Review Article

Comprehensive review on ultrasound and microwave extraction of pectin from agro-industrial wastes

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ABSTRACT

Food additives are substances added to food to preserve flavor or enhance its taste, appearance, or other qualities. Food wastage and its accumulation are becoming a critical problem around the globe due to the continuous increase in the world population. The exponential growth in food waste is imposing serious threats to our society such as environmental pollution, health risk, and scarcity of dumping land. Food waste is a rich source of essential components such as protein, carbohydrate, oil, mineral, and fat that can be converted to many value-added products. In conclusion, there is a necessity of eco-friendly technologies to develop and utilize agro-industrial wastes as a powerful source of alternative food products or food additives such as pectin, starch, protein, and cellulose and as well as of proper methods of food waste management that can prevent it.

KEY WORDS: Food additives, Microwave extraction, Pectin, Ultrasound extraction, Waste utilization

INTRODUCTION

"There is no question that Earth is a giving planet. "Nature," in the broadest sense, is the natural, physical, or universe. The study of nature is a large part of science. Even if humans are part of nature, human activity is often understood as a separate category from other natural phenomena. Speaking in terms of the entire human history, nature has always provided for all of man's needs. Only in the past few centuries has man started to produce things he could not find in nature, but nature is still the great nurturer, even if we have lost our connection to it and responsiveness of it. Earth offers us so many gifts, from obvious ones such as food, water, and materials, and to less obvious ones such as art, motivation, spirituality, and beauty. Here, we explore the benefits of each of these gifts we are given freely."

WATER

It is hard to believe that there is the shortage of clean water on the planet when 70% of the surface is covered with water. No living thing can survive without water for long. Luckily, nature has a way of purifying polluted water through its freshwater ecosystems, where the soils, microorganisms, and plants filter out toxins from water, as is the case with natural wetlands and forest waters.

FOOD AND MEDICINE

Nature provides food for animals and plants and us, humans. Herbs, plants, and seeds are natural medicines we can use - as oils, teas, powder, extracts, essences, and so on, and they are still the most efficient in healing.

Food is any substance consumed to provide nutritional support for an organism. It is usually of plant or animal origin and contains essential nutrients, such as carbohydrates, fats, proteins, vitamins, or minerals. Food processing is the transformation of cooked ingredients, by physical or chemical means into food or of food into other forms. Food processing combines raw food ingredients to produce marketable food products that can be easily prepared and served by the consumer. Food engineers are employed in food processing, food machinery, preservation, packaging, canning of various food products, ingredient manufacturing, instrumentation, and control.

PECTIN

Pectins are natural complex hetero-polysaccharide which comprise a functionally significant moiety of

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the primary cell walls of terrestrial plants.[1] With the increase in the production of processed fruit products, the amount of fruit wastes generated is increasing enormously. The pectin could be utilized for preparing jelly. Most of the jellies made using pectin from fruit wastes were found to have good quality. Those jellies with defects were in different corrective measures to upgrade their quality.[2] Pectin, a naturally occurring polysaccharide, has in recent years gained increasingly in importance. The benefits of natural pectin are also more and more appreciated by scientists and consumer due to its biodegradability. Pectin is the methylated ester of poly-galacturonic acid.[3] It is commercially extracted from citrus peels and apple pomace under mildly acidic conditions. Pectin's are divided into two major groups on the basis of their degree of esterification (DE). The association of pectin chains leads to the formation of the three-dimensional networks that are to gel formation.[4] Pectin's have been utilized for their functionality in foods for many years. Ubiquitous in the conserves and preserves industries, development of pectin's has centered on its use to impart texture in high sugar systems. Over 50 years, many scientific information have described the composition of pectins isolated from various plants.[5,6] Pectic substances are heterogeneous consisting essentially of (1–4) D-galacturonic acid residues, controlled on a linear backbone.[7] Pectic polysaccharides are of higher molecular weight and strongly linked with other polymer components in the cell walls, which reduce their release from the cell matrix.[8] Nanoemulsions are submicron sized systems utilized in the food and pharmaceutical industries for the delivery of active ingredients. Compared to other emulsion-based systems, nanoemulsions have shown to be more stable to environmental, and process stresses due to their large active surface area, but are also susceptible to destabilization, after prolonged storage at non-optimal temperatures, from some mechanisms. Several studies have been conducted to improve the stability of nanoemulsions, such as adding carbohydrates to the formulation. The main potential application of pectin, an anionic polysaccharide, for the stabilization of nanoemulsion systems.[9] A large amount of food wastes and by-products are produced from farm to plate. However, nowadays, the number of novel food waste and byproducts sources for pectin extraction is increasing. Moreover, the application of innovative approaches is necessary due to the limitation of conventional processes. The present review will focus on the conventional and innovative processing techniques (microwave extraction, enzymatic extraction, and ultrasound-assisted extraction [UAE]) to extract pectin from different wastes and by-products. The pectin extraction differs according to the matrix studied as well as temperature, pH, time, solvents, and solid to liquid ratio. They represent valuable sources for the production of high-added value compounds such as pectin. Pectin is the methylated ester of poly-galacturonic acid and presents a wide range of applications in pharmaceutical and cosmetic products as well as in food industry such as gelling agent in fruit-based products, stabilizer in fruit and milk beverages and fruit filling for bakery and confectionary products, and among others. Therefore, pectin recovery is of great importance. Moreover, the combination of solvent modeling and the use of particular extraction processes can enable the selective recovery of pectin.[10]

ULTRASOUND AND MICROWAVE EXTRACTION OF PECTIN FROM VARIOUS FRUIT PEELS

UAE of pectins from grapefruit pomace with citric acid (CA) as an extracting agent. A Box-Behnken Design (BBD) was utilized to optimize the extraction temperature, time, and pH to get the highest yield of pectins with high molecular weight and DE from grape pomace. According to the response surface methodology (RSM), model gave the highest pectin yield (~32.3%) is carried out at 75°C for 60 min using a CA solution of pH 2.0. The results suggest that the UAE can be a good alternative for the extraction of functional pectin's with CA from grapefruit pomace at an industrial sector.[11] In another study, extraction of pectin from pomelo (*Citrus maxima)* peels with the assist of microwave and tartaric acid. There are numerous ways to isolate pectin from different resources and solvents. One way to manufacture pectin is from the extraction of pomelo peel and the isolation using tartaric acid as the solvent under microwave assistance. Thus, the results showed that the yield of pectin obtained 23.83%, and it had been rate as high methoxyl pectin (HMP) with a low viscosity.[12]

Ultrasound-assisted heating isolation of pectin from grapefruit peel: Optimization and composition with the conventional method using RSM. The experimental optimized yield was 27.34%, which was well coordinated with the predicted value (27.46%). Compared with conventional method, ultrasound-assisted heating isolation provide the highest yield rising (16.34%) at the temperature lower (13°C) and the time shortened, respectively.[13] UAE of pectin from pomegranate peel was optimized using BBD coupled with numerical optimization techniques such as solid-liquid ratio, pH, extraction time, and temperature on the pectin yield. The optimized isolation conditions were obtained to be 1:17.52 g/ml of solid-liquid ratio, 1.27 of pH, 28.31 min of time, and 61.90°C of temperature, respectively.[14] Optimization of microwave-assisted extraction (MAE) of dragon fruit (*Hylocereus polyrhizus*) peel using various extracting conditions such as pH, time, and solid-liquid ratio on the extraction yield using a central composite design (CCD). The optimized conditions of MAE were as follows: pH (2.07), time (65s), solid-liquid ratio (66.57), and the maximum predicted yield of pectin were 18.53%.[15] In another study Hartati and Subekti[16] have evaluated the MAE of pectin from watermelon rind and can be investigated by applying microwave extractor at numerous conditions such as sulfuric acid solution concentration (0.25–1.5 M), time (5–25 min), solid-liquid ratio (1:6–1:14), and microwave power (39.9, 119.7W, and 119.5W). In another study, optimization of MAE of pectin from orange peel using RSM was carried out with acidified water using concentrated nitric acid. The various processing parameters such as pH (1.5, 2, and 2.5), solid ratio (10, 20, and 30), microwave power (360, 540, and 720 W), and time (30, 60, and 90 s) were optimized using RSM. The optimized condition was found to be pH (1.5), solid ratio (20), microwave power (630 W), and time (89 s) for an optimized pectin yield (13.32%),[17] respectively.

Extraction of pectin from wet and dried peels using water-based and microwave strategies. Sulfuric acid was used in setting the pH of the various solutions (1, 2, and 3) in the water-based isolation method while the use of ethylene diamine tetraacetic acid and sodium hydroxide was used to set pH (1.5 and 10) for the microwave extraction techniques. The results also revealed that rising in acidity; time and temperature will also increase.[18] Ultrasound-microwave assisted acid extraction of pectin from pomelo peels using CA and various effects of pH, sonication time, microwave power, irradiation time, and DE of pectin. Under the optimized conditions of pH at 1.80, 27.52 min sonication, followed by microwave irradiation at 643.44 W, the yield and the DE value of pectin obtained at 38.00% and 56.88%,[19] respectively. This has the highest pectin yield of 36.88% from ultrasound-microwave assisted extraction, their compatibility and potentially in pectin extraction techniques. Evaluated the MAE of watermelon rind pectin was proved to give the highest extraction yield (11.25%) was achieved at 15 min of extraction time, 0.5 M of the sulfuric acid solution and solid-liquid ratio (1:08) gave better extraction yield. The results reveal that the highest foaming capacity was found that pectin from celery and the emulsifying stability of model emulsion systems with 0.6% pectins solution was examined.[20]

According to Liu *et al.*[21] have investigated the ultrasound-microwave synergistic extraction of pectin from pomelo peels. The ANOVA test and RSM were employed for the optimization of the extraction conditions. 328.64 ± 4.19 mg/g of pectin yield was achieved using the obtained optimal conditions, which was significantly higher than the yields of conventional methods with reference solvents. The differences revealed by the images of atomic force microscopy and scanning electron microscopy; Fourier transform infrared spectroscopy (FTIR), and TGA suggested the physiochemical properties of pectin could be affected by the extraction solvents. Swamy and Muthukumarappan[22] have examined the optimization of continuous and intermittent microwave extraction of pectin from banana peels. Extraction parameters which were utilized in the continuous process were microwave power (300–900 W), time (100–300 s), pH (1–3), and in the intermittent process were microwave power (300–900W), pulse ratio (0.5–1), and pH (1–3) using BBD with the desirability function methodology. The results revealed that the independent factors have substantial effect on the pectin yield (2.18%) from banana peels were obtained with the microwave power (900 W), time 100s, and pH 3.00 in the continuous method whereas the intermittent process yielded the highest pectin content (2.58%) at microwave power (900 W), pulse ratio (0.5), and pH 3.00.

Optimization of MAE and preliminary characterization of pectin from *Opuntia ficus-indica* using RSM. The various effects of extraction time (X1), microwave power (X2), pH (X3), and solid-to-liquid ratio (X4) on the extraction yield were examined. The maximum obtained yield of pectin extraction was 12.57%. Overall, application of MAE can give rise to high-quality pectin.[23] In another study, the different effects of microwave power (119.7 W, 199.5 W, and 279.3 W) and irradiation time (6, 9, and 12 min) on pectin extraction using microwave-assisted extraction with acetic acid and to do a preliminary characterization of pectin from watermelon rinds. A randomized factorial design with two factors was used to determine the effect of microwave power and processing time on the yield, equivalent weight, degree of methoxylation (DM), galacturonic acid content, and the DE of extracted pectin. The results showed that extracted pectin from watermelon rinds using MAE method has yield ranged from 3.925% to 5.766%, with equivalent weight ranged from 1249.702 to 2007.756. The DE value ranged from 56.86% to 85.76%, and this value exhibited a relatively HMP (>50%). The best pectin properties were obtained at a microwave power of 279.3 watts for 12 min.[24]

UTILIZATION OF AGRO-WASTE

Mohamed and Hassan[25] have investigated that the isolation of pectin from Kalamanzi pineapple waste and cocoa pods using ethanol, metallic salt, and acetone precipitation was compared and evaluated in terms of yield and gelling characteristics. Kalamanzi gave a very high yield of pectin; however, the pectin consistency was gooey and could not be ground to a powder. Normah and Hasnah[26] have studied the extraction of pectin content in various local fruits such as cocoa, calamansi lime, guava, *Mas* banana, carambola, pineapple, papaya, pomelo, plantain, rambutan, passion fruit, and *cempedak* by-products. Pomelo peels had the highest pectin content (6.87–5.12%) while pineapple skins had the lowest (0.01–0.05%). Pectin content reduced in the following order: Calamansi skins, guava press cake, papaya skins, passion fruit pods, cempedak skins, rambutan skins, plantain skins, cocoa pods, and mas banana skins.

Extraction of pectin from fruit wastes after processing[27] and it could be utilized for preparing jelly. It can be concluded that most of the jellies using pectin from fruit wastes having good quality. In another study, extraction of pectin from the by-product of apple pomace and to establish the optimum conditions for acid extraction. It was concluded that the highest yields were obtained when the CA concentration was 6.2 g/100 ml and the time of reaction was 153 min.

Extraction of pectin from raw papaya peel, a waste from restaurants and food processing industries was carried out using ethanol and aluminum chloride precipitations. The optimized trials yielding was 2.23% and 5.84% on the papaya fresh weight basis, papaya pectins from ethanol and aluminum chloride precipitation have DE of 46 and 51%, respectively, as accessed by FT-IR.[28] Modification of pectin differs in the structure of the chains in which the modified version of pectin is shorter in length, non-branched, and galactose-rich. Durian (*Durio zibethinus*) rind (DRP) that is regarded as agri-food waste was processed into DRP and modified durian rind pectin (mDRP). DRP and mDRP were evaluated as bio-sorbent for removal of toxic heavy metals were compared with two commercial products such as citrus pectin (CP) and modified CP (MCP). A commercial bio-sorbent showed that the best and mDRP a waste product from durian were also a positive sorber that should be measured for sorption and removal of heavy metals.[29]

Pectin was extracted from a by-product of dragon fruit processing residues. Dragon fruit peels were treated separately with oxalic acid 0.25%, pH 4.6, 85°C; HCl 0.03 M, pH 1.5, 85°C; and deionized water, 75°C. The highest yield for the extracted pectin from dragon fruit peels was 20.1% using oxalic acid extraction.[30] Isolation of pectin from a by-product of dragon fruit peels processing, and it was optimized under various conditions such as pH 2–5 and extraction periods 30–120 min so that the highest yield was obtained after 120 min of extraction at pH 3.5, could be a considerable source in food production.[31] In another study, the extraction of pectin from various citrus fruit wastes, namely lime peel, spent guava extract, and apple pomace. Physical characteristics of various citrus fruit wastes were also determined. Results showed that total solid, total undissolved solid, and total dissolved solid calculated for fresh lime peel were 30.8%, 9.58%, and 21.22%, respectively.[32] Extraction of value-added products such as orange oil and pectin from orange peel, which is the waste of orange juice processing industry. The process in which orange oil is first extracted using the technique of simple distillation followed by acid extraction of pectin is most suitable for industrial production for the isolation of pectin. These results reveal the successful isolation of orange oil and pectin; provide possible advantages for industrial extraction of pectin from an environmental point of view.[33,34] Comparative isolation of pectic and polyphenols from Mexican Lime Pomace and Bagasse using conventional and microwave-assisted isolation methods.[35] Pomace extracts had the higher pectin yield and also the lower polyphenols content. Conventional pectic isolates from Mexican lime bagasse and pomace presented bioactive compounds with possible application for edible films and coatings in the food industry. Isolation, characterization, and modification of CPs from orange and lemon peels were used for obtaining pectic polysaccharides. Citrus peels were treated with ethanol, and therefore the obtained alcohol-insoluble solids were subjected to a sequential extraction with hot distilled water and hot 0.5% HCl. Acid extraction gave higher yields of pectin than water extraction, and lemon peels were richer in pectin.[36] Similar studies to be reported by Shaha[37] have investigated the optimized extracting condition and characterization of pectin from Kaffir Lime (*Citrus hystrix*) using three different acids (citric, hydrochloric, or nitric) at three different temperatures (45°C, 65°C, and 90°C). The results reveal that the pectin yields varied from 10.4% to 59.30% for sun-dried peel, but for microwave dried peel was 25.9–61.80%. The isolated pectin from Kaffir lime peels can be classified as LMP and is of possible use in the manufacture of low sugar products such as jam and jellies.

Pectin was extracted from orange peel and characterized for useful alternative pharmaceutical excipients. The pectin was subjected to the phytochemical and physicochemical characterization of its safety and quality to use as binding and suspending agent. Aceclofenac suspensions were prepared with orange peel pectin powder at 0.5, 1, 1.5, and 2% w/v as suspending agent and 1.5% w/v of sodium carboxymethylcellulose as reference suspending agent. Orange peel pectin powder showed good binding and suspending properties at 10% w/w and 2% w/v, respectively.[38] In another study, the pectin was extracted from sisal waste. This study was investigated the various effects of the liquid-solid ratio (%), time and temperature on the yield of the pectin obtained from waste using a BBD were applied to determine by the attractive environmentally friendly process. These conditions that produced the highest yield (19.2%) were a temperature of 85°C, extraction time of 1 h and a liquid-solid ratio of 2%, respectively.[39] The extraction and characterization of pectin from citric waste produced in Santana do Mundau city, Brazil. These conditions were evaluated through a 2^3 factorial design, with the acid concentration, temperature, time, yield of extraction, and the DE. In the experimental conditions studied, it was noticed that at the higher heating time (90 min), acid concentration (6%), and temperature (90°C) it was obtained the highest yield of pectin extraction, around 78% that indicates a low degree of pectin methoxylation.[40] Ultrasound-assisted isolation and characterization of pectin from tomato waste using two different methods to assess its potential utilization as an alternative source of commercial pectin production. Tomato waste treated with oxalic acid by a conventional isolation process, under reflux, and UAE at 37 kHz and temperatures of 60°C and 80°C. Therefore, the results suggested that the UAE could be used as efficient techniques for the isolation of pectin from tomato waste and by-products.[41]

Extraction and characterization of pectin from agro-food wastes using 1 $NHNO_3$, at different temperature (60°C, 90°C, and 100°C) and time (60, 90, and 120 min) from five different non-citrus agricultural wastes, namely Pumpkin seed peel, Pumpkin seed white pod, Breadfruit seed peel, Breadfruit creamy peel, and Horse-eye bean peel. Preliminary results showed that optimum condition for the extraction of pectin was at a temperature of 100°C for 90 min with horse-eye bean peel recording the highest pectin yield (4.40%), while pumpkin seed peel recorded the least amount (2.81%) on a dry weight basis. The overall results showed that the pectin from these non-citrus agro-food wastes will be fitting for industrial use.[42] In another study, Girma and Worku[43] have investigated the extraction and characterization of pectin from selected fruit peel waste such as banana and mango peels using acid extraction technique. The experimental design was performed using CCD for parametric optimization. The optimum temperature, time, and pH for the extraction of pectin for both peels were determined to be 82°C, 105, min and 2, respectively. The yields of pectin under these optimum conditions were found to be 11.31% and 18.5% for banana and mango peel, respectively.

Extraction of pectin from orange waste: A valuable carbohydrate source for the improvement of beads with improved adsorption properties for cationic dyes from the eco-friendly pectin leads were synthesized using various compounds extracted from orange bagasse, solid waste from the food industry. Recycling study established that both pectin samples can be enforced in six successive adsorption cycles without losing their adsorption capacity.[44] Utilization of agro waste pectin for meaningful use to produce valuable biocatalyst. A number of bacterial strains isolated from rotten fruits and vegetables were screened for the manufacture of industrially important polygalacturonase using pectin present in these agro-industrial wastes. The results conclude that the wheat bran was established as an economical and simply available resource all over the year for hyperproduction of pectinase and to decrease the concerned ecological issues.[45] In another study, the ultrasound-assisted CA-mediated pectin extraction from the industrial waste of *Musa balbisiana,* and optimization was done through CCD under RSM. The best extraction method condition was ultrasound power – 322 W, pH of 3.2, isolation time - 27 min, and solid-liquid ratio - 1:15 g/ml. The mean experiments yield of pectin (8.99 ± 0.018%) was fine accord among predicted yield of pectin (9.02%), respectively.[46] In another study, the optimized extraction and characterization of pectin jackfruit wastes using oxalic acid were found to be 90°C and 60 min using CCD, respectively. The yield of pectin under these optimum conditions was 38.42%. Extraction time and temperature showed a significant ($P < 0.05$) effect on the pectin yield. This agreed well with the experimental result of 39.05 ± 0.59 g/g of pectin, under similar conditions. Experimental studies on a large scale using 10 kg of jackfruit wastes, gave a yield of 38% pectin. Pectin isolated from jackfruit wastes can be classified as low methoxyl pectin with promising applications in low sugar products.[1]

Extraction of pectin from rind of passion fruit (*Passiflora edulis var. flavicarpa Degener*), which is kind of waste, can be utilized as edible coating through pectin extraction process. The purposes of this work were to determine the suitable solvent for the pectin extraction and techniques for applying the produced edible coating on strawberry, to produce edible coating from the pectin, and the test the performance of the edible coating which was applied to strawberries. Pectin from passion fruit rind was collected through conventional extraction method using two types of solvent, i.e. acetic acid solution and hydrochloric acid solution with a concentration of 0.01 N, 0.015 N, 0.02 N, 0.025 N, and 0.03 N. The results showed that chloric acid solution was more suitable for the pectin extraction from passion fruit. Maximum yield of 30.78% was obtained at a hydrochloric acid concentration of 0.02 N. Obtained pectin from the extraction was then processed into the edible coating by adding plasticizers and calcium chloride dihydrate.[47] Extraction of pectin from the Nigerian citrus *sinensis* peel and its physicochemical characterization using RSM. The yields of pectin from the citrus peels were optimized using the RSM through the CCD, and the process variables were extraction temperature (50–90°C), extraction pH (1–4.2), extract to ethanol ratio

(EER) (1:0.5–1:2), and extraction time (30–120 min). The results of the physiochemical characterization revealed that the Nigerian *Citrus sinensis* peels have moisture content (11%), ash (2.33%), titratable acidity (0.23%), crude protein content (3.68%), reducing sugars (2.24%), total sugars (4.42%), and fat content (0.43%). The pectin has an average moisture content (9.23%), pH 4.5 (for high methoxyl, HM pectin), pH 2.5 (for low-methoxyl, LM pectin), ash content (1.04–1.096%), protein content (1.62–3.33%), acetyl content value (1.20–1.344%), and methyl content value (0.992–12.245%). The optimization results show that temperature, pH, EER, and time strongly influenced the pectin yield. The optimized conditions for the extraction of HM-pectin and LM-pectin were (temp., (90°C), pH 1; EER 0.53; extraction time (120 min)), (temp., (70°C), pH 2.6; EER 1.25; extraction time (75 min)), and the experimentally validated pectin yields were 55% and 5.9% for LM and HM pectin, respectively. Hence, it can be concluded that the Nigerian *Citrus sinensis* peel is a potential source of pectin for commercial purpose.[48]

Extraction of pectin and the influence of various physic-mechanical factors were taken into consideration to achieve the maximum yield from three new sources of pectin. Three different fruit peels obtained from sapodilla, banana, and muskmelon were included in the study. Among the three fruits investigated in the study, banana recorded highest (10.5%), while sapodilla (4.7%) and muskmelon (4.4%), subsequently. The variation in yield occurred due to the different physic-mechanical procedures (MPs) used to extract pectin from these fruits. The study elaborates the effect of major influencing factors and their collaborative effect on the yield of pectin from three new sources while confirming the effects through already two known sources (apple and orange). The results indicated that different variables (MP), pH level, and boiling method) have significant impacts on the yield of all five fruits. Hence, it was concluded from the study that pectin can be extracted from these new sources effectively by applying the desired variables of extraction procedure.[49] In another study, the pectin was extracted from orange peel. Orange peels are a major commercial source of pectin. In Maharashtra, Nagpur region is well known in central Asia to produce the highest production of orange and is also known as the California of India. In the past two decades, researchers are working on the development of the part of the process technology needed for the extraction of value-added products, i.e., orange oil and pectin from orange peel, which is the waste of orange juice processing industry. Many operating parameters are affecting the extraction of pectin. Hence, it is necessary to understand the effect of various operating parameters on the extraction of pectin. In this study, it includes the effect of temperature, solvent used for extraction, Time used for extraction was discussed. Furthermore, effects of pH on the extraction of pectin were discussed. pH is one of the most important crucial parameters which effects on extraction of pectin. This study extends the effect of operating parameters on the extraction of pectin from orange peels.[50]

Majee *et al.*[51] investigated the therapeutic and pharmaceutical benefits of native and modified plant pectin. In this study, the plant pectin constitutes an important class of naturally occurring polysaccharides and are widely distributed in various fruits and vegetables consumed on a regular basis. These biomolecules are reported to exhibit a vast array of biological activities including effects on the digestive system, the chemopreventive effect in colon cancer, regulation of blood cholesterol level, and immune-potentiating effects. However, variation in the spectrum of activity and efficacy occurs due to different sources of pectin and also different methods of extraction. Pectin modification by pH treatment, change in temperature or enzymatic modification methods can ensure derivatives with variable but defined degrees of esterification, customized physicochemical properties, and improved pharmacological and therapeutic profile, and mainly in cancer prevention and management. Pharmaceutical utility of plant pectin is attributed to the unique rheological behavior and gelling properties in an aqueous medium and have been successfully employed in the development of colon specific sustained release drug delivery systems and edible pectin films with stabilizing effect on entrapped labile molecules. Although several milestones toward understanding the process of pectin modification have been established, most of the data generated until date are obtained from *in vitro* studies or on commercial varieties of modified pectin. In another study, Sandarani[52] investigated the different extraction techniques of pectin in different applications in food industry, medicinal, and pharmaceutical field. Recent studies involving the extraction of pectin using acids, microwave assisted, and enzymes are reviewed, with the aim to capture state of the art on current research about pectin extraction. Extraction techniques have been discussed in related to different acids and enzymes. Adamczewska and Selvaraj[53] have investigated the extraction of pectin from the watermelon rind using UAE. Four extraction parameters, namely solid-liquid ratio, pH, time, and temperature were optimized using BBD, a RSM. The results suggested that all the four factors were influencing the pectin extraction. An optimum pectin yield of 15.48% was obtained, and it was found that a solid-liquid ratio: 45 g/ml, pH: 1.1, time: 12 min, and temperature: 69°C. Hence, UAE could be employed to extract the pectin from watermelon rinds.

Limphapayom[54] investigated the extraction of essential oil and pectin from lime and its waste using hydro-distillation. The essential oil ranged from 1.72% to 2.20%. The chemical composition of essential oil composed of alpha-pinene, beta-pinene, D-limonene, comphene, aphellandrene, g-terpinene, and others when analyzed using gas chromatography-mass spectrometry method. Pectin extractions were found 40.11–65.81 g/100g of lime peel. The best extraction condition was found to be higher in yield using ethanol extraction. The present study was also focused on lime powder production as a source of Vitamin C or ascorbic acid and the potential of lime waste as a source of essential oil and pectin. Lime powder produced from spray dryer. Lime juice with two different levels of maltodextrins DE 10, 30, and 50% w/w was sprayed at 150°C inlet air temperature and 90°C outlet temperature. Lime powder with 50% maltodextrin gave the most desirable quality product. This product has Vitamin C contents of 25 mg/100 g (w/w). In another study, the extraction of pectin acid from citrus fruit peels and its application as textile printing thickener to use it as an alternative substitute of sodium alginate thickener in reactive printing.[55] Pectic acid is extracted from the identified citrus fruit peels, i.e., orange peel, lemon peel, and bitter orange peels. Extraction time, type of solvent, and extraction pH were standardized based on pectin yield obtained. The research found environmentally friendly extraction of pectic acid by sodium carbonate instead of acid hydrolysis with HCl or H_2SO_4.

Lin and Cze have investigated the drying kinetics and optimization of pectin extraction from banana peels using RSM. Banana peels which are the waste in abundance are used to extract valuable pectin. The gelling ability of the pectin has gained attention in the food and pharmaceutical industries. In this study, oven drying with temperature 50°C was chosen as the best drying temperature due to the highest extraction yield. Furthermore, page-two-term model was selected as the best model to describe the drying kinetics of banana peels due to highest R^2 value (0.9991) and lowest RMSE value (0.001). The optimal extraction conditions given by BBD were 75°C extraction temperature, 23 min extraction time, and 1:33.3 g/ml solid-liquid ratio. Likewise, the DE for both pectins extracted using un-optimized and optimized conditions were 71.92 1.38% and 76.1 2.07%, respectively. Both of the pectins were classified as high-methoxyl pectins. The pectin with higher DE also indicated that the rate of gel formation is higher. The results showed that the pectin yield and gelling time have successfully improved after optimized the pectin extraction process.[56] In another study, optimization of pectin extraction from Uba mango peels using RSM. A CCD was used to determine effects of pH (1.16.2.84), extraction temperature (63.97°C) and time (35.85 min) on the yield, degree of DE, and viscosity of pectins extracted. For pectin extraction, the previously sanitized mango shells were dried and crushed to obtain the flour that was treated with an ethanol solution obtaining the alcohol insoluble residue (AIR). Subsequently, the AIR was mixed in ethanol with the extraction solution of hydrochloric acid. Pectin yields ranged from 18.8 to 32.1 g/100 g of AIR, whereas the DE and viscosity values ranged from 62.2% to 86.2% and from 1.58 to 45.85 mPaEs, respectively.[57]

The various effects of microwave power and irradiation time on pectin extraction from watermelon rinds (*Citrullus lanatus*) with acetic acid using microwave-assisted extraction method. A randomized factorial design with two factors was used to determine the effect of microwave power and processing time on the yield, equivalent weight, DM, galacturonic acid content, and the DE of extracted pectin. The results showed that extracted pectin from watermelon rinds using MAE method has yield ranged from 3.925% to 5.766%, with equivalent weight ranged from 1249.702 to 2007.756. Extracted pectin has a DM value ranged from 3.89% to 10.81%. The DE value ranged from 56.86% to 85.76%, and this value exhibited relatively HMP (>50%). The best pectin properties were obtained at a microwave power of 279.3 watts for 12 min, respectively.[58] In another study, the microwave-assisted extraction of pectin from cocoa peel using CA as solvent. Cocoa peels (moisture content of 10%) with CA solution (pH of 1.5) irradiated by microwave energy at various microwave power (180, 300, 450, and 600 W) for 10, 15, 20, 25, and 30 min, respectively. Pectin obtained from this study was collected and filtrated by adding 96% ethanol to precipitate the pectin. The best results obtained from the extraction process using microwave power of 180 Watt for 30 min. This combination of power and time yielded 42.3% pectin with moisture content, ash content, weight equivalent, methoxyl content, and galacturonate levels was 8.08% and 5%, 833.33 mg, 6.51% and 58,08%, respectively. The result finding suggested that microwave-assisted extraction method has a great potency on the commercial pectin production.[59]

Extraction and characterization of pectin from pomelo peel and its impact on nutritional properties of carrot jam during storage. Influence of various concentrations of extracted pomelo peel pectin on physicochemical, bioactive compounds, color, and sensory attributes of carrot jam during storage was also studied. Pectin extracted at pH 2.0 had higher ash content, equivalent weight, and total anhydrobiotic acid content than that extracted at pH 1.0. Extracted pomelo peel pectin was categorized as high-methoxyl pectin based on the DE. The b-carotene and total phenol content were increased in a jam after 90 days of storage. Ascorbic acid content decreased with increasing storage period. Jam prepared using commercial pectin had higher DE values than jam prepared using pomelo peel pectin. Physicochemical properties were influenced by pectin concentrations and storage time. Overall, acceptability was similar for all samples on the basis of sensory evaluation. The results showed that pomelo peel might be used as a rich source of pectin and pomelo peel pectin could be used as an alternative to commercial pectins for carrot jam preparation.[60] Colodel and Petkowicz[61] reported that the pectin extraction from cubiu fruit peels using boiling mineral acid (HNO_3) or organic acid (CA) at pH 2 for 1h. The highest uronic acid content was obtained using $HNO_3$and the pectin obtained under these conditions was characterized by chromatographic, spectroscopic, and spectrophotometric methods. The polymer was mainly composed of a high methyl-esterified homogalacturonan with low acetyl content. It formed gels in acidic medium with 60% sucrose and the gel strength increased with decreased pH, suggesting possible applications as an additive in acidic products with high soluble solids content.

Apple pomace which is the main waste of fruit juice industry was utilized to extract pectins in an environmentally friendly way, which was then compared with chemically-extracted pectins. The water-based extraction with combined physical and enzymatic treatments produced pectins with 693.2 mg g^-1 galacturonic acid and 4.6% yield, which were less than those of chemically-extracted pectins. Chemically-modified extracted pectins exhibited lower DE (58%) than the pectin samples obtained by physical/enzymatic treatments (69%), which were also confirmed by FT-IR analysis. When subjected to steady-shear rheological conditions, both pectin solutions were shown to have shear-thinning properties. Moreover, the pectins which were extracted by combined physical/enzymatic treatments, showed less elastic properties under high shear rate conditions, compared to the chemically-extracted pectins.[62] In another study, the extraction of pectin from orange peels. To increase profits for citrus orange growers and processors, citrus orange peels, a by-product of citrus orange processing, were investigated as a source of pectin. An orange, specifically, the sweet orange is the most commonly grown tree orange in Ethiopia. The outcome of the work highlighted that the sweet orange peels are good source of pectin and do have the potential to become important raw material for food processing industries. It was found from the experimental observations that the peel source. It was concluded that the process in which pectin was first extracted using the technique of water bathing or drying followed by acid extraction of pectin was most suitable for industrial production for isolation of pectin. These results demonstrated the pectin, providing potential benefits for industrial extraction of pectin from an economic and environmental point of view. The pectin yields for the centrifugation and cheesecloth methods were 14.3% and 10.6%, respectively. These results indicated that more pectin was retained using the centrifugation method.[63]

CONCLUSIONS

The recycling of fruit and vegetable wastes is one of the major significant means of utilizing it in a number of novel ways yielding new food products/additives and meeting the necessities of an essential products key role in human and animal nutrition as well as in the pharmaceutical industrial sectors. The industrialized process should be planned to exploit the recycling of potential and reduce the production of agro-wastes.

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