high pressure inside a material builds up during microwave heating, changing the physical characteristics of plant tissues by disrupting cell structure and enhancing the capillary porous structure of the tissues. This speeds up the extraction solvent's rate of tissue penetration and pectin extraction.

5. Acid extraction

Strong mineral acid solutions are used to extract pectin; ideal parameters are pH 1-3, temperature 80–100 ◦C, and 0.5–6 hours of continuous agitation. Pectin is released as a result of the dissociation of numerous intricate cross-linked networks in the cell wall caused by acid hydrolysis. According to Cui *et al.* (2021), pectin yield is influenced by the kind of acid, extraction temperature, liquid-solid ratio, extraction time, and acid concentration. The most popular technique for obtaining commercial pectin is acid extraction, however, it degrades the neutral side chain (Levigne, Ralet, & Thibault, 2002). Because of its ease of use and convenience, the acid extraction method is frequently employed in the food sector to extract pectin. According to a number of studies, the yield, structure, and physicochemical characteristics of pectin might vary depending on which acid extractant is used (Chan & Choo, 2013; Ma *et al.* 2013). HCl, H_2SO_4, HNO_3, citric acid, and acetic acid are the most commonly utilized acids in this process of pectin extraction. Research by Kumar and Chauhan (2010) and Kermani *et al.* (2014) demonstrated that citric acid can extract higher pectin contents than HCl or H2SO4. Citric acid's chelating property allowed for the extraction of more chelator-soluble pectin fractions, which resulted in significantly higher extraction yields than those of other acids without chelating properties. Conversely, acetic acid extraction had the lowest yield (4.08%).

6. High pressure extraction

HPE uses high pressure for the extraction of bioactive compounds from plant sources. Principally, HPE consists of three stages. One for an instant boost of pressure, the second for maintenance of pressure, and the third for pressure release (Huang, Hsu, Yang, & Wang, 2013; Jolie *et al.* 2012). The pressure boost stage, a fluid pressure of 100-1000 MPa is applied to the plant product at room temperature. The pressure is subsequently increased within a short period. This high pressure disrupts the plant tissues and cells, enhancing the mass transfer of surrounding solvents into the plant materials.

HPE technique involves an instant compression and decompression of plant materials, altering their molecular and physical properties, causing a high extraction rate and efficiency. The extraction by HPE involves simple, easily operable mechanical equipment having a higher safety and faster extraction. Since HPE uses room temperature and no thermal energy, it extracts the biological compounds in their natural state with a high level of bioactive potential and chemical solubility

The primary cell wall structure is partially disintegrated under high pressure and helps in recovering the phytochemicals without destroying it. An extraction pressure of 250–550 Mpa could change the molecular weight of extracted pectin (Peng *et al.* 2016). Xie *et al.* (2018) extracted the pectin's from potato peel by using high hydrostatic pressure and high-pressure homogenization of 200 Mpa for 5 min. Pectin's extracted under high-pressure results in increased galacturonic acid content as well as a lower degree of esterification. High hydrostatic pressure significantly affects the rheology and viscosity of extracted pectin. Pectin obtained through high-pressure enzymatic extraction had better viscosity and gelling ability, probably due to its high methoxyl content (Zhao *et al.* 2015).

CONCLUSION

Pectin can extracted from many fruit parts such as peel, core, rind, pomace, etc., and many vegetables also. Pectin extraction methods have been explored for various fruit wastes, with various methods achieving different pectin yields. Various pre-treatments apply for the extraction of pectin. Pre-treatment is used to increase the extraction yield of pectin. The maturity stage of fruit also affects the pectin content. Pectin yield depends on various factors, such as pH, temperature, extraction time, types of acid used, and the nature of the pectin source.

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