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Effect of Citric Acid Concentration on the Pectin Characteristics of Robusta Coffee (*Coffea canephora*) Pulp

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ABSTRACT

Coffee pulp waste, a by-product of the coffee industry, is often considered low-value and poses environmental concerns if not properly managed. However, its high pectin content presents potential for use in producing edible films. This study investigated the effect of citric acid concentration (0.1, 0.5, and 1 M) during extraction on the yield and characteristics of the pectin produced. The results showed that the higher the citric acid concentration, the higher the pectin yield, ranging from 7.7% at 0.1 M to 22.13% at 1 M. However, higher acid concentration resulted in decreases in equivalent weight (235.59±11.76 to 93.53±3.71 mg/eq), methoxyl content (5.43±0.22 to 1.86±0.00%), and degree of esterification (38.4±0.34 to 5.56±0.22%). In contrast, the galacturonic acid content increased (80.23±3.95 to 190.18±7.47%). FTIR analysis confirmed that higher citric acid concentrations significantly influenced the structural and chemical characteristics of the pectin. Overall, extraction using citric acid at concentrations of 0.1–1 M produced pectin classified as low-methoxyl and low-ester pectin, with potential applications in calcium-induced gel systems, low-sugar food products, thickeners, and biodegradable edible films. Future studies should optimize extraction conditions, including pH, temperature, time, and solvent-to-solid ratio, to enhance pectin yield and quality.

Keywords: citric acid, coffee pulp waste, galacturonic acid, methoxyl content, pectin

INTRODUCTION

Indonesia, as one of the largest coffee bean producers in the world, has a coffee production of 813,340 tonnes in 2024, representing a 7.4% increase compared with 2020 (BPS, 2025; Direktorat Jenderal Perkebunan, 2023). The largest contribution came from South Sumatra Province, with production reaching 219,586 tonnes or 26.99% of the national total (BPS, 2025). Robusta coffee (*Coffea canephora*) is the predominant type produced, contributing approximately 81% of total coffee production (Direktorat Jenderal Perkebunan, 2023). The high production of robusta coffee inevitably results in a large amount of coffee pulp waste.

Coffee pulp waste, one of the significant wastes from the coffee industry, is estimated to reach 50% of every coffee fruit produced (Reichembach and Petkowicz, 2020). Therefore, the rise in coffee production in Indonesia will lead to an increase in the production of coffee pulp waste (Rahmah *et al.*, 2023). This waste is often regarded as a low-value by-product and may pose environmental concerns if not properly managed. Improper disposal can also lead to economic losses for farmers and the coffee industry. Therefore, innovative and sustainable management strategies are needed to utilize coffee pulp waste effectively while minimizing its negative impacts (Lee *et al.,* 2023).

Robusta coffee pulp has the potential to form edible films, which can reduce the use of plastic packaging (Dea *et al.,* 2022). This is due to the significant content of pectin compounds in coffee pulp, reaching around 35% (Hasanah *et al.,* 2019; Reichembach *et al.,* 2024). With this composition, the coffee pulp has the potential to be an ideal source of pectin for making edible films (Vallejos-Jiménez *et al.*, 2025; Reichembach *et al.,* 2024). However, research on the extraction of pectin from coffee pulp using citric acid as a solvent is still relatively rare. Using citric acid is considered more environmentally friendly than other strong acids (Belkheiri *et al.*, 2021). It has been

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shown to significantly increase pectin yield compared with hydrochloric acid in watermelon rind extraction (Lee and Choo, 2020). In addition, citric acid is considered a milder extracting agent that can reduce pectin depolymerization compared with strong mineral acids (Belkheiri *et al.,* 2021).

Previous studies have shown that the ratio between coffee pulp and citric acid has a significant effect on the yield and characteristics of pectin. For example, a 1:20 (w/v) ratio at pH 4 resulted in high methoxyl pectin (Hasanah *et al.,* 2019). In addition, pectin was extracted from coffee pulp using 1 M citric acid at pH 1.8, obtaining a pectin yield of 6.14%, a methoxyl content of 4.85%, and a degree of esterification of 72.74% (Vallejos-Jiménez *et al.*, 2025). These findings indicate that both the solvent ratio and acid concentration strongly influence pectin yield and quality, particularly the methoxyl content and esterification degree.

However, previous studies have mainly focused on differences in solvent ratio, pH, or the use of a single citric acid concentration, while no study has systematically evaluated the effect of varying citric acid concentrations under identical extraction conditions on pectin derived from robusta coffee pulp. Consequently, the optimum citric acid concentration for maximizing pectin yield while maintaining desirable quality parameters, including methoxyl content, galacturonic acid content, equivalent weight, and degree of esterification, remains unclear. A study by Jong *et al.* (2023) on the extraction of pectin from durian skin showed that acid type and concentration significantly affected pectin yield and characteristics, indicating that acid concentration is a critical parameter in the extraction process (Jong *et al.,* 2023). Therefore, this study was conducted to address this gap by systematically evaluating several citric acid concentrations for the extraction of pectin from robusta coffee pulp in order to determine their effects on pectin yield and quality in accordance with the standards established by the International Pectin Producers Association (IPPA, 2014).

MATERIALS AND METHOD

Materials

The main material in this study was robusta coffee pulp waste, which was collected from a coffee bean mill in Gunung Liwat Village, Ogan Komering Ulu Regency, South Sumatra Province, Indonesia, in May 2024. Other supporting materials included citric acid, ethanol (96% food-grade), ethanol (p.a. Merck), sodium chloride (p.a. Merck), distilled water (aquadest), sodium hydroxide (0.1 N and 0.2 N), hydrochloric acid (0.2 N), and phenol red (1%) as an indicator.

Raw material preparation

The coffee pulp was washed thoroughly under running water to remove surface contaminants. Subsequently, the coffee pulp was dried in an oven (Advance AOV-500, 900 W, Indonesia) at 105 °C for 3 h. The drying and weighing processes were repeated every 30 min using an analytical balance (OHAUS PX224/E, China) until a constant weight was achieved. The dried coffee pulp was subsequently ground using a universal mill (Fomac, Indonesia) and sieved using a 60-mesh sieve (KZM, Indonesia) to obtain a uniform particle size.

Extraction process

Thirty grams of coffee pulp powder were dissolved in citric acid solution (0.1 M, 0.5 M, and 1 M) with a ratio of 1:25 (w/v). The mixture was heated at 90 °C for 90 min while being stirred at 900 rpm using a digital magnetic stirrer with a hot plate (DMS-HS, EMCLAB, Germany). After heating, the solution was cooled to room temperature and filtered using a Buchner funnel (IWAKI, Indonesia) lined with filter paper and connected to a vacuum pump (Joanlab VP-10L, China) to separate the filtrate. The pH of the filtrate was measured using universal pH paper (Merck, Germany). If the pH is not as expected, it should be adjusted by adding small amounts of acid to lower it or a base to raise it, followed by gentle stirring until the desired pH is reached.

Pectin deposition

The filtrate was mixed with 96% food-grade ethanol at a 1:1 (v/v) ratio and allowed to stand at room temperature for three days to precipitate the pectin. The resulting precipitate was separated using a Buchner funnel (IWAKI, Indonesia) and then dried in an oven (Advance AOV-500, 900 W, Indonesia) at 60 °C for 10 h until a constant mass was achieved.

Determination of pectin yield

The extracted pectin was weighed, and the weight was recorded. The pectin yield was calculated using Equation 1.

$$\text{Yield (\%)} = \frac{\text{dry pectin mass (g)}}{\text{dry coffee pulp mass (g)}} \times 100\% \quad \ldots\ldots\ldots (1)$$

Determination of equivalent weight (EW)

A total of 0.5 g of pectin was weighed and moistened with 2 mL of ethanol p.a. The sample was then dissolved in 40 mL of aquadest and stirred at 40 °C for 1 h until fully dissolved. Subsequently, 1 g of NaCl and five drops of phenol red indicator (1%) were added. The solution was titrated with NaOH (0.1 N) until a persistent pink color remained for 30 s. The volume of NaOH used was recorded, and the equivalent weight was calculated using Equation 2 (Baraiya *et al.,* 2023).

$$EW\ \left(\frac{mg}{eq}\right)=\frac{\text{weight of the sample (mg)}}{\text{V NaOH (mL)}\times\text{N NaOH (N)}} \quad \text{..... (2)}$$

EW is the equivalent weight (mg/eq), V NaOH is the volume of NaOH used in the titration (mL), and N NaOH is the normality of the NaOH solution (N).

Determination of methoxyl content (MC)

The solution obtained from the equivalent weight determination was added with 25 mL of NaOH (0.2 N) and stirred for 1 h under closed conditions. Then, 25 mL of HCl (0.2 N) and five drops of phenolphthalein indicator (PP) were added. The solution was titrated with NaOH (0.1 N) until a pink color persisted for 30 s. The volume of NaOH used was recorded, and the methoxyl content was calculated using Equation 3. (Silsia *et al.,* 2021).

$$MC\ (\%)=\frac{\text{V NaOH (mL) x 31 x N NaOH (N)}}{\text{weight of the sample (mg)}}\times 100\% \text{.. (3)}$$

MC is the methoxyl content (%), V NaOH is the volume of NaOH used in the titration (mL), N NaOH is the normality of the NaOH solution (N), and 31 is the molecular weight of the methoxyl group (g/mol).

Determination of galacturonic acid content (GAC)

The galacturonic acid content was calculated using Equation 4 (Silsia *et al.,* 2021).

$$GAC\ (\%)=\frac{176x0.1V_1(mL)x100\%}{\text{weight of the sample (mg)}}+$$

$$\frac{31x\ 0.1V_2(mL)x100\%}{\text{weight of the sample (mg)}} \quad \text{..... (4)}$$

GAC is the galacturonic acid content (%), V_1 is the volume of NaOH used in determining the equivalent weight (mL), V_2 is the volume of NaOH used in determining the methoxyl content (mL), 176 is the molecular weight of galacturonic acid (g/mol), and 31 is the molecular weight of the methoxyl group (g/mol).

Determination of degree of esterification (DE)

The degree of esterification was calculated using methoxyl content and galacturonic acid values, as shown in Equation 5.

$$DE\ (\%)=\frac{MC\ (\%)}{GAC\ (\%)}\times 100\% \quad \text{..... (5)}$$

DE is the degree of esterification (%), MC is the methoxyl content (%), and GAC is the galacturonic acid content (%).

Analysis of Fourier transform infrared spectroscopy (FTIR)

The FTIR analysis of the pectin samples was performed using an FTIR spectrometer (Agilent Carry 630, USA). The analysis involved 32 scans at a resolution of 16 cm^{-1}, covering the range from 4000 to 650 cm^{-1}, to identify the functional groups and molecular structure of the pectin samples.

RESULTS AND DISCUSSION

Coffee pulp pectin yield

The concentration of citric acid had a significant effect on the pectin yield. The lowest yield was obtained at 0.1 M citric acid, with a value of 7.7%, while the highest yield was observed at 1 M, reaching 22.13%. These results indicated that increasing citric acid concentration enhanced the extraction efficiency and promoted greater recovery of pectin from coffee pulp. Figure 1 shows a consistent increase in yield as the acid concentration increased from 0.1 to 1 M.

The higher the concentration of acid involved in the extraction process, the more H^+ ions are formed. This increases the acid's ability to break the bonds between protopectin and cellulose, thereby improving pectin extraction (Filianty *et al.,* 2024). As a result, more pectin is released, while cellulose and some minerals are separated (Putri *et al.*, 2021; Trang *et al.*, 2024). In addition, low pH accelerates the cleavage of hydrogen and ester bonds between pectin and cell walls, thereby increasing pectin diffusion and extraction (Lee and Choo, 2020; Trang *et al.*, 2024). Figure 2 illustrates the visual differences in the amount of pectin obtained at each citric acid concentration.

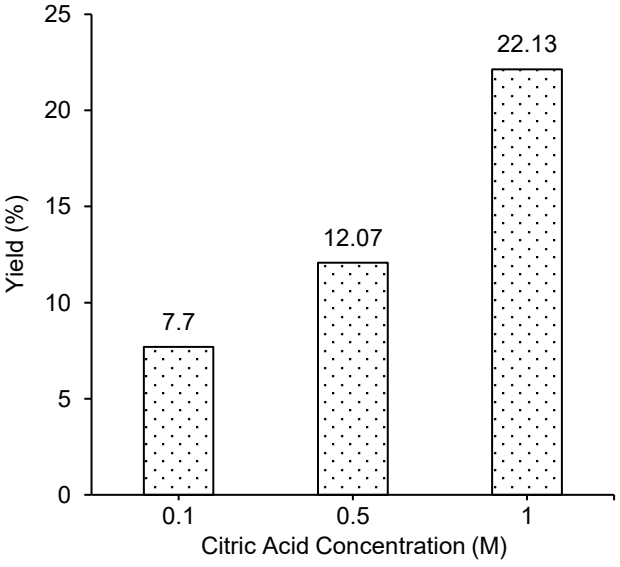

Figure 1. Effect of citric acid concentration on coffee pulp pectin yield

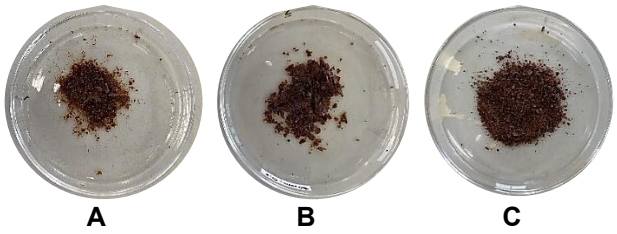

Figure 2. The appearance of coffee pulp pectin based on variations in citric acid concentration (A) 0.1 M; (B) 0.5 M; (C) 1 M

Characterization of coffee pulp pectin

The characterization of pectin involves several important parameters, such as equivalent weight, methoxyl content, galacturonic acid content, degree of esterification, and components in the sample. Characterization can also determine the quality and usefulness of pectin in various applications. Table 1 and Figure 3 illustrate the characterization of pectin based on different concentrations of citric acid.

Table 1. Comparison of equivalent weight, methoxyl content, galacturonic acid content, and degree of esterification of coffee pulp pectin extracted using different citric acid concentrations with IPPA standards

Paramater	IPPA Standard (IPPA, 2014)	Citric Acid Concentration (M)		
		0.1	0.5	1
Equivalent weight (mg/eq)	600–800 mg/eq	235.59±11.76	116.53±7.67	93.53±3.71
Methoxyl content (%)	High methoxyl (>7.12%) Low methoxyl (2.5-7.12%)	5.43±0.22	2.79±0.00	1.86±0.00
Galacturonic acid content (%)	Min. 35%	80.23±3.95	154.15±9.96	190.18±7.47
Degree of esterification (%)	High ester (Min. 50%) Low ester (Max. 50%)	38.40±0.34	10.30±0.67	5.56±0.22

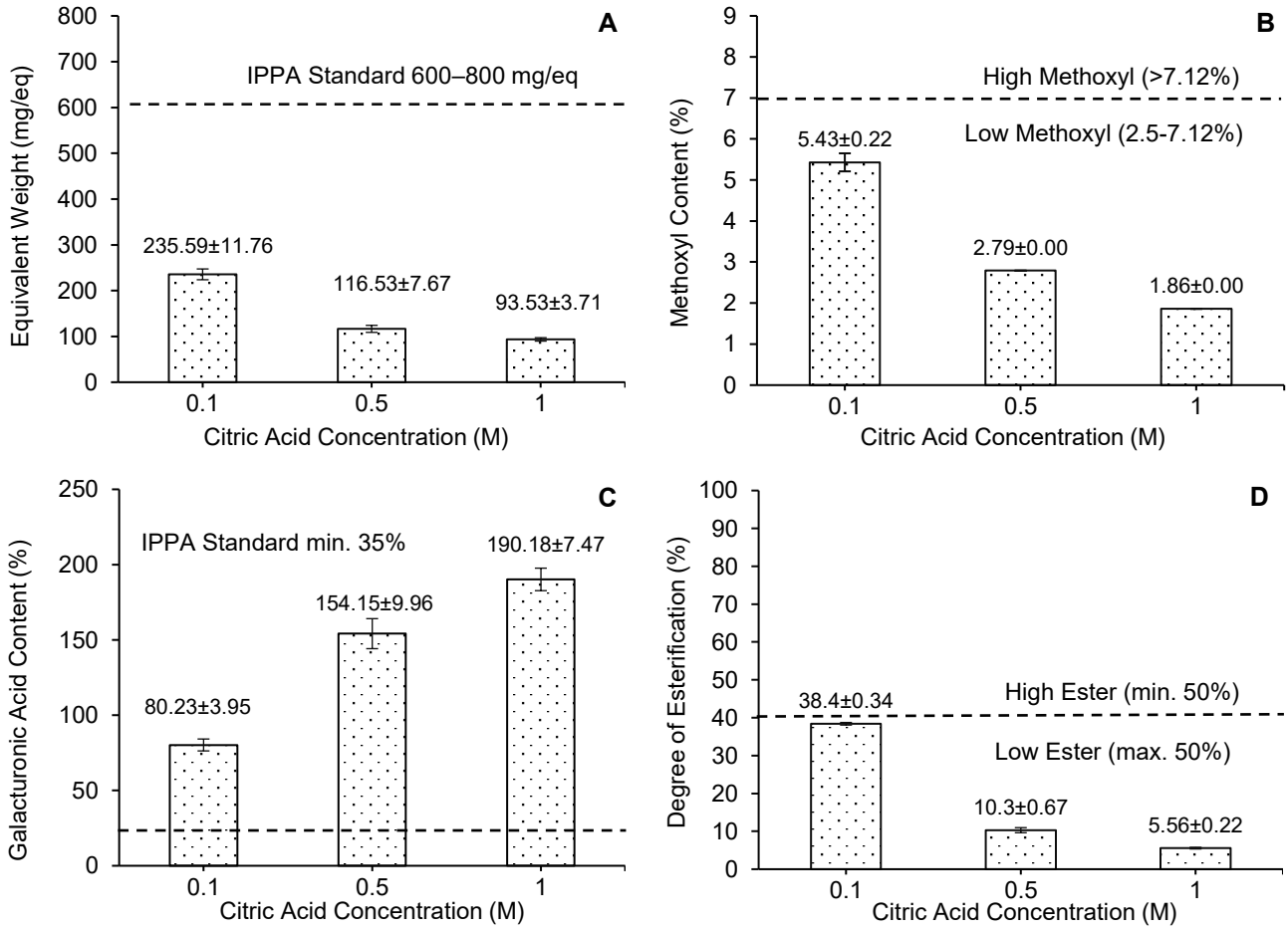

Figure 3. Effect of citric acid concentration on (A) equivalent weight, (B) methoxyl content, (C) galacturonic acid content, and (D) degree of esterification

Equivalent weight

Equivalent weight (EW) reflects the content of anhydrouronic acid and the degree of esterification in pectin. This measurement is carried out through titration using sodium hydroxide until it reaches pH 7.5 with a phenol red indicator (Baraiya *et al*., 2023). EW indicates the amount of free galacturonic acid in pectin, reflecting the pectin molecular structure's methoxyl and carboxyl content. Generally, the higher the EW, the higher the methoxyl content, and vice versa (Biratu *et al.,* 2024).

Titration analysis showed a decrease in EW with increasing acid concentration (Figure 3A). This trend is likely due to the deesterification of pectin into pectic acid, which raises the free acid content and thereby reduces the EW (Kurniawan and Adenia, 2022). These findings are consistent with previous studies showing that acid type and extraction conditions strongly influence pectin characteristics. Vallejos-Jiménez *et al.* (2025) reported a higher EW value of 602.79 mg/eq for pectin extracted from coffee pulp using 1 M citric acid at pH 1.8, indicating a more preserved pectin structure than that obtained in the present study. Similarly, Biratu *et al.* (2024) found that pectin extracted from Coffee arabica pulp using 0.1 M H_2SO_4 had a higher EW value of 1,429±54 g/mol. In a broader comparison using H_2SO_4, HNO_3, and HCl, EW ranged from 1,111 to 1,667 g/mol (Biratu *et al.,* 2024). These values were generally higher than those obtained in the present study, suggesting that differences in solvent type, acid concentration, pH, and extraction conditions significantly affect pectin deesterification, hydrolysis, and structural integrity (Belkheiri *et al.,* 2021; Biratu *et al.,* 2024; Vallejos-Jiménez *et al.,* 2025).

The EW values obtained in this study fall below the IPPA standard range of 600–800 mg/eq (IPPA, 2014). Fruit ripeness may influence these results, as pectin extracted from overripe fruits generally has lower EW values than pectin from ripe fruits. In this study, the coffee pulp was collected from fully ripe robusta coffee fruits (red cherry stage). Therefore, the EW of each fruit may vary depending on its ripeness (Ahsan *et al*., 2024).

Methoxyl content

The amount of methoxyl in the galacturonic acid chain in the pectin molecule is shown by the methoxyl content (MC). Extraction conditions, such as acid concentration, affect the degree of methoxyl (Filianty *et al.,* 2024; Haque *et al*., 2025). Pectin is categorized as high methoxyl pectin (HMP) if its MC exceeds 7.12%, while if its MC is less than 7.12%, the pectin is considered low methoxyl pectin (LMP) (IPPA, 2014). MC plays an important role in determining the functional properties of pectin solutions, the resulting gel texture, and sensitivity to metal ions (Said *et al*., 2023).

Figure 3B demonstrates that pectin degradation causes the MC to decrease with increasing acid concentration. This degradation breaks polymer bonds, resulting in a decrease in MC (Haque *et al*., 2025). The MC of the extracted pectin ranged from 5.43±0.22 to 1.86 ± 0.00%, categorizing it as LMP (IPPA, 2014). Similar results were reported by Vallejos-Jiménez *et al*. (2025), who obtained an MC of 4.85% from coffee pulp pectin extracted using 1 M citric acid at pH 1.8. Biratu *et al*. (2024) reported slightly higher MC values of 4.23–7.13% for pectin extracted from *Coffea arabica* pulp using H_2SO_4, HNO_3, and HCl, indicating that solvent type and extraction conditions significantly influence methoxyl retention (Biratu *et al.,* 2024; Vallejos-Jiménez *et al.,* 2025). LMP can form gels with polyvalent cations, such as calcium ions (Belkheiri *et al*., 2021). This advantage enables the direct production of LMP, eliminating the need for the demethylation process that transforms HMP into low-methoxyl pectin (Tran *et al*., 2026).

Galacturonic acid content

Galacturonic acid (GalA) is the main component of pectin, which plays an important role in determining the structure and texture of the gel produced. Higher galacturonic acid content (GAC) generally reflects higher pectin quality (Putri *et al.,* 2020). The primary pectin bonds consist of GalA, linked by α-1,4 glycosidic bonds to form homogalacturonan or by alternating units of α-1,4-linked D-galacturonan and α-1,2-linked L-rhamnose residues to form rhamno-galacturonan-I, which can form monosaccharide side bonds (de Moura *et al.,* 2017).

Based on Figure 3C, the GAC ranged from 80.23±3.95 to 190.18±7.47%, with the highest value at 1 M citric acid and the lowest at 0.1 M. According to IPPA standards, the minimum GAC allowed is 35% (IPPA, 2014). Thus, this study's GAC of pectin has met the established pectin quality standards. The result shows that the GAC increases with increasing solvent concentration. An increase in the kinetics of the hydrolysis reaction of protopectin into pectin causes the GAC, the main component of pectin, to rise (Kurniawan and Adenia, 2022). In addition, GAC increases due to the breaking of galacturonic bonds with other compounds, such as hemicellulose. When the solvent breaks these bonds, it prevents the precipitation of other compounds during the pectin precipitation process. The higher the acid concentration, the greater the number of bonds that can be broken, which ultimately increases the percentage of GalA and the purity of pectin so that the quality of the pectin produced also increases (Haque *et al*., 2025).

Comparable trends have been reported in previous studies on coffee pulp pectin extraction under different conditions. Jiménez *et al*. (2025) reported a lower GAC value of 72.74% for coffee pulp

pectin extracted using 1 M citric acid at pH 1.8, whereas Biratu *et al.* (2024) obtained GAC values of 35.5–68.8% from coffee arabica pulp extracted using H_2SO_4, HNO_3, and HCl. These values were lower than those obtained in the present study, suggesting that solvent type, acid concentration, pH, and extraction severity strongly influence the release of galacturonic acid and the resulting pectin purity (Biratu *et al.,* 2024; Vallejos-Jiménez *et al.,* 2025). Extraction with higher concentrations of citric acid tends to produce higher GAC values, whereas mineral acids result in moderate values that still meet IPPA standards.

Degree of esterification

The comparison of MC and GAC yields the degree of esterification (DE), which is the percentage of the amount of D-galacturonic acid residue whose carboxyl group alcohol esterifies (Chandel *et al.*, 2022). DE is influenced by raw materials and extraction conditions (Prasetyo *et al.,* 2023). Figure 3d demonstrates that an increase in solvent concentration decreases the DE of pectin. This is due to the high acid concentration, which can change pectin into pectic acid so that the number of methyl ester groups decreases. Under acidic conditions, methyl ester groups may be hydrolyzed to form free galacturonic acid residues, while severe hydrolysis may also cleave glycosidic linkages in the pectin backbone (Frommhagen *et al.*, 2025).

Based on IPPA standards, pectin with a DE below 50% is classified as low-ester pectin (IPPA, 2014). In the present study, pectin extracted using 0.1–1 M citric acid showed DE values ranging from 5.56 to 38.40%, indicating that all samples were classified as low-ester pectin. This type of pectin is suitable for gel formation in the presence of divalent ions such as Ca^{2+} and is applicable in low-sugar products, food thickeners, and biodegradable edible films (Chandel *et al.*, 2022). In contrast, Vallejos-Jiménez *et al*. (2025) reported a DE value of 72.74% for coffee pulp pectin extracted using 1 M citric acid at pH 1.8, classifying it as high ester pectin. Similarly, Biratu *et al.* (2024) obtained a DE value of 77.9% using 0.1 M H_2SO_4, while extraction with H_2SO_4, HNO_3, and HCl produced DE values of 53 to 68.5%. These results indicate that milder or optimized extraction conditions better preserve esterified groups and pectin structural stability (Biratu *et al.,* 2024; Vallejos-Jiménez *et al.,* 2025).

Functional group of pectin

FTIR is a laboratory instrument used for qualitative and quantitative analysis of functional groups in a compound. The working principle of FTIR is to detect the interaction of molecules with infrared radiation and produce a spectrum, which is usually expressed in units of transmittance and wave number (cm^{-1}) (Davitadze, 2023). FTIR analysis of pectin from coffee pulp aims to identify bonds or functional groups and molecular structures in pectin. Figure 4 displays the graph of the FTIR analysis results, illustrating the impact of citric acid concentration on pectin quality.

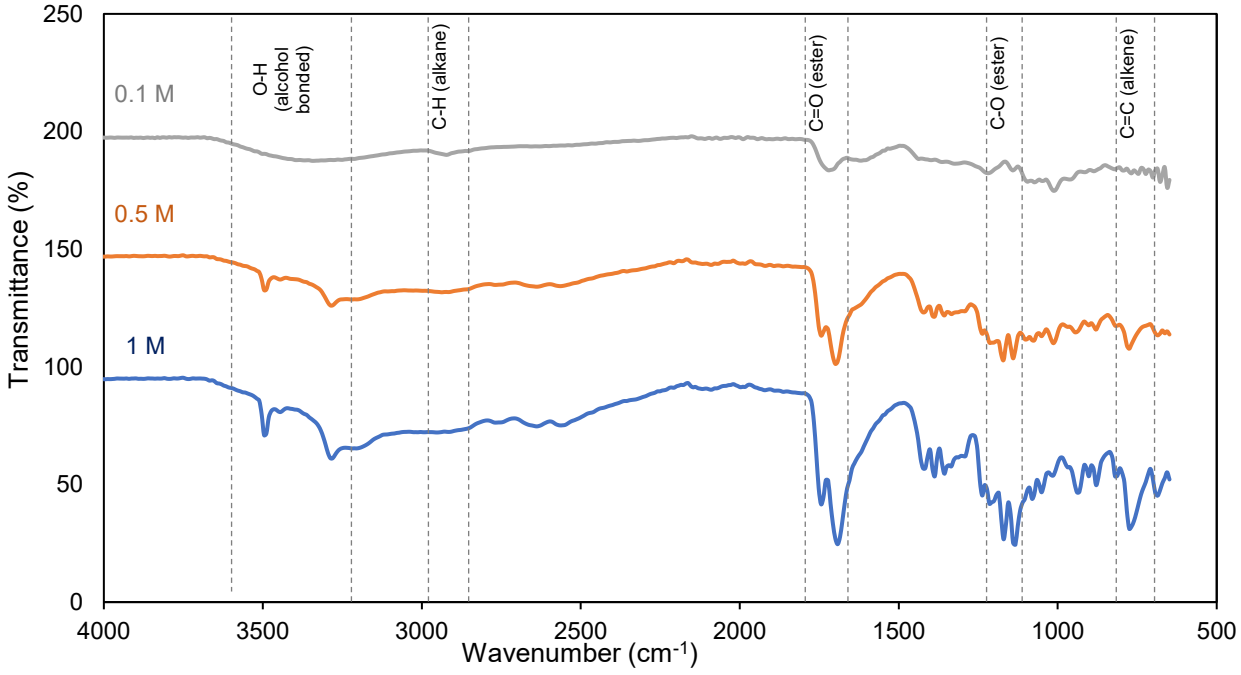

Figure 4. FTIR spectrum of coffee pulp pectin with varying concentrations of citric acid (0.1, 0.5, 1 M)

Based on the results of the FTIR spectrum analysis, variations in citric acid concentrations provide significant differences in the chemical structure of the extracted pectin. Stronger absorption in the ester carbonyl region (1740–1700 cm^{-1}) is commonly associated with higher methoxyl and esterified groups, whereas stronger absorption in the carboxylate region (1650–1600 cm^{-1}) indicates deesterification and the formation of free carboxyl groups. Likewise, increased intensity in the polysaccharide fingerprint region (1200–1000 cm^{-1}) is often related to higher galacturonic acid content and pectin backbone integrity (Costa *et al*., 2025; Wang *et al.,* 2023; Xiao *et al.,* 2025). Thus, differences in % transmittance among samples may reflect structural modifications caused by citric acid concentration during extraction (Dranca and Mironeasa, 2024).

In addition to peak position, broader and more intense absorption bands observed at higher citric acid concentrations indicate larger effective peak areas, reflecting a higher abundance or stronger interaction of the corresponding functional groups (Chandrasekar *et al.,* 2026). In particular, the enhanced carbonyl and polysaccharide-related bands at 1 M citric acid were consistent with the higher GAC and lower MC, DE, and EW values obtained previously. This confirms enhanced pectin extraction accompanied by deesterification and structural modification.

At a concentration of 0.1 M, the peak observed between 3990 and 2990 cm^{-1} indicates the hydrogen bonding of the galacturonic acid (GalA) backbone through O-H stretching absorption (Dimopoulou *et al.,* 2019). The peak at 2914.78 cm^{-1} indicates the presence of a C-H bond from the alkyl group. While in the 1750–1680 cm^{-1}, the carbonyl peak (C=O) indicates the presence of methyl esters and uronic acids. The range of 1200-1000 cm^{-1} shows the C-O-C bond (ether), indicating the effect of acid concentration on the chemical structure of pectin. The relatively higher transmittance at this concentration suggests lower absorption intensity, which is consistent with the lower GAC and weaker structural modification observed chemically.

At a concentration of 0.5 M, the FTIR spectrum showed the presence of hydroxyl groups (-OH) at 3280.06 cm^{-1}, which are important for the hydrophilic properties of pectin. The peak at 1699.66 cm^{-1} indicates the ester's carbonyl group (C=O), which is important in gel formation. The C=O bond of the carboxylic group (COO^-) is seen at 1744.39 cm^{-1}, and the glycosidic bond (C-O-C) appears at 1140.56 cm^{-1}, indicating the polysaccharide structure of pectin. The lower transmittance compared with 0.1 M suggests stronger absorption, indicating increased extraction of pectin components and partial structural modification.

At a concentration of 1 M, the absorption at 3488.78 cm^{-1} indicates hydroxyl groups (-OH). The peak at 1744.39 cm^{-1} indicates the presence of galacturonic acid with C=O bonds, while the ester group is at 1692.12 cm^{-1}. These spectral differences indicate that the higher the acid concentration, the greater the effect on the structure and chemical composition of the extracted pectin. This sample exhibited the lowest transmittance intensity in several regions, indicating the strongest absorption. This behavior is consistent with the highest GAC and lowest MC, DE, and EW values obtained in this study, suggesting that higher citric acid concentration enhanced pectin solubilization while promoting deesterification and structural rearrangement. Overall, these spectral differences confirm that increasing acid concentration significantly affected the structure and chemical composition of the extracted pectin.

CONCLUSION

Citric acid concentration significantly affected the extraction yield and quality characteristics of pectin obtained from robusta coffee pulp. Increasing the citric acid concentration from 0.1 to 1 M enhanced pectin recovery and altered its physicochemical properties, as indicated by lower equivalent weight, methoxyl content, and degree of esterification, while galacturonic acid content increased. FTIR analysis further confirmed structural modifications of the extracted pectin caused by different extraction conditions. Overall, extraction using citric acid at concentrations of 0.1-1 M produced pectin classified as low-methoxyl and low-ester pectin, indicating its potential application in calcium-induced gel systems, low-sugar food products, thickeners, and biodegradable edible films. Therefore, citric acid concentration is a key parameter for optimizing the valorization of coffee pulp waste into value-added pectin products.

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