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Pectin Extraction of Jackfruit Peel as A Biopolymer Potential with Microwave Assisted Extraction Method

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ABSTRACT - Polyacrylamide and polysaccharides are commonly used polymers, but they have certain disadvantages. Hydrolyzed polyacrylamide (HPAM) is particularly susceptible to harsh reservoir conditions, including high shear forces, salinity, and temperature. Xanthan gum biopolymer has drawbacks, such as high cost and susceptibility to reservoir biodegradation. In contrast, pectin is a viable alternative owing to its excellent biodegradability, natural decomposition, transparency, good elongation properties, and strong gel-forming ability. In this study, we characterize and analyze the rheology of biopolymers derived from jackfruit skin. Jackfruit peel, a waste product, contains a high pectin content of 23.47%, which can be extracted through microwave assisted extraction (MAE). The MAE method combines microwave and solvent extraction, offering the advantage of a fast extraction time. The resulting biopolymer is expected to enhance water viscosity and meet characterization standards for petroleum applications. FTIR test results reveal the functional groups that constitute the pectin compounds. Biopolymer concentrations used were 1,000, 2,000, and 3,000 ppm. The viscosity values of pectin were 0.503, 0.565, and 0.592 cp, while the viscosity values of xanthan gum were 1.266, 3.096, and 13.13 cp. Pectin has a lower viscosity compared to xanthan gum, and the viscosity of both biopolymers decreases as salinity increases. The reduction in viscosity for pectin during thermal testing was 26%, 28%, and 30%, whereas for xanthan gum, it was 21%, 49%, and 42%. This decrease in viscosity is attributed to the high shear rate and high salinity, which disrupt gel formation

Keywords: biopolymer, xanthan gum, pectin, microwave assisted extraction.

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INTRODUCTION

The demand for petroleum energy is increasing. However, discovering new petroleum reserves is challenging and time-consuming. Polymer injection is an enhanced oil recovery (EOR) method where polymers are injected into a reservoir to improve the mobility ratio, resulting in more efficient oil extraction with water (Purnama et al. 2023). According to (Ryles 1988; Saputra et al. 2022 and Yang 2008), polyacrylamide and polysaccharides are commonly used polymers. However, these polymers, such as hydrolyzed polyacrylamide (HPAM), are susceptible to harsh reservoir conditions, including high shear forces, salinity, and temperature. Meanwhile, the xanthan gum biopolymer has drawbacks, including its relatively high cost and increased susceptibility

to biodegradation in reservoirs (Elella et al. 2021; Ramadhan et al. 2020). Pectin can be an alternative owing to its excellent biodegradability, natural decomposition, transparency, good elongation properties, and strong gel-forming ability (Induru 2021; Martău et al. 2019).

Based on research by (Windiarsih 2015), previous studies primarily focused on the effects of parameters related to the use of jackfruit skin pectin, optimizing its physical and chemical properties through factors such as extraction time and hydrochloric acid concentration, using a response surface methodology. However, in this study, we aim to produce biopolymers from jackfruit skin using the microwave assisted extraction method. In this context, pectin is defined as a group of polysaccharides that are soluble in water and acids and contain methoxyl groups. Pectin is useful as a thickening and gelling agent in the food industry. Industrially, it is commonly used as an emulsifier and stabilizer in food products and as an ingredient in cosmetics and medicines (Kumar et al. 2020). Currently, the use of jackfruit is limited to its flesh and seeds, while the large jackfruit skin is often discarded despite its high pectin content, which has significant economic value (Sarangi et al. 2023).

Figure 1
Microwave qxone OX-899RC

In this study, we characterize and perform a rheological evaluation of biopolymers derived from jackfruit peel (Artocarpus heterophyllus), a waste product with a high pectin content of 23.47%. We use the microwave assisted extraction (MAE) process. The MAE method combines microwave and solvent extraction, offering the advantage of fast extraction time. The resulting biopolymer is expected to increase water viscosity and meet characterization standards for petroleum applications (Purnama et al. 2023). The microwave used in this research is the Qxone model OX-899RC, operating at 220 V and 50 Hz, with a power rating of 1,600 W.

METHODOLOGY

In this study, we investigate the extraction of pectin from jackfruit (*Artocarpus heterophyllus*) skin and evaluate its properties using various tests. The extraction process includes several steps. First, the jackfruit skin is heated in an oven at 60°C for 40 h. Next, the skin is ground into flour using a disk mill and a 60-mesh sieve. The resulting powder is then mixed with hydrochloric acid at a 1:10 (w/v) ratio and heated in a microwave at 450 W. Finally, the mixture is dried using a vacuum evaporator at 70°C and 50 rpm. To remove residual chloride, the pectin is washed three times with 95% alcohol in a 1:2 (w/v) ratio. The solid residue obtained after washing, referred to as chloride-free pectin, is then dried at 30°C for 6 h in preparation for analysis.

The research includes four primary tests: viscosity testing, thermal testing, shear rate measurement using a Fann viscosimeter model 35SA, and salinity testing. These tests evaluate the properties and effects of the extracted biopolymer under different conditions. In the viscosity test, the viscosity of the pectin solution is measured to understand its flow characteristics. Thermal testing involves determining the kinematic viscosity using a digital Redwood viscosimeter, which assesses the pectin's thermal stability and behavior at different temperatures.

The Fann viscosimeter model 35SA is used to measure fluid viscosity in the oil and gas industry. This instrument regulates temperature, rotational speed, and the torque necessary to rotate a cylinder immersed in the fluid. Additionally, the Fann VG meter is used to determine the shear rate, providing insights into how the pectin responds to varying mechanical stresses. Furthermore, the salinity test assesses the influence of salt concentration on the viscosity of the pectin solution, elucidating its performance under saline conditions. Through these tests, the properties and potential applications of the extracted biopolymer can be comprehensively analyzed and understood (Harangus & Kakucs 2021; Windiarsih 2015). Dynamic viscosity is calculated using the following equation:

Figure 2
Fann viscosimeter model 35SA

$$\mu\, kin = (A \times t) - (B / t) \quad (1)$$

Where:μ kin = Kinematic viscosity (Cst)μ din = Dynamic viscosity (Cp)ρb = Density of biopolymer (g/ml)

$$\mu\, din = \rho b \times \mu\, kin \quad (2)$$

In this study, characterization was performed using the FTIR-IR (Prestige 21, Shimadzu), as illustrated in the figure below.

Table 1
Redwood viscometer formula (Damayanti et al. 2018)

No	Flow time (t in seconds)	A	
1	1 until 100	0.0026	1.27
2	>100	0.00247	0.5

Figure 3
FTIR-IR analysis (Prestige 21, Shimadzu)

RESULT AND DISCUSSION

Viscosity Test Results

Viscosity Comparison of Pectin with Xanthan Gum

The viscosity of jackfruit skin pectin and xanthan gum was evaluated using an Oswald viscometer, with solutions prepared at 1,000, 2,000, and 3,000 ppm concentrations. Figure 2 illustrates the results of this viscosity test, providing a comparison between the viscosities of jackfruit skin pectin and xanthan gum.

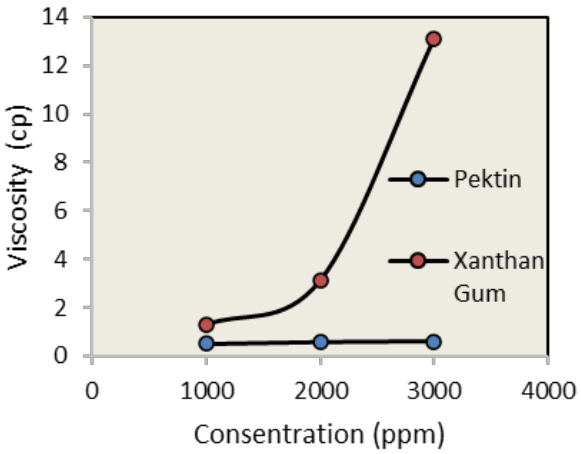

Figure 4
Viscosity test results for pectin and xanthan gum

According to Figure 2, the viscosity of jackfruit skin pectin at concentrations of 1,000, 2,000, and 3,000 ppm measured 0.503, 0.565, and 0.592 cp, respectively. In contrast, the viscosity of xanthan gum at the same concentrations was significantly higher, measuring 1.266, 3.096, and 13.130 cp,

respectively. This observation underscores the influence of polymer concentration on viscosity because higher concentrations are associated with increased viscosity. This relationship is supported by previous research (Ponthier et al. 2020), which emphasizes the direct correlation between polymer concentration and viscosity.

However, the viscosity of jackfruit pectin biopolymers is significantly lower than that of xanthan gum. This difference can be attributed to various factors in the jackfruit pectin extraction process, including temperature, extraction duration, and the type of acid used. The presence of impurities extracted alongside jackfruit pectin owing to incomplete extraction processes may also contribute to this difference. Research performed by (Patience et al. 2021) suggests that prolonged extraction times and higher temperatures can lead to pectin depolymerization, resulting in larger molecular structures and lower viscosity in the pectin solution.

In summary, although the viscosity of jackfruit pectin increases with higher concentrations, it is still lower than that of xanthan gum. Improving extraction conditions and effectively removing impurities could potentially enhance the viscosity of jackfruit pectin biopolymers, thereby enhancing their competitiveness in various industrial and biomedical applications.

Effect of Salinity on Viscosity Test

The salinity test performed in this study aimed to evaluate how the viscosity of the extracted biopolymers responded to different salinity concentrations. Salinity levels of 5,000, 10,000, and 15,000 ppm were used for the test.

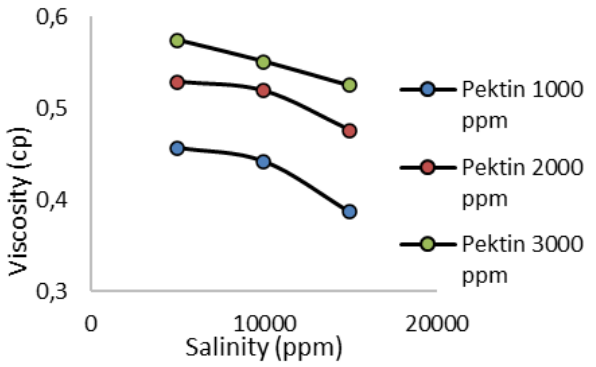

Figure 5
Salinity test of pectin

The results of the salinity test (Figure 3) illustrate the viscosity changes of jackfruit skin pectin at concentrations of 1,000, 2,000, and 3,000 ppm under different salinity levels. Initially, the viscosity values of pectin at these concentrations were measured at 0.503, 0.565, and 0.592 cp, respectively. After adding 5,000 ppm salinity, the viscosity decreased to 0.457, 0.529, and 0.574 cp, respectively, indicating a reduction in viscosity. Subsequently, at salinity levels of 10,000 ppm and 15,000 ppm, further decreases in viscosity were observed, with values reaching 0.442, 0.519, and 0.551 cp and 0.387, 0.476, and 0.525 cp, respectively.

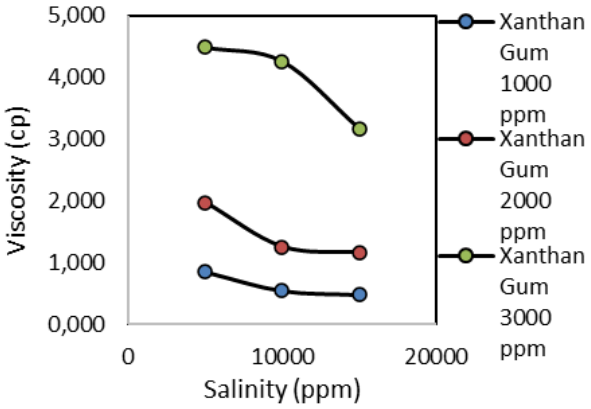

Figure 6
Salinity test of xanthan gum

Similarly, the results of the salinity test for xanthan gum (Figure 4) demonstrated viscosity changes at concentrations of 1,000 ppm, 2,000 ppm, and 3,000 ppm under varying salinity conditions. At these concentrations, xanthan gum exhibited viscosity values of 1.266, 3.096, and 13.130 cp. After adding 5,000 ppm salinity, viscosities decreased to 0.844, 1.967, and 4.487 cp. Subsequent reductions in viscosity occurred at salinity levels of 10,000 and 15,000 ppm, resulting in values of 0.540, 1.249, and 4.259 cp and 0.475, 1.153, and 3.163 cp, respectively.Comparing the results of jackfruit pectin and xanthan gum, it is evident that jackfruit pectin biopolymers exhibit greater resistance to salinity-induced viscosity reduction compared to xanthan gum. This observation is consistent with previous research (Walter et al. 2019), which suggests that salt ions, such as NaCl, can reduce viscosity in polymer solutions by attracting polymer branches, resulting in shorter polymer chains and decreased viscosity. Therefore, the study indicates that jackfruit pectin biopolymers maintain their viscosity more effectively in saline conditions compared to xanthan gum, which experiences a more significant decrease in viscosity under similar salinity levels.

Thermal Testing Results

Comparison of Thermal Pectin and Xanthan Gum Tests

Thermal tests are performed using a laboratory Redwood viscosimeter at 30°C and 60°C. These tests assess the biopolymer's stability under reservoir temperatures over a specific period (Fayaz et al. 2019). The screening criteria for polymer injection involve temperatures ranging from 23°C to 114°C (Afdhol, M.K. et al. 2023).

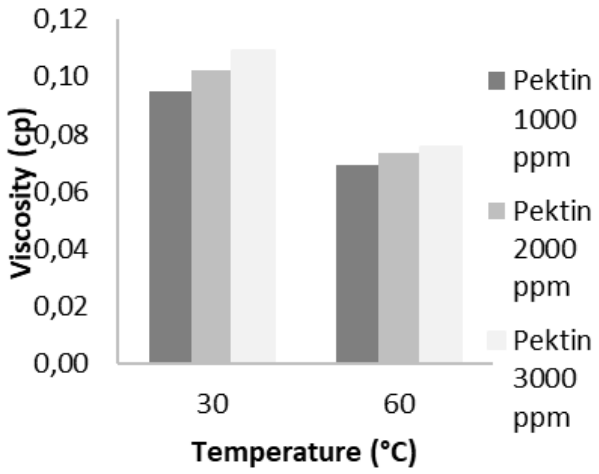

Figure 7
Results of thermal tests on pectin

Figure 5 shows that as temperature increases, the viscosity of pectin decreases. This decrease in viscosity is observed at concentrations of 1,000, 2,000, and 3,000 ppm. Specifically, at a concentration of 1,000 ppm, viscosity decreased from 0.095 cp at 30°C to 0.069 cp at 60°C. At a concentration of 2,000 ppm, viscosity decreased from 0.102 cp at 30°C to 0.073 cp at 60°C. At a concentration of 3,000 ppm, viscosity decreased from 0.109 cp at 30°C to 0.076 cp at 60°C. Therefore, the percentage decrease in viscosity for pectin concentrations was 27% at 1,000 ppm, 28% at 2,000 ppm, and 30% at 3,000 ppm.

Figure 6 shows that as the temperature increases, the thermal test results for xanthan gum show a decrease in viscosity. This decrease occurs at concentrations of 1,000, 2,000, and 3,000 ppm. Specifically, at a concentration of 1,000 ppm, viscosity decreased from 0.202 cp at 30°C to 0.159 cp at 60°C. At a concentration of 2,000 ppm, viscosity decreased from 0.599 cp at 30°C to 0.305 cp at 60°C. Similarly, at a concentration of 3,000 ppm, viscosity decreased from 0.865 cp at 30°C to 0.493 cp at 60°C. At a concentration of 3,000 ppm, viscosity decreased from 0.865 cp at 30°C to 0.493 cp at 60°C. Therefore, the percentage decrease in viscosity for xanthan gum concentrations was 21% at 1,000 ppm, 49% at 2,000 ppm, and 42% at 3,000 ppm.

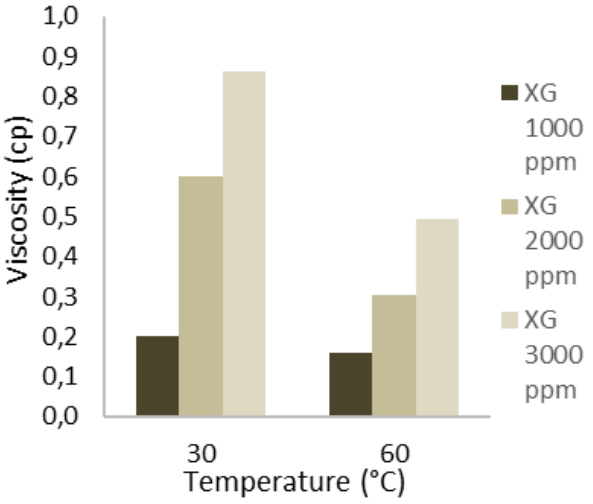

Figure 8
Results of thermal tests on xanthan gum

Figures 7 and 8 present the results of testing jackfruit pectin and xanthan gum at various concentrations - specifically, concentrations of 1,000, 2,000, and 3,000 ppm. Based on thermal testing results comparing jackfruit pectin and xanthan gum, as noted in previous studies (Akpan, E.U. et al. 2020; Yoo, H.M. et al. 2021), viscosity decreases with increasing temperature. This decrease is attributed to reduced particle interaction as the temperature rises, increasing particle mobility and causing polymer macromolecular coils to unwind, thereby decreasing viscosity (Agi, A. et al. 2020; Gerry, S. et al. 2022).

Effect of Salinity on Thermal Testing

The thermal test includes salinity concentrations of 5,000, 10,000, and 15,000 ppm to evaluate the influence of salinity. During testing, each biopolymer concentration is subjected to these salinity levels.

Figure 7 shows that the initial viscosity of pectin decreases progressively as salinity concentration increases. Adding 5,000 ppm salinity during thermal pectin tests on jackfruit showed viscosity decreases of 29%, 32%, and 33% at concentrations of 1,000, 2,000, and 3,000 ppm, respectively. Specifically,

viscosity decreased from 0.090 to 0.064 cp at 1,000 ppm, from 0.096 to 0.060 cp at 2,000 ppm, and from 0.103 to 0.069 cp at 3,000 ppm, as temperatures increased from 30°C to 60°C. Adding 10,000 ppm salinity during thermal pectin tests on jackfruit resulted in viscosity decreases of 33%, 37%, and 34% at 1,000, 2,000, and 3,000 ppm concentrations, respectively.

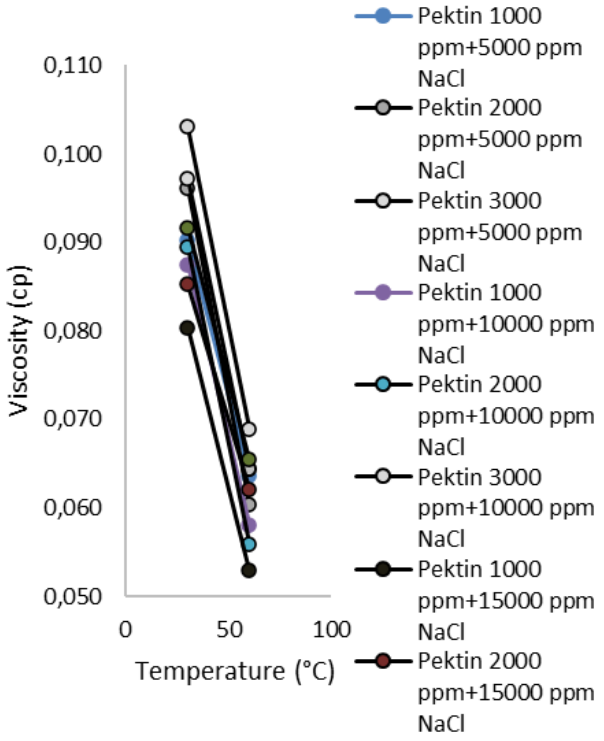

Figure 9
Effect of salinity on thermal tests of pectin

Specifically, viscosity decreased from 0.087 to 0.058 cp at 1,000 ppm, from 0.090 to 0.056 cp at 2,000 ppm, and from 0.097 to 0.064 cp at 3,000 ppm as temperatures increased from 30°C to 60°C. The addition of 15,000 ppm salinity during thermal pectin tests on jackfruit resulted in viscosity decreases of 34%, 27%, and 28% at concentrations of 1,000, 2,000, and 3,000 ppm, respectively. Specifically, viscosity decreased from 0.080 to 0.053 cp at 1,000 ppm, from 0.085 to 0.062 cp at 2,000 ppm, and from 0.092 to 0.065 cp at 3,000 ppm as temperatures increased from 30°C to 60°C.

Figure 8 shows that the initial viscosity of xanthan gum decreases with increasing salinity concentration. For instance, with the addition of 5,000 ppm salinity at xanthan gum concentrations of 1,000, 2,000, and 3,000 ppm during the thermal xanthan gum test, viscosity decreased by 38%, 25%, and 24%, respectively. This viscosity reduction occurred from 30°C to 60°C at 1,000, 2,000, and 3,000 ppm concentrations with 5,000 ppm salinity, resulting in values of 0.137–0.084, 0.212–0.158, and 0.355–0.268 cp, respectively. The addition of 10,000 ppm salinity at pectin concentrations of 1,000, 2,000, and 3,000 ppm during the thermal pectin tests of jackfruit resulted in a decrease in viscosity by 32%, 20%, and 6%, respectively. This viscosity reduction occurred from a temperature of 30°C to 60°C at concentrations of 1,000, 2,000, and 3,000 ppm with 10,000 ppm salinity, resulting in values of 0.128–0.087, 0.175–0.139, and 0.339–0.316 cp, respectively. The addition of 15,000 ppm salinity at pectin concentrations of 1,000, 2,000, and 3,000 ppm during the thermal pectin tests of jackfruit resulted in a decrease in viscosity by 32%, 11%, and 12%, respectively. This viscosity reduction occurred from a temperature of 30°C to 60°C at concentrations of 1,000, 2,000, and 3,000 ppm with 15,000 ppm salinity, resulting in values of 0.113–0.077, 0.139–0.124, and 0.225–0.195 cp, respectively.

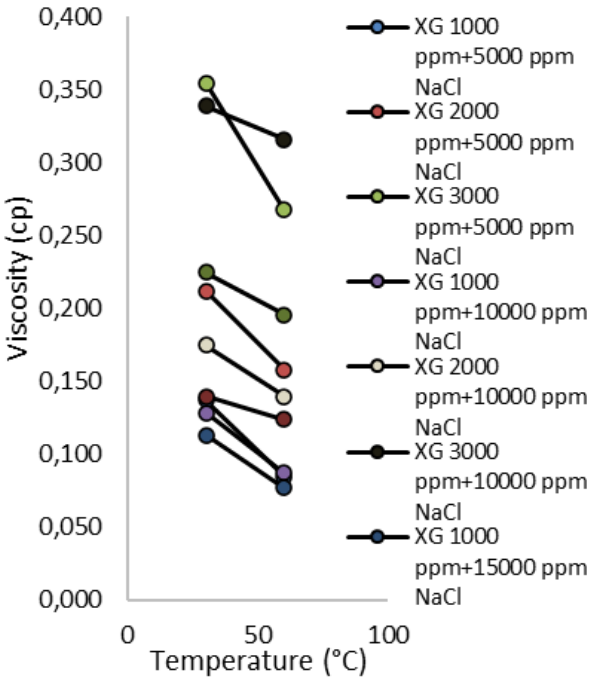

Figure 10
Effect of salinity on thermal testing of xanthan gum

Figures 7 and 8 show that, according to previous studies (Akpan et al. 2020; Yoo et al. 2021), the viscosity of a biopolymer decreases with increasing temperature. This phenomenon aligns with another study (Muhammad et al. 2017), which indicates that viscosity decreases in fluids or liquid lubricants as temperature rises. Viscosity is a measure of a fluid's resistance to deformation, and higher

temperatures lead to greater molecular activity, thereby increasing fluid mobility and decreasing viscosity in gases. Compared to gases, the molecules in liquid substances exhibit stronger molecular cohesion owing to shorter intermolecular distances. However, an increase in temperature can weaken this molecular cohesion, reducing fluid viscosity, as noted in previous studies (Alsarraf et al. 2021; S.-R. Yan et al. 2020; Yourong et al. 2019). This phenomenon is further elucidated in other studies (Abidin et al. 2012; Agi, Junin, Abdullah, et al. 2020; Muhammed et al. 2020), which explain that as the temperature rises, the increased thermal energy between particles causes them to spread further apart, thereby decreasing the viscosity of the biopolymer. Further elaboration reveals that the increase in temperature and salinity can precipitate polymers significantly owing to the influence of metal ions in salts (Jouenne 2020).

Rheological Testing Results

Comparison of Pectin and Xanthan Gum Shear Rate Test

Polymers are classified as non-Newtonian fluids, which means their viscosity does not remain constant with changes in temperature, shear stress, shear rate, or shear gradient (Babar et al. 2019; Zare & Rhee 2019; Zatz et al. 2020). Therefore, viscosity is considered a function rather than a constant value over time. A shear rate test was performed using the Fann VG Meter at the UIR Drilling Laboratory, operating at 100, 200, 300, and 600 rpm to assess the impact of shear rate on biopolymer viscosity.

Figure 9 shows the shear rate test results of pectin. The data indicate that pectin behaves as a non-Newtonian fluid. Specifically, at concentrations of 1,000, 2,000, and 3,000 ppm, the viscosity of pectin at a shear rate of 170 is 10.43, 11.17, and 11.92 cp, respectively. As the shear rate increases to 1,022, the viscosity of pectin decreases to 4.35, 4.72, and 5.09 cp at the same concentrations.

Figure 10 depicts the test results showing the shear rate behavior of xanthan gum. The graph demonstrates that xanthan gum exhibits non-Newtonian fluid characteristics. Specifically, for concentrations of 1,000, 2,000, and 3,000 ppm, at a shear rate of 170, the viscosity of pectin is 13.41, 22.35, and 30.54 cp, respectively. At higher shear rates of 1,022, the viscosity decreases to 5.96, 8.07, and 12.04 cp for the same concentrations of 1,000, 2,000, and 3,000 ppm.

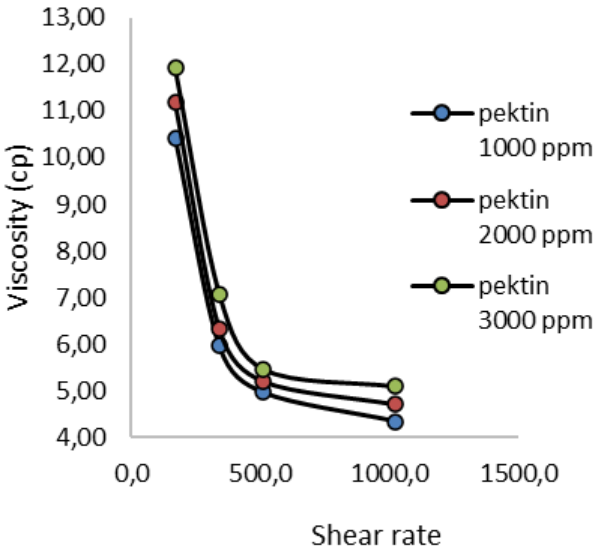

Figure 11
Results of shear rate tests on pectin

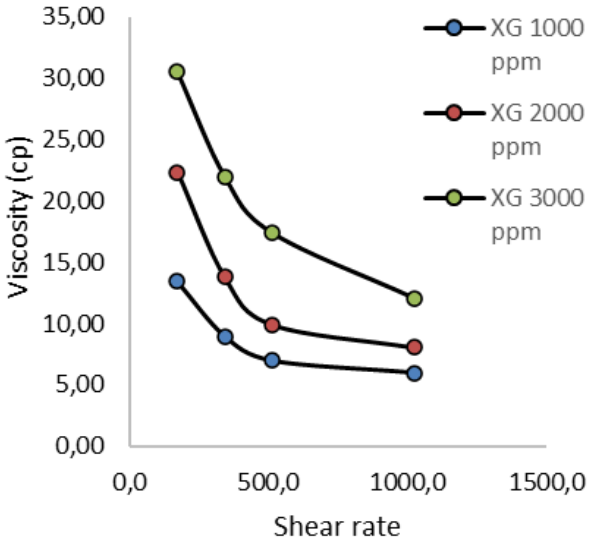

Figure 12
Shear rate test results of xanthan gum

Influence of Salinity on Shear Rate Testing

In this study, salinity is tested at concentrations of 5,000, 10,000, and 15,000 ppm.

Figure 11 depicts the results of salinity tests on pectin, showing a decrease in viscosity with increasing salinity concentrations at 5,000, 10,000, and 15,000 ppm. Specifically, at shear rates of 170 and salinity levels of 5,000 ppm, the viscosity of pectin was measured at 11.17, 11.92, and 12.66 cp for concentrations of 1,000, 2,000, and 3,000 ppm, respectively. At concentrations of 1,000, 2,000, and 3,000 ppm, with a salinity of 5,000 ppm and

a high shear rate of 1,022, the viscosity of pectin decreased to 4.10, 4.35, and 4.47 cp, respectively. At concentrations of 1,000, 2,000, and 3,000 ppm, with a shear rate of 170 and a salinity of 10,000 ppm, the viscosity of pectin increased to 12.66, 13.41, and 14.15 cp, respectively. At concentrations of 1,000, 2,000, and 3,000 ppm, with a salinity of 10,000 ppm and a high shear rate of 1,022, the viscosity of pectin decreased to 4.35, 4.59, and 4.84 cp, respectively. At concentrations of 1,000, 2,000, and 3,000 ppm, with a shear rate of 170 and a salinity of 15,000 ppm, the viscosity of pectin increased to 13.41, 14.15, and 15.64 cp, respectively. The viscosity of pectin decreased to 4.47, 4.84, and 5.09 cp, respectively, at concentrations of 1,000, 2,000, and 3,000 ppm with a salinity of 15,000 ppm and a high shear rate of 1,022.

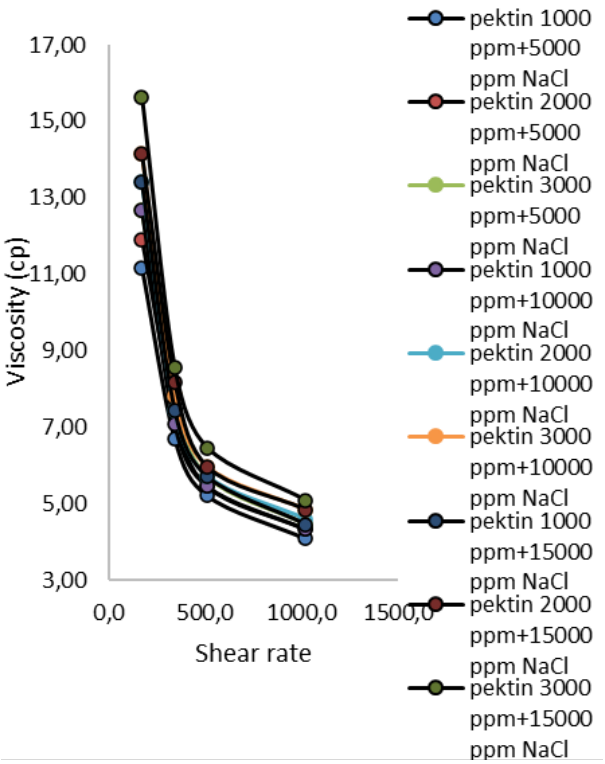

Figure 13
Effect of salinity on the shear rate of pectin

Figure 12 illustrates the results of salinity tests on xanthan gum. Viscosity decreases with increasing salinity concentrations at 5,000, 10,000, and 15,000 ppm. Specifically, at concentrations of 1,000, 2,000, and 3,000 ppm, with a shear rate of 170 and a salinity of 5,000 ppm, the viscosity of xanthan gum is 8.34, 10.43, and 14.15 cp, respectively. The viscosity of xanthan gum decreased to 3.97, 4.72, and 5.21 cp, respectively, at concentrations of 1,000, 2,000, and 3,000 ppm with a salinity of 5,000 ppm and a high shear rate of 1,022. At concentrations of 1,000, 2,000, and 3,000 ppm, with a shear rate of 170 and a salinity of 10,000 ppm, the viscosity of xanthan gum increased to 9.68, 12.66, and 14.90 cp, respectively. The viscosity of xanthan gum decreased to 4.35, 4.97, and 5.83 cp, respectively, at concentrations of 1,000, 2,000, and 3,000 ppm with a salinity of 10,000 ppm and a high shear rate of 1,022. At concentrations of 1,000, 2,000, and 3,000 ppm, with a shear rate of 170 and a salinity of 15,000 ppm, the viscosity of xanthan gum is 11.17, 14.90, and 17.13 cp, respectively. The viscosity of xanthan gum decreased to 4.72, 5.21, and 5.96 cp, respectively, at concentrations of 1,000, 2,000, and 3,000 ppm with a salinity of 15,000 ppm and a high shear rate of 1,022.

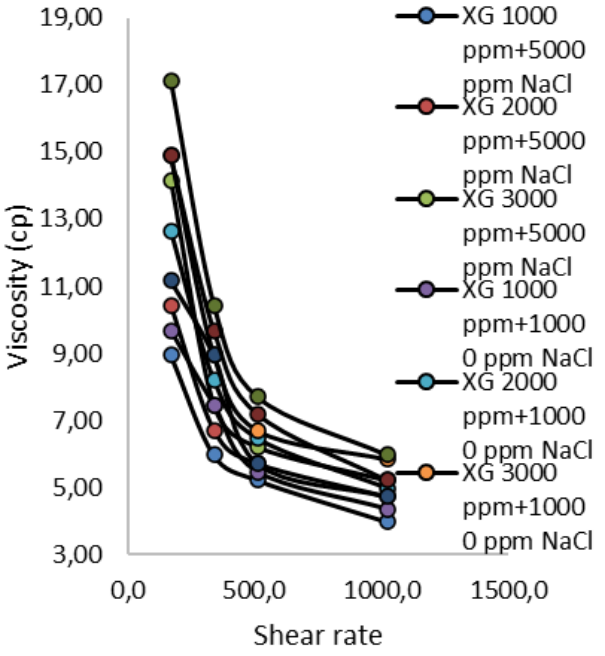

Figure 14
Effect of salinity on shear rate tests of xanthan gum

The results of salinity testing on pectin and xanthan gum demonstrate that viscosity values are influenced by salinity and shear rate. According to (Brown et al. 2010), Newtonian fluids exhibit decreased viscosity as flow velocity increases. Based on the performed tests, the evaluated biopolymer exhibits non-Newtonian behavior with pseudoplastic properties, where viscosity decreases with increasing shear rate. However, in the absence of shear rate influence, the viscosity of the polymer gradually returns to its initial viscosity level, as noted by (Hashmet et al. 2017). Furthermore, the deformation of molecule structure is another factor influencing the decrease in viscosity in polymer solutions. Initially large and irregular under low shear rate

conditions, the molecules become more regular at higher shear rates. Therefore, as the shear rate increases, the viscosity of the polymer decreases. The impact of salinity on the viscosity of pectin at different concentrations indicates that the viscosity reduction is relatively more consistent compared to xanthan gum.

FTIR Test Results

The FTIR testing conditions using the Prestige 21 Shimadzu FTIR-IR instrument are typically defined by specific parameters. The wavelength range for FTIR tests is typically 400–4,000 cm^{-1}. Additionally, the resolution, crucial for precise analysis, is typically 0.5–16 cm^{-1}. These parameters are carefully chosen to ensure the accuracy and reliability of FTIR analysis. FTIR measurements reveal the presence of functional groups formed on jackfruit skin after extraction. FTIR spectroscopy uses Fourier transforms to analyze spectrum results (Novais et al. 2019). The infrared spectrum is generated by measuring the transmission of light passing through the sample, using detectors to measure light intensity, and comparing it with the intensity of the reference signal via a wavelength function (Crockett et al. 2022; Petrack 2020; L. Yan et al. 2022). The absorption band of the aliphatic CH group is observed at 2,910.61 cm^{-1}. In standard pectin, this absorption band is typically at 2,900–2,919 cm^{-1} (Afdhol, M. K. et al. 2023). The vibration of C–H is detected at 1,307.79 cm^{-1}, and an ether group (R–O–R) is identified at 1,103.33 cm^{-1}, consistent with previous studies indicating the presence of ether bonds in the spectrum at 1,050–1,260 cm^{-1} (Antika & Kurniawati 2017; Chiang et al. 2023; Perdana et al. 2023). The FTIR spectrum confirms the structural characteristics of pectin, including the presence of aliphatic CH_3 bonds, methoxyl branches ($COOCH_3$), carbonyl –C–H vibrational bonds, and ether groups R–O–R (Chauhan et al. 2020; Nguyen et al. 2021; Perdana et al. 2023).

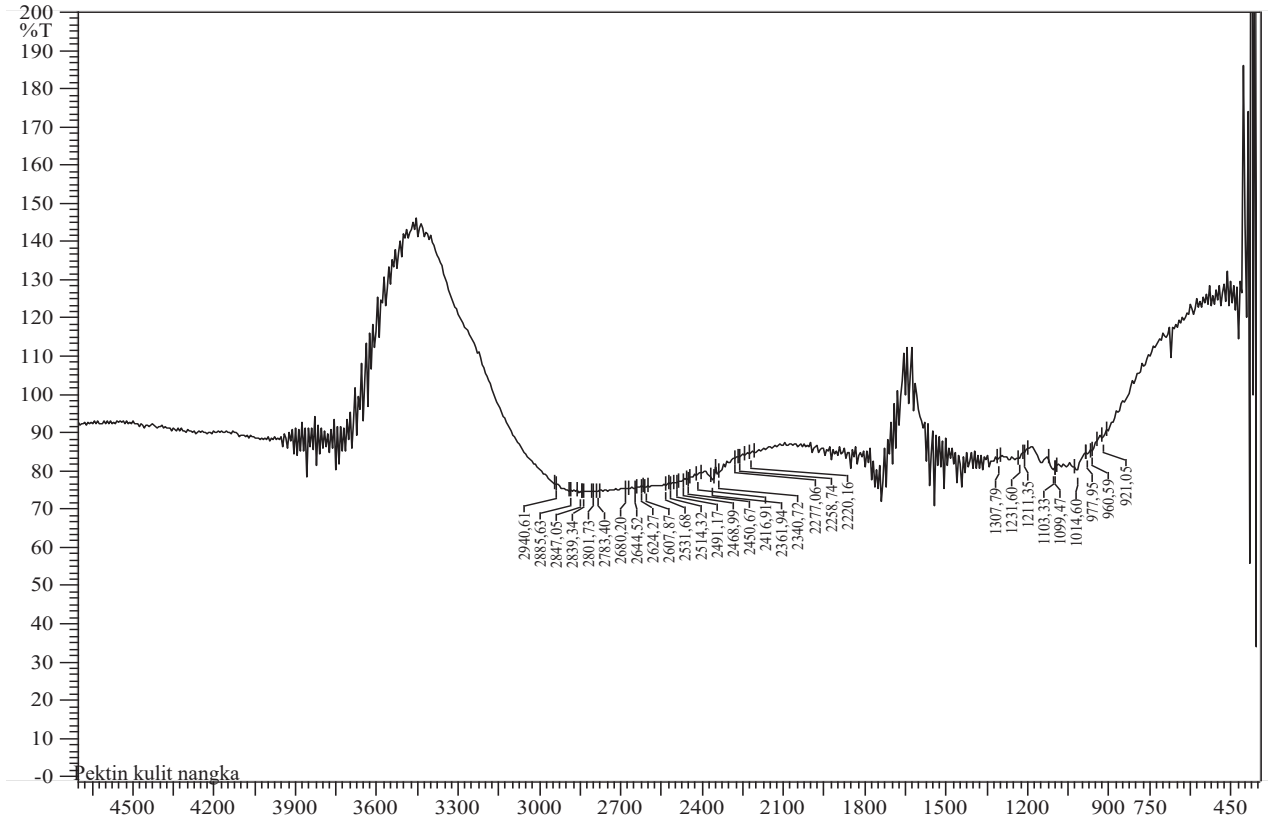

Figure 15
FTIR testing of pectin

CONCLUSION

The results of this study allow us to make several important conclusions, elucidating the properties and potential applications of jackfruit pectin.

FTIR Analysis Validation: FTIR analysis confirms the presence of functional groups in the extracted jackfruit skin pectin sample that correspond to those found in standard pectin. This confirms the successful extraction of pectin from jackfruit skin and indicates its suitability for various industrial and biomedical applications where pectin is used as a biopolymer.

Viscosity Performance: Comparative viscosity testing between jackfruit pectin and xanthan gum, a widely used biopolymer, indicates that jackfruit pectin exhibits lower viscosity values than xanthan gum. However, the reduction in viscosity is less pronounced in jackfruit pectin. This suggests that while jackfruit pectin is promising, further optimization of its viscosity properties is required to achieve or surpass the performance of established biopolymers such as xanthan gum.

Performance Gap with Xanthan Gum: Despite its potential. jackfruit pectin's performance as a biopolymer falls short compared to xanthan gum. This performance gap is attributed to challenges in the purification process and insufficient removal of impurities during extraction. Enhancing the purification process to improve the purity and consistency of jackfruit pectin could narrow this performance gap and unlock its full potential as a biopolymer.

Thermal Stability Assessment: Thermal stability testing indicates that jackfruit pectin exhibits superior stability compared to xanthan gum. This indicates that jackfruit pectin may be particularly well-suited for applications requiring thermal resilience, such as in the food and pharmaceutical industries where temperature fluctuations are common.

Rheological Behavior Examination: Rheological testing confirms that jackfruit pectin and xanthan gum exhibit nonNewtonian fluid behavior, highlighting their versatility in applications where accurate viscosity control is crucial. Understanding their rheological properties is essential for optimizing their performance in industrial and biomedical applications.

Salinity Sensitivity Evaluation: The sensitivity of jackfruit pectin viscosity to changes in salinity levels indicates its potential applicability in environments with fluctuating salt concentrations. This characteristic is advantageous in industries such as food processing and pharmaceuticals, where maintaining stable viscosity is essential during fluctuating salt content.

In conclusion, while jackfruit skin pectin is promising as a biopolymer, further research and refinement of extraction techniques are essential to enhance its quality, purity, and performance. Addressing challenges related to viscosity optimization, impurity removal. and thermal stability could fully unlock the potential of jackfruit pectin as a valuable biopolymer resource for a wide range of industrial and biomedical applications.

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GLOSSARY OF TERMS

Symbol	Definition	Unit
HPAM	hydrolyzed polyacrylamide	
MAE	Microwave assisted extraction	
μ kin	Kinematic viscosity	Cst
μ din	Dynamic viscosity	Cp
ρb	Density of biopolymer	gr/ml
ppm	Part per million	
cp	Centi Poise	

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