International Journal of Food and Fermentation Technology
Citation: *Int. J. Food Ferment. Technol.*, **14**(01): 325-342, June 2024
DOI: 10.30954/2277-9396.01.2024.6

ASSOCIATION FOR AGRICULTURE ENVIRONMENT AND BIOTECHNOLOGY

Research Paper

Microwave Convective Extraction of Pectin from Jackfruit Waste and its Quality Evaluation

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Paper No.: 290 **Received:** 23-02-2024 **Revised:** 24-05-2024 **Accepted:** 03-06-2024

ABSTRACT

Jackfruit peel, as a new source, was used for pectin extraction using the Microwave Convective method. The extraction process factors were analyzed using a Completely Randomized design (CRD), and under optimal conditions (temp. 85°, 90°, 95°, pH 1.5, 2.0, 2.5), the predicted extraction yield (8.120%) was validated by the experimental results. The Jackfruit peel pectic was examined in terms of physicochemical properties. The desirable best results were obtained by 85° temps and 1.5 pH exatraction condition as; Yield (8.120%), Moisture content (8.001%), Ash content (2.77 %), pH (3.555%), Methoxyl Content (3.794 %), Anhydronic acid (52.529 %), Equivalent weight (457.268 mg/mol), degree of esterification (32.623 %), Galacturonic acid (42.887 %), Intrinsic viscosity (2.259 dl/g), Spredability (127.610 mm), Colour L (52.911), Colour a (13.213), Colour b (18.589).

Keywords: Microwave, viscosity, Jackfruit, CRD, Galacturonic acid, pH

The jackfruit-processing industry and vendors have disposed of rinds and cores as wastes. Approximately 60% of the whole jackfruit is considered waste. The disposal of these wastes may have negative environmental effects. Nevertheless, proper utilization of jackfruit waste could turn it into a valuable commodity and reduce the cost of waste disposal. To reduce the wastes and their negative impact on the environment, beneficial compounds, such as pectin, in jackfruit wastes can be extracted (Koh *et al*. 2014) extracted pectin from jackfruit rind by using acid extraction and alcohol precipitation (Suhaila and Zahariah, 1995).

Pectin is the most complex structural and functional polysaccharide present in the cell walls of plant. Pectin is composed of methylated ester of polygalacturonic acid, consisting of chains of 300-1000 units of galacturonic acid connected together by $\alpha 1 \rightarrow 4$ linkages. The average molecular weight of pectin is about 50,000 to 180,000 Da, in which mainly carboxyl groups in its chain are included. The ratio of esterified D-galacturonic acid units to total D-galacturonic acid units is called the degree of esterification (DE). The gelling properties of pectin depend upon the degree of esterification. The structure of pectin shows three methyl ester forms

How to cite this article: Sontakke, P.B., Swami, S.B., Zambre, S. and Venkatesh, K.V. (2024). Microwave Convective Extraction of Pectin from Jackfruit Waste and its Quality Evaluation. *Int. J. Food Ferment. Technol.*, **14**(01): 325-342.

Source of Support: None; **Conflict of Interest:** None

(-COOCH3) for every two carboxyl groups (-COOH). Therefore, it has 60% degree of esterification. The substituted residues at C-4 with neutral and acidic oligosaccharide side chains are composed of galactose, arbinose, fructose, and glucuronic acid (Pawar *et al.* 2022). Generally, pectin is summarized as a heteropolysaccharide of three components: homogalacturonan (HG), rhamnogalacturonan-I (RGI), and rhamnogalacturonan-II (RGII). The backbone structure can branch with other neutral chains of sugar, such as xylogalacturonan (XGA), arabinan, arabinogalactan I (AG-I), and arabinogalactan II (AG-II) (Vanitha & Khan 2019).

It plays an important role in the morphology, defense, growth, and development of plants. It serves as a stabilizing and gelling polymer in various food products. It has various biomedical uses and constructive effects on human health (Mohnen, 2008). The word pectin is derived from Greek word pektikos, which means gelling or congealing. It was recognized first by Nicholas Vauquelin in apple and later described and isolated by Henri Braconnot in 1825. It is structurally acidic heteropolysaccharide present in primary and middle lamella and the cell walls of terrestrial plants. The main component of pectin is galacturonic acid, which is a sugar acid derived from galactose. Commercially it is manufactured as a powder having white to light brown. It is mostly extracted from citrus fruit peels and used in foods such as jams and jellies as a gelling agent. It is also used in medicines, stabilizers in milk drinks and fruit juices, sweets, dessert fillings and as a dietary fiber source. The physicochemical properties and structural entities of pectin depend on their source and extraction method.

MATERIALS AND METHODS

The Jackfruit waste material was collected from Roha and Kolad local markets. Jackfruit of variety was used for this study Kokan Prolific. Jackfruit contains 29% bulbs, 12% seeds, and 60% waste material (rind). The bulbs and seeds are edible portions and hence removed.

Extraction process

The microwave convective extraction method for extraction of pectin from Jackfruit peel powder prepared from (a) convective hot air drying and (b) solar drying was carried out as per the procedure (Hao, 2002; Koh, 2014).

Samples (10 g) of (a) Convective hot air-dried jackfruit peel powder and (b) Solar air-dried jackfruit peel powder separately of dried ground cell wall materials (Jackfruit rind powder) were dispersed in 150 mL 0.1 M HCl. The dispersion was stirred and kept in a microwave convective oven at (a) 85°, (b) 90°, (c) 95°, and (a) pH 1.5, (b) pH 2.0, (c) pH 2.5 for 30 min. The hot extract was filtered through four folds of nylon cloth and cooled to 4° temperature. After, the suspensions were centrifuged for 30 min at 4000 rpm. Then the same volume of 85% Isopropyl alcohol was added, and the mixture was stirred for 5 minutes and allowed to settle at 4° for 2 h. The mixture was then centrifuged at 4000 rpm for 30 min, and the pectin residue was washed with 70, 80, 90%, Isopropyl alcohol successively (until the decant water became colorless). Finally, the extracted purified pectin was pressed by muslin cloth and then dried using 40 for 5 hours in a tray dryer, ground, and then stored at normal atmospheric temperature in polyethylene pouches.

Physio-chemical Parameters for determination of the quality of pectin

1. Yield of Pectin, (%)

The yield of pectin was determined as per the procedure of Lin *et al.* (2018). The pectin yield based on the total peel used for extraction was calculated using the Eq (1).

$$\text{Pectin Yield} = \frac{\text{Weight of dried pectin (g)}}{\text{Initial weight of dried jackfruit rind powder (g)}} \times 100 \quad \ldots (1)$$

2. Moisture content, (%)

Pectin (1 g) was weighed and dried in a hot air oven at 105° for 24 h to determine the moisture content (AOAC, 2010) as mentioned in section 2.

3. Ash content, (%)

For ash content, 1 g of pectin was weighed in a crucible and then incinerated in a Muffle furnace at 550° for four hours. The residue was cooled in a desiccator and weighed. Ash were determined by AOAC (Association of Official Analytical Chemists (2010). Ash content was determined as per the following formula (2);

Ash content (%) =

$$\frac{\text{Weight of crucible with ash} - \text{weight of crucible}}{\text{Weight of sample in g}} \times 100 \quad \ldots(2)$$

4. Equivalent weight, (%)

Equivalent weights for pectin samples obtained from different methods of pectin extraction were determined as per the procedure Ranganna's (1995). Pectin sample (0.5g) was weighed into 250 ml conical flask and moistened with 5ml ethanol. A 1.0g NaCl was added to the mixture, followed by the addition of 100ml distilled water, and to this aliquot 6 drops of phenol red indicator was added. The solution was titrated with 0.1 M NaOH to an end point where pink color was obtained.

Equivalent weight was used for the determination of anhydrouronic acid (AUA) and the degree of esterification (DE).

Equivalent weight was calculated by following formula (3).

Equivalent weight (%) =.

$$\frac{\text{Weight of sample (g)} \times 1000}{\text{Volume of alkali} \times \text{Normality of alkali}} \quad \ldots(3)$$

5. Methoxyl Content (MeO), (%)

Methoxyl content (MeO) of pectin samples developed for all the extraction methods were determined as per the method described by Girma and Worku (2016). This was done using the neutralized solution from equivalent weight determination, by the saponification of pectin, followed by titration of the liberated acid. 25ml of 0.25M NaOH was added to neutralize the solution, which was used for the determination of equivalent weight was used and the mixture was stirred thoroughly and allowed to stand for 30 min at room temperature. A 25 ml of 0.25 N HCL was added to it and titrated with 0.1 N NaOH. The endpoint for the solution was brown color was obtained. The methoxyl content (MeO) was determined as per the following formula (4);

Methoxyl Content % =

$$\frac{\text{ml of alkali} \times \text{Normality of Alkali} \times 3.1}{\text{Weight of sample pectin}} \quad \ldots(4)$$

6. Anhydrouronic Acid content (AUA), (%)

The Anhydrouronic acid content (AUA) was obtained by using the formula (3.6) that was reported in the literature by Mohamed and Hasan 1995. The alkali milli-equivalents from equivalent weight and methoxyl content were taken to calculate anhydrouronic acid (AUA)content. The anhydrouronic acid (AUA) was determined as per the following formula (5);

$$\% \text{ of AUA} = \frac{176 \times 0.1z \times 100}{w \times 1000} - \frac{176 \times 0.1y \times 100}{w \times 1000} \quad \ldots(5)$$

When molecular unit of AUA (1 unit) = 176g

Where,

z = ml (titre) of NaOH from equivalent weight determination.

y = ml (titre) of NaOH from methoyl content determination.

w = weight of sample, g

7. Degree of Esterification (DE), (%)

The degree of esterification for all pectin samples extracted for all the treatments were determined as per the procedure Daud *et al.* 2019. The DE of extracted pectin is calculated from methoxyl and anhydrouronic acid content as per the following equation described (6).

$$\% \text{ DE} = \frac{176 \times \%MeO}{31 \times \%AUA} \times 100 \quad \ldots(6)$$

Where, % *MeO* = Methoxyl Content

% *AUA* = Anhydrouronic acid

8. Galacturonic acid, (%)

The galacturonic acid (GalA) content was ascertained in the light of carbazole-sulfuric acid colorimetric titration with some modifications. The galacturonic acid (GalA) was determined for the developed pectin sample from all those methods as per the procedure of Dische 1946; Filisetti-Cozzi *et al.* 1991; Galambos 1967; Li *et al.* 2007. 1 mL pectin solution in distilled water (200 µg/mL) was fully reacted with 5 mL concentrated sulfuric acid and hydrolyzed for about 20 min in a water bath of 75 °. Afterwards, alcohol-based carbazole solution (200 µL, 0.15 %, w/v) was added to the cooled reaction, and the end point of the mixture was left to color in a dark environment for about 2 h. The absorbance was recorded at 530 nm using a spectrophotometer (Make: Labindia Analytical, India).

9. Color

Color values of jackfruit waste pectin developed from different methods were determined by Hunter color values of jackfruit waste pectin produced by various drying methods were measured by using a color reader (M/S Minolta, Japan Model DP 301). Before each measurement, the color reader was standardized with the reference white tile provided with the equipment. The working of colorimeters is mainly based on Beer-Lambert's Law. This law states that the light absorption when it passes through a medium is directly proportional to the concentration of the medium. When a colorimeter is used, there is a ray of light with a certain wavelength is directed towards a solution. The L*, a*, and b*values of the pectin were recorded with four no. replication and L*, a* and b* value are recorded.

10. Intrinsic viscosity, (dl/g)

The viscosity of pectin extracted from jackfruit waste was determined using an Ostwlad capillary viscometer (Make: Physilab, India) using Iglesias and Lozano, 2004 procedure. The specific viscosity (η_{sp}) was measured by recording pectin solution flow time in an Ostwlad capillary viscometer at 25 ± 0.1 °C. The temperature was maintained by immersing the viscometer in a temperature-controlled water bath. Different concentrations of pectin solutions (0.005–0.02 g/L) were prepared in an aqueous solution with continuous stirring at room temperature. Pectin solutions and solvent were filtered using 0.45 µm membrane filters before viscosity was measured. The relative viscosity (η_{rel}) was measured from the ratio of the viscosity of the solvent (5.844 g/L NaCl) and that of the pectin solution. The intrinsic viscosity (η) was estimated from the relative viscosity of pectin solutions by extrapolation of Kraemer and Huggins curves to zero concentration (Kraemer, 1938 Billmeyer, 1984).

11. Determination of pH

The pH for the extracted pectin sample using various methods was determined according to the methods of (AOAC 2010) using a digital pH meter (A standard pH meter. Exactly 1 gram of pectin was added to 10 ml of distilled water in a beaker. The pH was measured by direct immersion of the electrode into the sample. A digital pH meter (LAB India Instruments Pvt. Ltd., Mumbai) was used. pH meter was calibrated before use with a standard buffer solution at 30°C each day before use buffer solutions of pH 4.0 and 7.0 were used to standardize the pH meter, and pH measurements were carried out in duplicate.

12. Spredability, (mm)

The spreadability of pectin samples developed from

the different methods were determined as per the procedure described by Ranganna's method (1995). Weigh 646 g of sugar and 4.33 g of pectin. Out of 646 g weight sugar take 20-30 g sugar and mix the pectin (4.33 g) thoroughly in weighed sugar in a dry beaker. Note the tare weight of a 3- quart stainless steel saucepan and a stirrer. Pour 410 ml of distilled water into the pan, followed by the sugar-pectin mixture. The mixture was stirred gently for about 2 min. Place the saucepan on a stove or a gas burner. If an electric heater is used, pre- heat the heater and heat with stirring till the contents come to a full rolling boil. Add the remaining sugar and continue heating and stirring until the sugar has dissolved. Continue boiling until the net weight of the jelly is 1015 g. If the net weight is less, add distilled water in slight excess and boil down to the correct weight. The entire heating time should not exceed 5-8 min. After removing from the scale, allow the jelly to stand for 1 min and then slightly tip the pan on the side so that the contents are nearly ready to overflow. Skim off any foam or scum. Remove the stirrer, place a thermometer in the pan, and stir gently with it, until the temperature is exactly 95°C. Then pour the jelly quickly into three glasses, each containing 2 ml of tartaric acid solution.

While pouring the jelly into the glasses, stir vigorously with a glass rod. Pour the jelly rapidly until the glasses are filled part way up the sideboard, and then pour more slowly so that the glass can be filled completely full to the point of overflowing. The acid solution gets mixed with the jelly when rapid pouring is done. Fifteen min after filling, cover the glasses with regular metal lids that fit snugly over the side boards. Store jellies for 20-24 h at 25°C. After 24 h take the glass and place invert on the glass slide. After pick up the glass and wait for 5-10 min to spread the pectin solution on the glass surface. Measure the diameter by the Vernier caliper three times.

RESULTS AND DISCUSSION

One extraction method (microwave convective extraction), two drying methods (convective hot air dryer and sun dryer), three extraction temperatures (85, 90, and 95 degrees Celsius), and three extraction pH levels (1.5, 2.0, and 2.5) were used in the experiment. Completely Randomised Design (CRD) was used to statistically analyse the experimental data. The yield, moisture content, ash content, pH, methoxyl content, anhydraunic acid, equivalent weight, degree of esterification, galacturonic acid, intrinsic viscosity, spreadability, colour (L), colour (a), colour (b), and other physical and chemical parameters of the pectin samples were noted along with the changes in these parameters.

Yield (%)

Table 1 and Fig. 1 illustrate the impact of extraction conditions, such as temperature (85, 90, 95), pH (1.5, 2.0, 2.5), and drying methods (solar dryer and convective hot air drier) on the pectin production from the waste jackfruit peel. The yield (%) of the sample ranges between 6.411-7.705.

Microwave Convective extraction method because microwaves penetrate and act upon polar substances within the plant cells, promoting the separation of pectin from cell walls and creating a higher yield of pectin (Misra and Yadav, 2020).

The most common factor influencing the amount of pectin is temperature. The results show increases in temperature decrease the yield of pectin. According to (Guo *et al.* 2016) ,the pectin yield was found to be increased up to some extent (up to a certain temperature); and later decreased upon increasing the temperature during the extraction of pectin. Temperature increases have the potential to disrupt ester and hydrogen bonding, which would enhance pectin solubility and solvent diffusion into plant tissues while also raising pectin extraction yield. Nevertheless, the yield of pectin decreases with increasing additional temperature. Pectin molecules may break at a higher temperature, which would enhance the de-esterification of polygalacturonic chains. Additionally, its quality decreases when pectin powder becomes a dark brown color (Mada *et al.* 2022).

The yield of pectin increases as the pH decreases. According to Zakaria *et al.* (2021), the pH indicates that increased pectin results and extracted pectin purity were observed at lower pH values. This finding showed similar results to the previous investigation, which found that pH 2.0 yielded the maximum pectin result. This might be the result of as pH decreases, hydrogen ions increase, which neutralizes more of the pectin's carboxylic groups and raises pectin yield (Mada 2022) and also (Swamy and Muthukumarappan 2016). At pH around 2.00 shows an increasing pectin yield, pH value increases may cause the decrease in the pectin yield. The lower acidic pH value of extraction solvent can have the ability to conduct with the insoluble form of pectin is hydrolysis to convert the soluble form of pectin to increase the pectin yield.

The yield obtained from the experiment was similar to that for overripe lemon pomace (10.33 %) extracted using strong mineral acids and a pH of 2, Azad *et al.* (2014). However the yield of jackfruit pectin was significantly lower than 17.21 % reported by Koh *et al.* (2014) using microwave-assisted extraction. It was, similar to the 14.7 % pectin yield for jackfruit peels using conventional extraction reported by Ahmmed (2017).

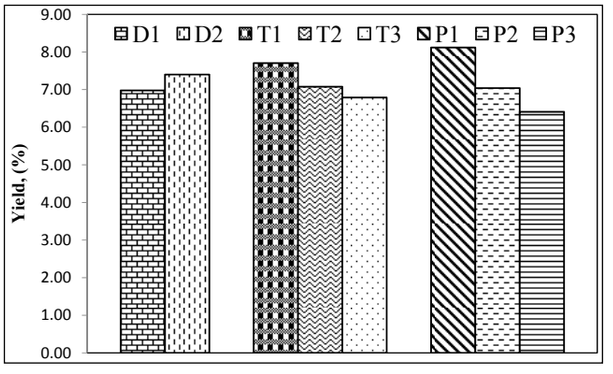

Fig. 1: Effect of Drying Method, Temperature (°C), and pH on Yield (%) of Pectin extracted by Microwave Convective Extraction method

Moisture Content, (%)

Table 1 and Fig. 1 illustrate the impact of extraction conditions, such as temperature (85, 90, 95), pH (1.5, 2.0, 2.5), and drying methods (solar dryer and convective hot air drier) on the pectin production from the waste jackfruit peel. The moisture content (%)of the sample range between 8.001-8.37.

Table 1: Effect of Drying Method, Temperature (°C), and pH on Yield (%) of Pectin extracted by Microwave Convective Extraction method

Factors	Yield (%)			F-Ratio	CD (5%)
Drying Method	7.404	6.978	—	44.315	0.13
Temperature	7.705	7.078	6.789	71.593	0.159
pH	8.120	7.042	6.411	244.039	0.159
Int A × B				8.001	0.224
Int A × C				0.489	N/A
Int B × C				19.813	0.275
Int A × B × C				6.596	0.389

The moisture content of pectin extracted using different extraction methods was non-significant. The Moisture content of pectin extraction using conventional extraction is higher than pectin extracted from microwave-assisted extraction. This result showed that pectin from Microwave assisted extraction had lower water holding capacity relative to that extracted by conventional extraction. In short, pectin powder extracted by conventional extraction is more susceptible to quality deterioration by action.

According to the quality standards of commercial pectin or IPPA (International Pectin Producers Association), the standard maximum acceptable limit of moisture is 12%. That means that pectin moisture content might not exceed 12% (Muhamadzadeh *et al.* 2010). Pectin must have a low to moderate moisture level in order to safely. Owing to the action of pectinase enzymes, elevated moisture levels might impact pectin quality by accelerating the growth of microorganisms (Oloye *et al.* 2021; Ismadji *et al.* 2008). This makes elevated moisture content an indication of spoiling.

Ash content, (%)

Table 2 and Fig. 2 illustrate the impact of extraction

conditions, such as temperature (85, 90, 95), pH (1.5, 2.0, 2.5), and drying methods (solar dryer and convective hot air drier) on the pectin production from the waste jackfruit peel. The ash content (%) of the sample ranged between 2.777-3.632.

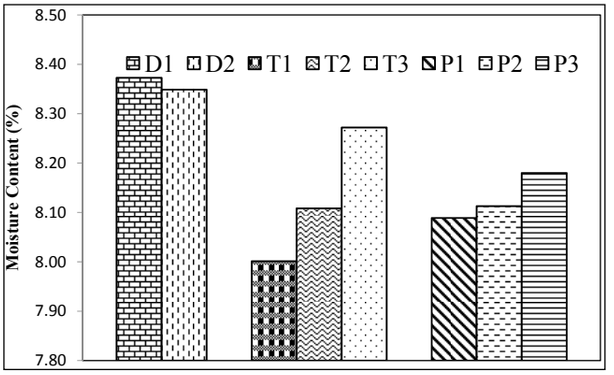

Fig. 2: Effect of Drying Method, Temperature (°C), and pH on Moisture content, (%) of Pectin extracted by Microwave Convective Extraction method

Table 2: Effect of Drying Method, Temperature (°C), and pH on Moisture content, (%) of Pectin extracted by Microwave Convective Extraction method

Factors	Moisture Content, (%)			F-Ratio	CD (5%)
Drying Method	8.372	8.348	—	697.831	0.07
Temperature	8.001	8.108	8.272	20.911	0.086
pH	8.089	8.112	8.180	2.492	N/A
Int A × B				6.066	0.121
Int A × C				17.62	0.121
Int B × C				12.2	0.148
Int A × B × C				31.166	0.21

Microwave convective extraction showed low ash content because the short extraction time of Microwave convective extraction is the factor contributing to the low ash content (Viet *et al.* 2011).

The marked difference between the values attributed to the solvent used for extraction and the purification process carried out (Mada *et al.* 2022). Isopropyl alcohol showed that the total ash content was higher than other those precipitated by solvent (Seggiani *et al.* 2009). The ash content increases as the pectin yield decreases, indicating that the sugar content and others constituent increases significantly due to the ripening of the fruit. Low ash content i.e., below 10%, and maximum limit of ash content 10% are one of good criteria for gel formation (Ismail *et al.* 2012). However, because of its decreased ash level, the pectin extracted in this study is thought to be of good quality for enhancing gel formation functionality. As a result, the use of pectin determines the desired ash content.

pH

Table 3 and Fig. 3 illustrate the impact of extraction conditions, such as temperature (85, 90, 95), pH (1.5, 2.0, 2.5), and drying methods (solar dryer and convective hot air drier) on the pectin production from the waste jackfruit peel. The pH of the sample ranged between 3.555-4.518.

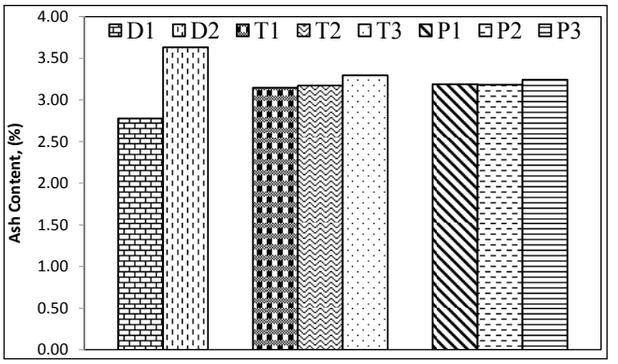

Fig. 3: Effect of Drying Method, Temperature (°C), and pH on Ash content, (%) of Pectin extracted by Microwave Convective Extraction method

Table 3: Effect of Drying Method, Temperature (°C), and pH on Ash content, (%) of Pectin extracted by Microwave Convective Extraction method

Factors	Ash Content, (%)			F-Ratio	CD (5%)
Drying Method	2.777	3.632	—	2325.149	0.036
Temperature	3.146	3.173	3.295	26.546	0.044
pH	3.183	3.188	3.243	4.698	0.044
Int A × B				190.809	0.062
Int A × C				1.232	N/A
Int B × C				4.687	0.076
Int A × B × C				9.487	0.108

The most important factor influencing the propagation of microorganisms and determining whether a product is suitable for preservation is its pH. Preventing the growth of pathogenic bacteria is preferable throughout storage since pH values may be lower than 4.5 (Bruno *et al.* 2020). In addition to pectin extracted from banana peels alone (which shows a higher pH of 4.60), in this case, pectin derived from banana peels is combined with papaya peels to prevent the growth of bacteria during storage (with a lower pH of 4.02). (Bamba *et al.* 2020).

The fruit variety (alone or combined), the acid that was used to adjust the pH, and the purity of the ethanol used to wash the pectin after alcohol precipitation were the main factors contributing to the difference in the pH of the pectin solution (Mada *et al.* 2022).

Methoxyl content, (%)

Table 4 and Fig. 4 illustrate the impact of extraction conditions, such as temperature (85, 90, 95), pH (1.5, 2.0, 2.5), and drying methods (solar dryer and convective hot air drier) on the pectin production from the waste jackfruit peel. The methoxyl content of the sample ranged between 3.338-3.794.

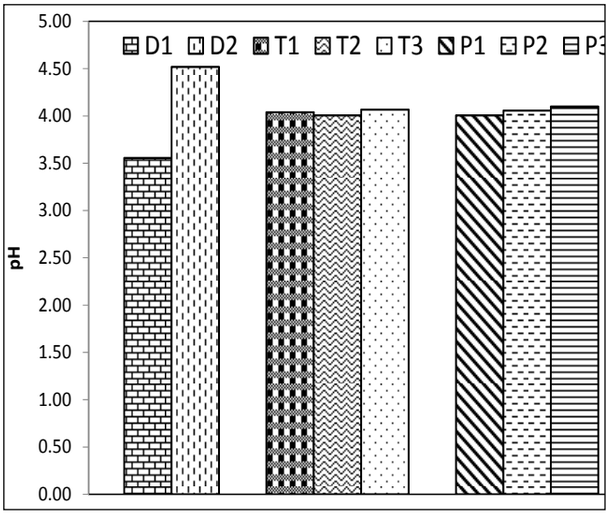

Fig. 4: Effect of Drying Method, Temperature (°C), and pH on pH of Pectin extracted by Microwave Convective Extraction method

Table 4: Effect of Drying Method, Temperature (°C), and pH on pH of Pectin extracted by Microwave Convective Extraction method

Factors	pH			F-Ratio	CD (5%)
Drying Method	3.555	4.518	—	649.994	0.077
Temperature	4.039	4.005	4.066	0.877	N/A
pH	4.100	4.005	4.005	2.78	0.133
Int A × B				5.259	N/A
Int A × C				0.701	N/A
Int B × C				5.822	0.163
Int A × B × C				1.495	N/A

Microwave extraction may lead to higher extraction efficiency but could also cause increased demethoxylation, potentially resulting in lower methoxyl content.

Extraction temperature significantly affects the methoxyl content of pectin; temperature levels resulted in pectin with values between 26.226 and 26.432% of methoxyl; as the extraction temperature increases, the methoxyl content decreases (Alcantara-Marteet *et al.* 2021). According to Lundberg (2018), this appears to be while prolonging the extraction period and elevating the temperature might increase yield, increasing esters hydrolysis in the methoxylated carboxyl groups causes the methoxyls percentage to decrease, which is directly related to pectin quality.

Methoxyl values were affected by the extraction pH; it was observed that the lower the pH, the higher the methoxyl content, which differs from the findings of Vasquez *et al.* (2008), where methoxyl content decreased with decreasing pH, showing 1.47% at pH 2.0 (66% lower compared to that obtained at pH 3.0) low pH conditions the preservation of methoxy groups in pectin, resulting in higher methoxyl content. Higher pH conditions lead to the demethylation of pectin, reducing its methoxyl content. Therefore, for pectin with high methoxyl content, acidic conditions are favorable. (Alcantara-Marte *et al.* 2021).

The fruits' sugar content rises, and their methoxyl content drops as they mature. As the methoxyl level increases, pectin's spreading quality and ability

to bind sugar both rise. The pectin in this study was classified as low methoxyl pectin based on the methoxyl contents of the extracted pulp. According to Brejnholt (2010), the food product's quantity of sugar would, therefore, have no effect on the pectin's ability to gel.

According to Wongkaew *et al.* (2020), methoxyl concentration is an essential indicator of pectin's setting time, ability to combine with metallic ions, ability to distribute in water and gels, and other desirable qualities. Less than 7% methoxyl pectin is classified as low methoxyl pectin, whereas 8–12% methoxyl pectin is classified as high methoxyl pectin. Based on the results of this study, pectin that was extracted from jackfruit peel can be classified as low methoxyl pectin, meaning that it doesn't need sugar to gel and is suitable for use for producing low-sugar food products (Panwar *et al.* 2022).

Anhydrouronic acid content, (%)

Table 5 and Fig. 5 illustrate the impact of extraction conditions, such as temperature (85, 90, 95), pH (1.5, 2.0, 2.5), and drying methods (solar dryer and convective hot air drier) on the pectin production from the waste jackfruit peel. The AUA of the sample ranged between 48.336-53.678 .

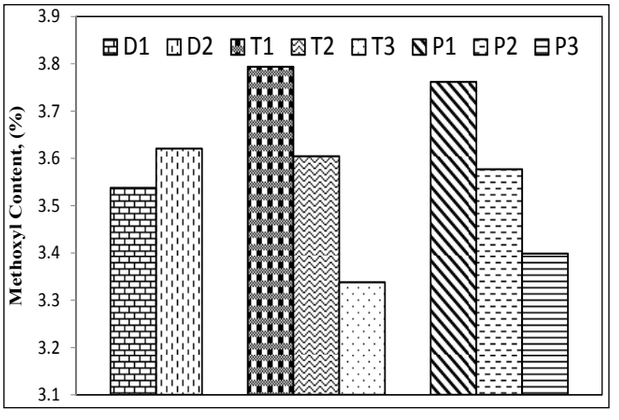

Fig. 5: Effect of Drying Method, Temperature (°C), and pH on Methoxyl Content, (%) of Pectin extracted by Microwave Convective Extraction method

Fig. 5: Effect of Drying Method, Temperature (°C), and pH on Methoxyl Content, (%) of Pectin extracted by Microwave Convective Extraction method

Factors	Methoxyl Content			F-Ratio	CD (5%)
Drying Method	3.537	3.621	—	5.132	0.075
Temperature	3.794	3.604	3.338	51.578	0.091
pH	3.762	3.577	3.398	32.507	0.091
Int A × B				7.623	0.129
Int A × C				5.078	0.129
Int B × C				2.174	N/A
Int A × B × C				3.525	0.224

AUA of pectin is significantly influenced by temperature, higher temperatures can lead to the degradation or breakdown of chemical compounds, including AUA. This might result in changes to the structural and functional properties of pectin. Higher temperatures potentially cause hydrolysis or other thermal degradation of AUA in pectin. This can lead to a decrease in molecular weight and altered physicochemical properties, affecting its gelling or thickening abilities. Monitoring and controlling temperature during the processing or storage of pectin-containing products is crucial to maintaining the desired quality and functionality of the pectin (Valdivia *et al.* 2021).

pH significantly affected the AUA; at Low pH AUA in pectin tends to increase. At low pH, the acidic environment promotes the ionization of carboxyl groups present in AUA of pectin. This ionization results in increased negative charges on the pectin molecules, which contributes to improved interactions with positively charged ions. This enhanced interaction, often through gel formation, is favorable for pectin's functionality in applications such as jams and jellies. Therefore, low pH conditions facilitate the strengthening of the gel network formed by pectin, making it more effective in providing structure and texture to products. The similar result was reported by Begum *et al.* (2017), who obtained anhydrouronic acid 56.11 % by acid-hydrolyzed jackfruit waste pectin.

Moreover, a lower AUA value means that the extracted pectin might consist higher amount of proteins, starch, and neutral sugars such as rhamnose, arabinose, galactose, glucose, and xylose (Grassino *et al.* 2020). The presence of these sugars works as a common interface in AUA quantification and might lead to the reduction of AUA detection (Grassino *et al.* 2020).

The content of AUA is the predominant factor that indicates the purity of extracted pectin and affects its gelling properties (Islam *et al.* 2023) According to the standards of the Food and Agriculture Organization (FAO) and Food Chemical Codex (FCC), the recommended value of AUA should not be less than 65 % for pectin used as food additives or for pharmaceutical agents on ash and moisture-free basis (FCC, 1981).

Equivalent Weight (mg/mol)

Table 6 and Fig. 6 illustrate the impact of extraction conditions, such as temperature (85, 90, 95), pH (1.5, 2.0, 2.5), and drying methods (solar dryer and convective hot air drier) on the pectin production from the waste jackfruit peel. The equivalent weight of the sample ranged between 428.013-462.838.

A higher gel-forming influence is indicated by a higher Equivalent Weight number. According to Islam *et al.* (2023) and Siddiqui *et al.* (2021), the equivalent weight of pectin indicates the amount of free galacturonic acid present. A higher or lower equivalent weight may be associated with the amount of free acid.

Extraction temperature significantly affected the equivalent weight of pectin because the equivalent weight of pectin generally decreases with an increase in temperature. This is because higher temperatures can lead to increased molecular mobility, making it easier for chemical reactions to occur. As a result, the effective molecular weight of pectin decreases, leading to a lower equivalent weight. Dranca *et al.* (2020).

pH also significantly influenced the equivalent weight of pectin. The equivalent weight tends to decrease as the pH increases. This is because pectin molecules undergo ionization at different pH levels. At higher pH, pectin carboxyl groups are more likely to be ionized, reducing the effective molecular weight and leading to a lower equivalent weight (Misra and Yadav, 2020).

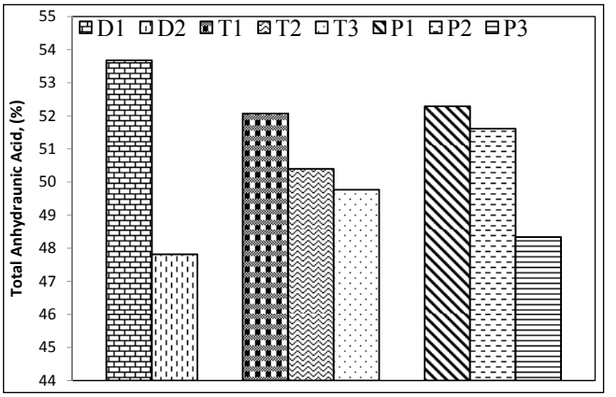

Fig. 6: Effect of Drying Method, Temperature (°C), and pH on Total Anhydrouronic acid content, (%) of Pectin extracted by Microwave Convective Extraction method

Table 6: Effect of Drying Method, Temperature (°C), and pH on Total Anhydrouronic acid content, (%)of Pectin extracted by Microwave Convective Extraction method

Factors	Total Anhydrouronic acid content, (%)			F-Ratio	CD (5%)
Drying Method	53.678	47.816			0.033
Temperature	52.073	50.400	49.769	7,001.87	0.041
pH	52.291	51.614	48.336	22,112.34	0.041
Int A × B				24,316.48	0.058
Int A × C				6,969.94	0.058
Int B × C				591.184	0.071
Int A × B × C				1,146.87	0.1

Azad *et al.* (2014) observed that equivalent weight depends on the maturity stage of the fruit. Pectin from overripe fruits shows lower equivalent weight, while pectin from mature fruits shows higher equivalent weights. The lower equivalent weight could be due to higher partial degradation of pectin. The results were, therefore, appropriate because peels of ripe fruits (representing important waste materials) were used for the extraction.

Similar to Panwar *et al.* (2022), the equal weight value of pectin was identified in this investigation reported for 477.89 0.43 from citrus limetta peel; but slightly lower than Ghoshal & Negi (2020), reported for 652.14 ±0.21 from kinnow peel.

Equivalent weight the equivalent weight was calculated in order to analyze the stability, and emulsion potential and to assess the amount of free acid contained in the pectin molecule.

Degree of Esterification, (%)

Table 7 and Fig. 7 illustrate the impact of extraction conditions, such as temperature (85, 90, 95), pH (1.5, 2.0, 2.5), and drying methods (solar dryer and convective hot air drier) on the pectin production from the waste jackfruit peel. The degree of esterification of the sample ranged between 30.996-33.713.

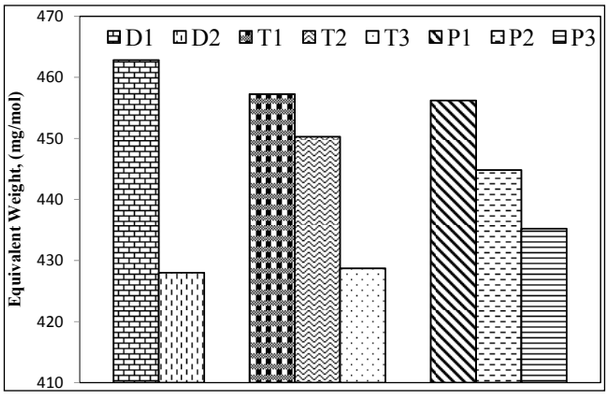

Fig. 7: Effect of Drying Method, Temperature (°C), and pH on Equivalent Weight, (mg/mol), of Pectin extracted by Microwave Convective Extraction method

The DE is an important factor indicating the methyl and acetyl groups linked to the Galacturonic acid. As maturity increases, the esterification degree reduces. Since the extraction process involved using the fruit skins of mature fruits, the final results remain constant. Mature passion fruit was used by Liew *et al.* 2018 and Lan *et al.* 2021 to extract pectin with esterification degrees ranging from 45 to 65 %. Ahmmed (2017) (reported a DE value of 34.29 % for the jackfruit pectin that was isolated from jackfruit peel. According to Sundar Raj *et al.* (2012) the degree of esterification depends on species, tissue and stages of maturity.

Fig. 7: Effect of Drying Method, Temperature (°C), and pH on Equivalent Weight, (mg/mol) of Pectin extracted by Microwave Convective Extraction method

Factors	Equivalent weight, (mg/mol)			F-Ratio	CD (5%)
Drying Method	462.838	428.013		289.236	4.154
Temperature	457.268	450.279	428.729	70.383	5.088
pH	456.223	444.829	435.224	35.161	5.088
Int A × B				24.401	7.196
Int A × C				1.462	N/A
Int B × C				2.66	8.813
Int A × B × C				1.988	N/A

The DE is significantly affected by temperature high temperature shows the low DE. The pectin extracted at low temperatures had a high equivalent weight. The results indicated that the higher the extraction temperature, the higher the yield of pectin but the equivalent weight decreased. The partial breakdown of pectin may be the cause of this. Similar results were found by (Garna *et al.* 2007) the DE in pectin from Jackfruit waste material was low. An increase in the temperature of extraction of pectin using hydrochloric acid at pH 2.5 from 50 to 95 °C produced pectin with a lower DE. This may be due to the hydrolysis of acetic acid groups from galacturonic acids under drastic extraction conditions. With the rise in temperature, as more thermal energy is available to hydrolyze the ester bonds, further de-esterification of pectin during extraction was evident in this study. Similar results were reported in previous studies for peels of citrus (Kanmani *et al.* 2014), (Sangheetha *et al.* 2019).

The DE is greatly affected by pH; as pH rises, the inadequate amount of H+ ions to de-esterify pectin during extraction is detected by a dramatic increase in DE up to pH 2.5 and an average increase after that up to pH 3.7. As a result, the DE value increases as pH increases and decreases as pH drops. This study showed that there was additional de-esterification of pectin during extraction as a result of temperature increase since higher temperatures provide more

thermal energy available to hydrolyze the ester linkages. Previous studies on citrus peels (Kanmani *et al.* 2014), mango peels (Sayah *et al.* 2014), and banana peels (Emanga *et al.* 2008) revealed similar findings. With the increase in the duration (time) of extraction, as the amount of thermal energy available to hydrolyze the ester bonds increases, de-esterification enhances, thereby reducing the DE of pectin (Adetunji *et al.* 2017).

The current data are well aligned with the DE 45.62 ± 0.64 % of pectin from citrus limetta peels using citric acid-assisted extraction, which was reported earlier (Panwar *et al.* 2022). Low DE pectin may form gels even in a lack of sugar, which makes it useful for creating food products with fewer calories (Panwar *et al.* 2022). A similar DE were reported by the Hosseini (2020) reported sour orange shows low methoxyl pectin (ranged formed 1.7-37.5 %).

However, in recent times, there has been more interest in the manufacturing of LM pectin due to its gelling characteristic, which is suitable for the production of low-calorie and dietetic foods. This is in accordance with the increased health awareness among consumers nowadays.

Galacturonic acid content, (%)

Table 8 and Fig. 8 illustrate the impact of extraction conditions, such as temperature (85, 90, 95), pH (1.5, 2.0, 2.5), and drying methods (solar dryer and convective hot air drier) on the pectin production from the waste jackfruit peel. The galacturonic acid content (%) of the sample ranged between 41.447-43.555.

One of the most crucial characteristics of pectin that determines its purity is its GalAcontent. The FAO recommends that GalA values of pectin should be higher than 65 % to be accepted as a food additive and for pharmaceutical purposes (Hosseini *et al.* 2020).

The galacturonic acid increases as the temperature increases and pH decreases. According to Fraeye *et al.* (2007), this could be explained by the faster acid hydrolysis of the side chains of pectin sugar at higher temperatures. Garna *et al.* (2004) deduced that chemical hydrolysis of pectin with acid at high temperature (100 °C) seems to combine two simultaneous phenomena: firstly, the release of sugars as a product of hydrolysis of the pectin, and secondly, their degradation under the action of the acid and the heat. They showed that a lower temperature of 80 °C caused less degradation to pectin sugar side chains as compared to a higher temperature of 100 °C.

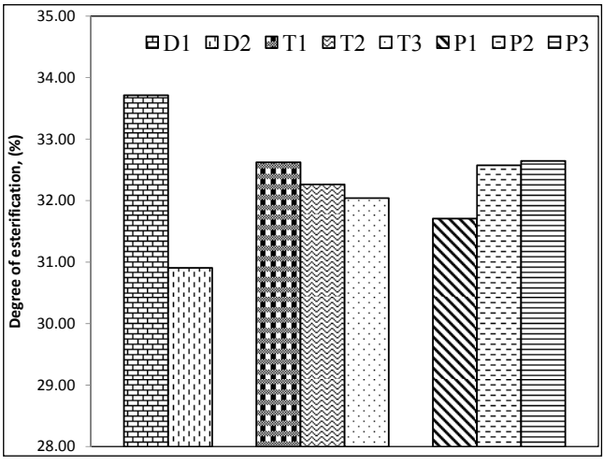

Fig. 8: Effect of Drying Method, Temperature (°C), and pH on Degree of Esterification, (%) of Pectin extracted by Microwave Convective Extraction method

Table 8: Effect of Drying Method, Temperature (°C), and pH on Degree of Esterification, (%) of Pectin extracted by Microwave Convective Extraction method

Factors	Degree of Esterification, (%)			F-Ratio	CD (5%)
Drying Method	33.713	30.906	—	30,855.87	0.032
Temperature	32.623	32.264	32.041	450.514	0.04
pH	31.708	32.574	32.646	1,424.29	0.04
Int A × B				6,693.77	0.056
Int A × C				1,809.06	0.056
Int B × C				646.671	0.069
Int A × B × C				868.026	0.097

A similar result was shown by Chan (2013); increasing the extraction temperature from using citric acid at pH 4.0 or hydrochloric acid at pH 2.5 produced pectin with a higher galacturonic acid content. Garna *et al.*

(2007) reported that the galacturonic acid content obtained from apple pectin was always higher at 90 than at 80 °C when extracted using sulphuric acid at pH 1.5 or 2.0.

Intrinsic viscosity, (dl/g)

Table 9 and Fig. 9 illustrate the impact of extraction conditions, such as temperature (85, 90, 95), pH (1.5, 2.0, 2.5), and drying methods (solar dryer and convective hot air drier) on the pectin production from the waste jackfruit peel. The intrinsic viscosity of the sample ranged between 2.205-2.259.

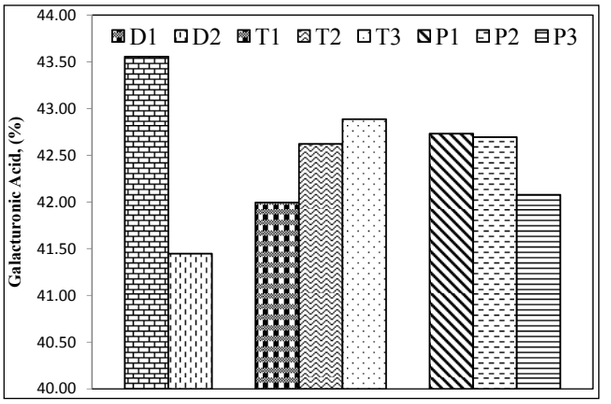

Fig. 9: Effect of Drying Method, Temperature (°C), and pH on Galacturonic acid content, (%) of Pectin extracted by Microwave Convective Extraction method

Table 9: Effect of Drying Method, Temperature (°C), and pH on Galacturonic acid content, (%) of Pectin extracted by Microwave Convective Extraction method

Factors	Galacturonic acid content			F-Ratio	CD (5%)
Drying Method	43.555	41.447	—	17,007.71	0.033
Temperature	41.994	42.622	42.887	1,069.73	0.04
pH	42.732	42.694	42.077	687.996	0.04
Int A × B				4,145.11	0.057
Int A × C				207.28	0.057
Int B × C				610.828	0.07
Int A × B × C				292.099	0.098

As temperature increases, the intrinsic viscosity of pectin decreases. This is due to the higher temperatures disrupting the molecular structure of pectin, reducing its ability to form a gel-like network. (Hua, 2015)

This shows an intrinsic viscosity increases as pH decreases. The viscosity of pectin is influenced by pH. Pectin is most effective at gelling in acidic conditions. As pH increases more alkaline, the viscosity of pectin increases Alfonso (2010).

Spredability, (mm)

Table 10 and Fig. 10 illustrate the impact of extraction conditions, such as temperature (85, 90, 95), pH (1.5, 2.0, 2.5), and drying methods (solar dryer and convective hot air drier) on the pectin production from the waste jackfruit peel. The spreadability of the sample ranged between 127.610-135.222

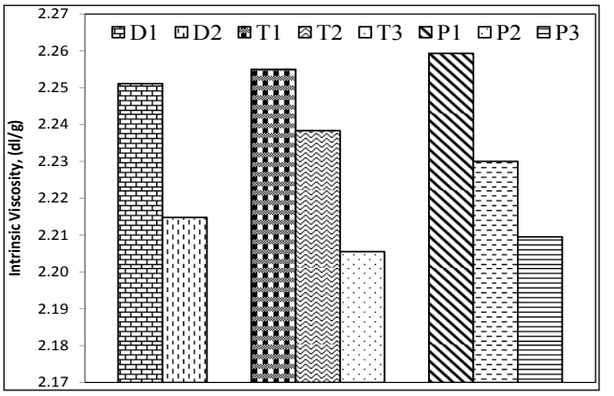

Fig. 10: Effect of Drying Method, Temperature (°C), and pH on Intrinsic viscosity, (dl/g) of Pectin extracted by Microwave Convective Extraction method

Table 10: Effect of Drying Method, Temperature (°C), and pH on Intrinsic viscosity, (dl/g)of Pectin extracted by Microwave Convective Extraction method

Factors	Intrinsic viscosity, (dl/g)			F-Ratio	CD (5%)
Drying Method	2.251	2.214	—	5.146	0.032
Temperature	2.255	2.238	2.205	3.299	0.04
pH	2.259	2.230	2.209	3.293	0.04
Int A × B				0.969	0.024
Int A × C				0.075	0.032
Int B × C				0.378	N/A
Int A × B × C				0.061	N/A

Spreadability is related to Intrinsic viscosity; as viscosity increases, spreadability decreases (Swami *et al.* 2004). As temperature increases, the viscosity and spreadability of pectin decreases. This is due to the higher temperatures disrupting the molecular structure of pectin, reducing its ability to form a gel-like network (Hua, 2015).

This shows a viscosity and spreadability increase as pH decreases. The viscosity and spreadability of pectin are influenced by pH. Pectin is most effective at gelling in acidic conditions. As pH increases more alkaline, the viscosity of pectin increases (Alfonso, 2010).

Colour (L) Value

Table 11 and Fig. 11 illustrate the impact of extraction conditions, such as temperature (85, 90, 95), pH (1.5, 2.0, 2.5), and drying methods (solar dryer and convective hot air drier) on the pectin production from the waste jackfruit peel. The Colour (L) value of the sample ranged between 44.926-52.911.

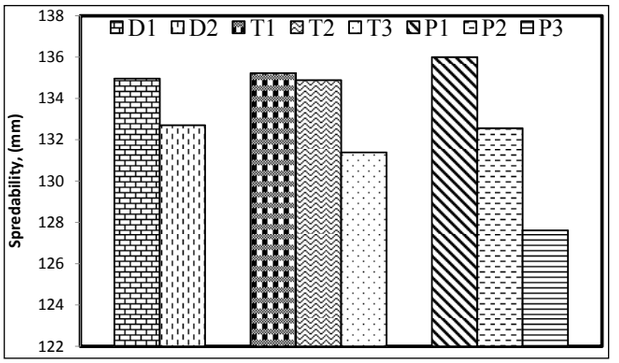

Fig. 11: Effect of Drying Method, Temperature (°C), and pH on Spredability, (mm)of Pectin extracted by Microwave Convective Extraction method

Table 11: Effect of Drying Method, Temperature (°C), and pH on Spredability, (mm)of Pectin extracted by Microwave Convective Extraction method

Factors	Spredability			F-Ratio	CD (5%)
Drying Method	134.962	132.703	—	5.331	1.985
Temperature	135.222	134.888	131.388	6.279	2.431
pH	135.999	132.5555	127.610	67.259	2.431
Int A × B				102.784	3.438
Int A × C				2.64	N/A
Int B × C				14.33	4.211
Int A × B × C				35.855	5.955

Colour (a) Value

Table 12 and Fig. 12 illustrate the impact of extraction conditions, such as temperature (85, 90, 95), pH (1.5, 2.0, 2.5), and drying methods (solar dryer and convective hot air drier) on the pectin production from the waste jackfruit peel. The Colour (a) Value of the sample ranged between 13.213-14.672.

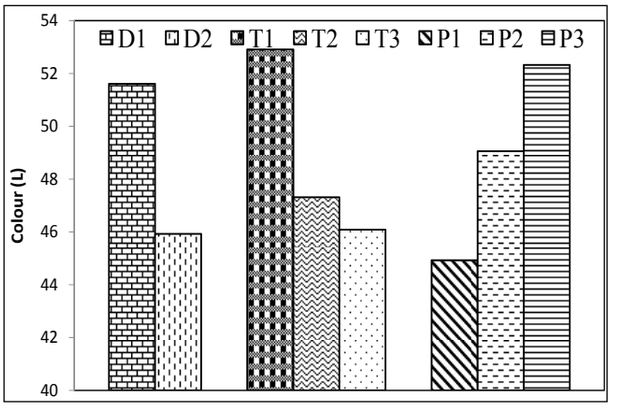

Fig. 12: Effect of Drying Method, Temperature (°C), and pH on Colour (L) Value of Pectin extracted by Microwave Convective Extraction method

Table 12: Effect of Drying Method, Temperature (°C), and pH color (L) Value of Pectin extracted by Microwave Convective Extraction method

Factors	Colour (L) Value			F-Ratio	CD (5%)
Drying Method	51.611	45.9277	—	7,573.86	0.132
Temperature	52.911	47.311	46.085	4,140.99	0.162
pH	44.926	49.056	52.325	4,297.59	0.162
Int A × B				2,478.01	0.229
Int A × C				1,705.12	0.229
Int B × C				784.659	0.281
Int A × B × C				443.173	0.397

Color (b) Value

Table 13 and Fig. 13 illustrate the impact of extraction conditions, such as temperature (85, 90, 95), pH (1.5, 2.0, 2.5), and drying methods (solar dryer and convective hot air drier) on the pectin production from the waste jackfruit peel. The Colour (b) value of the sample ranged between 18.428-20.714.

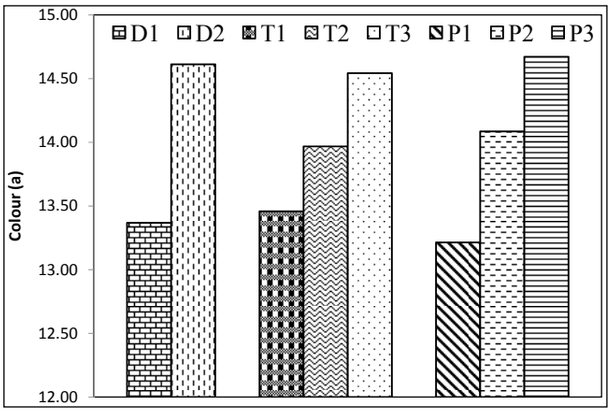

Fig. 13: Effect of Drying Method, Temperature (°C), and pH on Colour (a) Value of Pectin extracted by Microwave Convective Extraction method

Table 13: Effect of Drying Method, Temperature (°C), and pH on Colour (a) Value of Pectin extracted by Microwave Convective Extraction method

Factors	Colour (a) Value			F-Ratio	CD (5%)
Drying Method	13.368	14.612		3,197.85	0.045
Temperature	13.458	13.968	14.543	811.205	0.055
pH	13.213	14.085	14.672	1,482.54	0.055
Int A × B				2,073.76	0.077
Int A × C				2,608.35	0.077
Int B × C				147.987	0.095
Int A × B × C				642.818	0.134

Colour of pectin is an important factor affecting the appearance of the gel formed. Lighter color of pectin is preferred in order to have minimal effect on the Refinal appearance of end product. In general, the colour of pectin is varied according to a source (Mohamed and Hasan, 1995).

The colour that appeared on pectin is possibly due to the entrapment of polyphenols or water-soluble pigments in pectin during precipitation. Improvement of pectin color could be achieved by performing filtration using filter aid, activated carbon, diatomaceous earth, and others (Mohamed and Hasan, 1995).

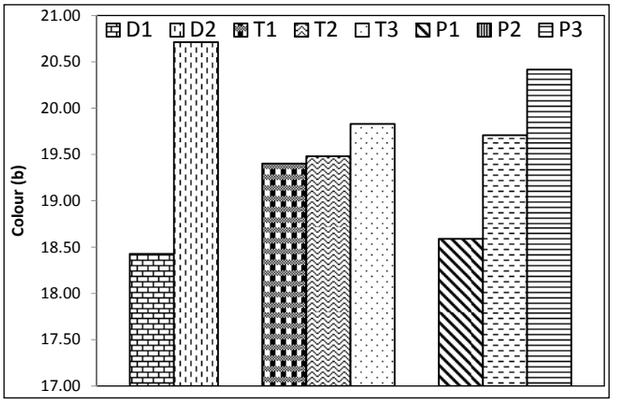

Fig. 14: Effect of Drying Method, Temperature (°C), and pH on Colour (b) Value of Pectin extracted by Microwave Convective Extraction method

Fig 14: Effect of Drying Method, Temperature (°C), and pH on Colour (b) Value of Pectin extracted by Microwave Convective Extraction method

Factors	Colour (b) Value			F-Ratio	CD (5%)
Drying Method	18.428	20.714	—	1,829.68	0.108
Temperature	19.403	19.481	19.829	23.986	0.133
pH	18.589	19.708	20.416	396.045	0.133
Int A × B				4.542	0.188
Int A × C				58.175	0.188
Int B × C				19.948	0.23
Int A × B × C				1.638	N/A

CONCLUSION

There is a need to develop a new extraction process as the old method took a long time and also had adverse effects on the pectin. So, Microwave Convective is an alternative method to minimize the time required to extraction of pectin and also the adverse effects on pectin. Microwave Convective is one of the

new emerging extraction methods. The desirable best results were obtained by 85° temps and 1.5 pHexatraction condition as; Yield (8.120%), Moisture content (8.001%), Ash content (2.77 %), pH (3.555%), Methoxyl Content (3.794 %), Anhydronic acid (52.529 %), Equivalent weight (457.268 mg/mol), degree of esterification (32.623 %), Galacturonic acid (42.887 %), Intrinsic viscosity (2.259 dl/g), Spredability (127.610 mm), Colour L (52.911), Colour a (13.213), Colour b (18.589).

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