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Effect of NaCI solution concentration, particle size and ratio on viscosity inhibitor of porang flour

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ABSTRACT

Porang flour has a fairly high glucomannan content, up to 65%, which can accelerate the formation or viscosity process in porang flour. The high viscosities cannot be applied to rotating flow nozzle-type hydrodynamic cavitation devices designed to form cavitation bubbles during degradation. In this study, the preeminent process parameters will be sought, especially for particle size, concentration of NaCl solution, and the ratio (porang flour : NaCl solution: isopropyl alcohol) to the inhibition of viscosity formation at porang flour. It aims to analyze those factors effect on viscosity inhibition to support the performance of cavitation bubble formation during the process of breaking cell walls in porang flour. This process was carried out in a factorial complete randomized design (CRD) on all 3 factors with 2 repetitions. The results show that the factor of particle size, the concentration of NaCl, and the ratio significantly affected the decrease in the viscosity of porang flour. Large particle sizes with high concentrations of NaCl can reduce the viscosity level up to 10 cP. The results of the addition of isopropyl alcohol in the ratio (mesh size 40: 5% NaCl: isopropyl alcohol) at a concentration of 2.5% can produce a viscosity of up to <10 cP with a gel level in the sample that is more invisible and not concentrated. In the experimental stage using the swirling flow nozzle type hydrodynamic cavitation technique with the selected formulation, it was seen that the calcium oxalate diminution in porang flour was up to 97.2 mg/100g with a degradation percentage of 52.63%. The residual calcium oxalate in porang flour contradicted the standard for human body tolerance, explicitly 71 mg/100g. Therefore, the resultant flour is not safe to consume. Furthermore, the yield of calcium oxalate at this experimental stage still does not meet SNI 7938:2020, that is, 30 g/100g.

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INTRODUCTION

Porang tuber is a plant that has a high glucomannan content and is widely used in several food industries such as a substitute for fat in yogurt (Dai et al. 2016), as an adhesive and emulsion former (Anindita et al. 2016), and raw materials for capsule shell products (Tester and Al-Ghazzewi 2017). The glucomannan content in porang tubers can reach 65% (Ermawat*i* et al. 2019) and has a viscosity level of >35,000 mPas. Porang tubers cannot be consumed directly due to the high calcium oxalate (K.O) levels, which reach 22.72%. Consequently, when porang tubers are consumed by humans, kidney stone disease may appear (Mawarni and Widjanarko 2015).

Calcium oxalate in porang, apart from being found in the mannan cells is also found outside the mannan cells. Calcium oxalate (K.O) is needle-shaped and can reach 72.7 microns long (Koswara 2009). The K.O degradation process can be carried out effectively by breaking down the cell wall in the sample. The breakdown process can be carried out easily by hydrodynamic cavitation bubbles at low temperatures with relatively small energy consumption and relatively prompt (Supardan et al. 2014). This process utilizes decreasing flow pressure at a narrow point with relatively high flow velocity to form cavitation bubbles (Meneguzzo et al. 2020).

One of the significant factors that can make the performance of cavitation bubbles effective is the viscosity level of the sample. The higher the sample's viscosity, the more inhibited the growth of cavitation bubbles (Ye et al. 2020). The nature of porang flour, which facilely absorbs water and contains high glucomannan can quickly form viscosity. Thus, this becomes a critical problem in forming cavitation bubbles. High viscosity can reduce the fluid flow rate during the cavitation process. The high viscosity causes the formation of cavitation bubbles is not achieved due to high flow pressure, low flow velocity, and no turbulent flow in the fluid.

In the process of forming microbubble bubbles, a specific ratio of air flow rate (*Qg*) and fluid flow rate (*Ql*) can cause the fluid flow to become turbulent, where the movement of the particles is irregular so that momentum exchange occurs from one fluid to another (Alam et al. 2021). A specific fluid flow rate and air flow rate can affect the size of the cavitation bubbles (Sheng et al. 2021). A high *Ql/Qg* value with low viscosity environments close to the viscosity of water (1cP) affects the diameter of the cavitation bubbles to become smaller and can produce higher operating pressures. High operating pressure can increase the concentration of bubbles so that the surface area and gas solubility increase (Alam et al. 2021); (Alam et al. 2022). According to (Mi et al. 2020), the frequency of the bubble volume increases as the air flow rate increases, but the increased fluid flow rate and viscosity cause a decrease in the bubble volume frequency. Increasing the viscosity of the liquid worsens the monodispersity of the bubbles. Therefore, reducing the viscosity of the liquid in the sample is necessary to achieve excellent bubble monodispersity.

Besides K.O, NaCl solution has hygroscopic properties that can absorb water in the sample (Zhang et al. 2018). The higher the concentration of NaCI solution, the lower the swelling ratio in the sample (Erizal et al. 2017). The high concentration of NaCl solution can also reduce the ability of the sample to absorb water caused by salting out, so that the viscosity level in the sample will decrease (Hardyawan et al. 2012). In this study, isopropyl alcohol solution was added to reduce viscosity in porang flour. In addition, another benefit of adding isopropyl alcohol is that it can bind higher water molecules than ethanol and methanol, so the sample is not readily soluble and forms a gel or viscosity.

The particle size and ratio (porang flour: NaCl solution: isopropyl alcohol) also significantly reduce porang flour's viscosity. The wider the surface area of the sample, the faster the swelling in the sample will be (Mursalin et al. 2020). This study aims to analyze the effect of the concentration of NaCl solution, particle size, and ratio on viscosity inhibition to support the performance of cavitation bubble formation during the process of breaking cell walls in porang flour.

METHOD

Material

The primary material used in this research is porang chips from PT. AAR. Other supporting materials are NaCI (Merck), isopropyl alcohol and distilled water.

Instrument

The equipment used in this study was a Brookfield viscometer, analytical balance, glinder, mesh sieves (20, 30, 40, 50, 60), 250 ml beaker glass, 1 liter beaker glass, hot plate, thermometer, spatula, and stopwatch.

Method

Porang Chip Size Reduction

The process of reducing the size of the porang chip was carried out using a grinder tool. The purpose of size reduction was to determine the effect of various particle size variations on the absorption capacity of NaCl solution in porang flour samples. The particle sizes used are mesh 20, 30, 40, 50, and 60.

NaCI Solution Construction

NaCl solution has hygroscopic properties which can bind water to the sample, thereby reducing the viscosity level of porang flour (Cao et al. 2021). The concentration of NaCl solution used in this research was 5%, 10% and 15%.

Viscosity Test

Testing the viscosity begins with dissolving various sizes of porang flour into several concentrations of NaCl solution. The ratio levels (porang flour : NaCl solution) used were 1:40, 1:60, and 1:80 (w/v). Consequently, a heating process was carried out with a hot plate to reach a temperature of 35°C (Mubarok and Ananda 2020). Next, the viscosity testing process was carried out with a Brookfield viscometer using spindle 3 at 30 rpm. The process was repeated up to 2 times for each treatment. Particle size, concentration of NaCl solution, and the chosen ratio were then dissolved with isopropyl alcohol at a concentration of 3.33%, 2.85% and 2.5% to reduce the viscosity level close to 1 cP water viscosity.

Data Analysis

This study used a factorial complete randomized design (CRD) with 3 factors: particle size, NaCl solution concentration, and the ratio in which each treatment was repeated 2 times. Research data were analyzed using Analysis of Variance (ANOVA). Treatments with a significant difference from the F-table of 0.05 were further tested using Duncan's Multiple Range Test (DMRT).

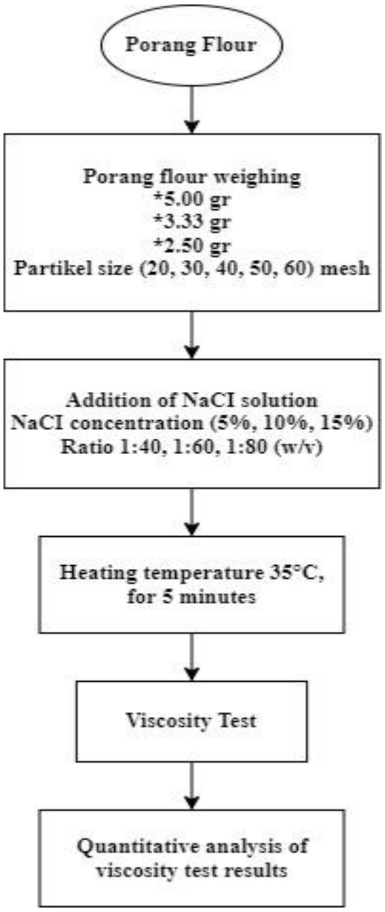

Figure 1. Viscosity Test Flow Chart

Selected Formulation Experiments

At this stage an experimental process was carried out with the selected formulation using a microbubble generator by hydrodynamic cavitation at a rotating flow nozzle type. It aims to examine the performance level of cavitation bubbles on the responses of calcium oxalate levels, glucomannan levels, viscosity, and water content in porang flour with a variable air flow rate of 3 lpm, fluid flow rate of 10 lpm, and cavitation time of 15 minutes.

RESULT AND DISCUSSION

Effect of NaCI Solution Concentration

Besides being used to bind K.O, NaCl solution can inhibit gel formation in porang flour. The hygroscopic properties contained in the NaCI solution can absorb water in the sample (Zhang et al. 2018). The results in Table 1, the analysis of variance (ANOVA) on the effect of the concentration of NaCI solution at the 5% test level, show F-count (26099.6) > F-table (3.20) which means it is very significant. In other words, the results of the study of the effect of various concentrations of NaCl solution showed a significantly different decrease in viscosity. This decrease occurs in all ratios 1:40, 1:60, and 1:80 (w/v). It can also be seen in Figure 2, Figure 3, and Figure 4 at 5%, 10%, and 15% NaCI concentrations which show that the high concentration of NaCI solution added to the sample can inhibit the growth of viscosity or swelling in porang flour.

The decrease in the viscosity level in porang flour with the addition of NaCl solution occurs due to the transfer of solvent from samples with a low osmotic pressure (hypotonic) to a NaCI solution with a high osmotic pressure (hypertonic). Solutions with a higher osmotic pressure than inner plasma can cause water to move from intracellular to extracellular; as a result, the conditions in the plasma become low in water content. The process of immersing taro flour in a NaCI solution also shows the decrease of water content in samples caused by the NaCI solution having a higher osmotic pressure (hypertonic) (Suharti et al. 2019).

It also occurs in glucomannan solution. The high NaCl solution concentration can reduce the sample's viscosity level. This decrease in viscosity is probably caused by a change in the conformation of the glucomannan molecule induced by the NaCl solution (Ma et al. 2020). The high concentration of NaCl solution can speed up the process of transferring solvent from porang flour which has a low osmotic pressure (hypotonic) to a NaCl solution which has a high osmotic pressure (hypertonic), so that the water content in porang flour can quickly decrease. The low concentration of NaCl solution used can slow down the ability of the material or sample to absorb water (Hardyawan et al. 2012). An additional advantage of NaCl solution is that it can prevent enzymatic browning.

In semi-interpenetrated polymer network hydrogels using konjac glucomannan, the addition of NaCl solution can increase the pH to become acidic and reduce the swelling ratio so that the viscosity level of konjac glucomannan will decrease (Liu et al. 2010). This process of decreasing viscosity occurs due to salting out, which is the process of attraction between water molecules, samples, and NaCl solution (Erizal et al. 2017);(Wu et al. 2013);(Pourjavadi et al. 2008). This process of decreasing viscosity also occurs in porang flour with the addition of NaCl solution, where the attraction process between water molecules is higher in NaCI solution than in porang flour. Therefore, the higher the concentration of NaCl solution, the easier the process of binding the water molecules to the porang flour molecules. As a result, porang flour cannot progress to form a gel ideally (Su et al. 2020). The decrease in viscosity in this study can support the formation of microbubble bubbles with the hydrodynamic cavitation technique in the swirling flow nozzle type to make it easier and faster (Alam et al. 2022).

Effect of Particle Size and Ratio

Particle size is one of the parameters that need to be considered in this study. The sample particle size will affect the mass transfer process and the diffusion distance. The larger the particle size, the lower the absorption capacity of the solution for the sample (Mursalin et al. 2020), whereas the smaller the sample particle size, the higher the absorption capacity of the solution for the sample (Salsabila and Fahruroji 2021). When the sample has a smaller particle size, the solvent will quickly diffuse into the sample tissue, and the swelling ratio will increase, causing the solution to enter the sample pores quickly. Determining the ratio (porang flour: NaCI solution) will also significantly effect the sample's viscosity level (Xiao et al. 2019). Using a high ratio can reduce the viscosity of the sample.

Table 1 Analysis of 3-factor variances on the viscosity inhibition of porang flour.

Source	F-value	F-table (5%)	Results
KN	26099,6	3,20	Sig
UP	62663,2	2,58	Sig
R	103895,1	3,20	Sig
KN*UP	6242,5	2,15	Sig
KN*R	12635,8	2,58	Sig
UP*R	37999,3	2,15	Sig
KN*UP*R	3299,4	1,87	Sig

Note : KN = NaCI concentration, UP = Particle size, R = Ratio, Sig = Significantly different at the test level of 5%.

The results in Table 1, the analysis of variance (ANOVA) on the effect of particle size and ratio at the 5% test level, show that the particle size F-count is (62663.2) > F-table (2.58) and the ratio of F-count is (103895.1) > F-table (3.20) which means that both factors are very significant. In other words, the result study of the effect of various particle sizes and ratios showed a significantly different decrease in viscosity. This decrease occurred due to differences in the surface area of the particle size, specifically at mesh 20, 30, 40, 50, and 60. The ratio also suggestively affected the level of viscosity in porang flour, all at ratios of 1:40, 1:60, and 1:80 (w/v). Dissolving more samples can increase the viscosity faster. It is due to the large amount of absorption space in the sample which allows the solution to diffuse quickly into the sample.

In Figure 2, 3, and 4, it can be seen that the particle size of 60 mesh tends to be higher in viscosity results when compared to particle sizes of 50, 40, 30, and 20 mesh, all at ratio 1:40, 1:60, or 1:80 (w/v). The smaller the particle size, the higher the viscosity of porang flour, and vice versa. This increase is caused by the breakdown of the cell wall and cell membrane in porang flour getting smaller, so that it can accelerate the process of transferring water solvents from high concentrations (hypertonic) to porang flour which has low concentrations (hypotonic) through a selective permeable membrane (Fatmawati et al. 2013). It also occurs at the level of activated carbon particle size. The greater the surface area of activated carbon, the faster the absorption process of pollutants in wastewater, and vice versa (Erawati and Arifah 2018);(Solihudin et al. 2017). Defining the accurate particle size and ratio can inhibit swelling or viscosity in the sample, optimizing the process of forming cavitation bubbles.

Identification of Viscosity Test Results

The nature of porang flour, which has an immense glucomannan content, can absorb up to 100 times its water weight. It causes porang flour to experience swelling effortlessly, increasing its viscosity of porang flour.

The purpose of solving the cell wall is to streamline the performance of the solvent to bind the K.O levels in the cell wall. The breaking of cell walls can be completed using cavitation bubbles, which utilize the formation, effectiveness, and bursting of the bubbles to produce micro jets that have enough energy to break the cell wall of a sample. Cavitation bubbles can quickly form at a maximum viscosity level of 200 cP (Golykh et al. 2020). Therefore, sample with a viscosity level of >200 cP require relatively high energi to form cavitation bubbles. Consequently, it is necessary to control the viscosity of <200 cP in the sample to support the effectiveness of cavitation bubble performance in the extraction process.

This study controlled the viscosity level of porang flour samples using 3 factors: the concentration of NaCl solution, particle size, and the ratio (porang flour:NaCI solution). The results of the analysis showed that there was a significant effect on the 3 factors used, as shown in Table 1: first, the results of the analysis of variance (ANOVA) combining the effect of NaCI concentration and particle size at the 5% test level showed the results of F-count (6242 .5) > F-table (2.15) which means significantly different; second, the combination of the effect of NaCI concentration and ratio at the 5% test level showed that the results of F-count (12635.8) > F-table (2.58) were significantly different; likewise, the combination of the effect of particle size and ratio at the 5% test level shows the results of F-count (37999.3) > F-table (2.15) which also means significantly different, and similarly the combination of the 3 factors at the 5% test level shows the result of F-count (3299.4) > F-table (1.87) which means it is also significantly different. It can be said that the results of the research on the influence of the 3 factors at various levels showed a significant effect on reducing the viscosity of porang flour.

Table 2 Duncan advanced test results for the 3 factors

Treatment		DMRT + average
NaCI Concentration	5%	$1081,1^{c}$
	10%	$645,60^{b}$
	15%	$291,20^{a}$
Particle size (mesh)	20	$78,667^{a}$
	30	$128,00^{b}$
	40	$332,89^{c}$
	50	$842,67^{d}$
	60	$1980,9^{e}$
Ratio (w/v)	1 : 40	$1578,1^{c}$
	1 : 60	$309,87^{b}$
	1 : 80	$129,87^{a}$

Note : Numbers followed by symbols (a,b,c,d,e) that are different for each treatment show a significant difference based on the Duncan test at the 5% level.

In Figure 2.3.4, it can be seen that the ratios 1:40, 1:60, and 1:80 (w/v) have a declining viscosity once the surface area of the particles is more significant and the concentration of NaCl is higher. The higher the ratio, the lower the viscosity of porang flour produced by up to 10 cP. Low viscosity can accelerate the process of cavitation bubble formation. Still, the higher ratio can increase production costs and reduce the amount of yield produced. In contrast, the lower ratio in the sample can increase the viscosity of porang flour up to 3640 cP. High viscosity can inhibit the process of forming cavitation bubbles, but the lower ratio can reduce production costs and increase yield. For particle size, the larger it is, the lower the viscosity of porang flour. However, sample's large particle size can inhibit the cavitation device's fluid flow rate. It is due to the large particle size cannot pass through the nozzle of the cavitation device perfectly and thus cavitation bubbles are challenging to form. The results in Table 2 show a significant difference in symbols for each factor in terms of particle size, NaCl concentration, and ratio (porang flour:NaCl solution). It can be concluded that the 3 factors in this study significantly reduce the viscosity level in porang flour.

The viscosity test results in Figure 2, Figure 3, and Figure 4 show a significant effect on particle size and concentration of NaCl at all ratios of 1:40, 1:60 and 1:80 (w/v). The large particle size and high concentration of NaCl can reduce the viscosity value of porang flour which subsequently positively impacts the process of forming cavitation bubbles.

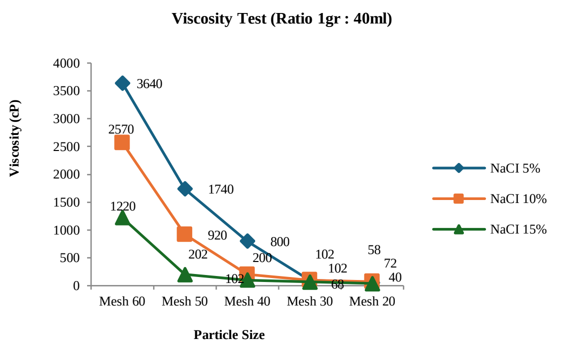

Figure 2 Viscosity result for ratio 1:40 (w/v)

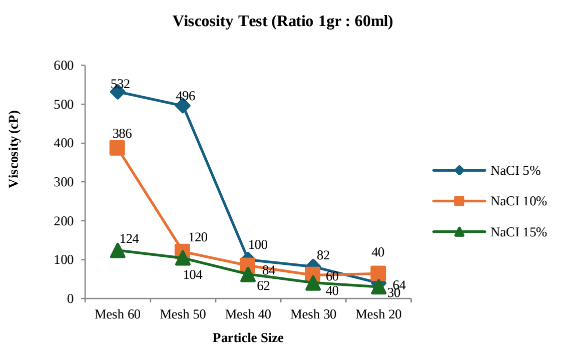

Figure 3 Viscosity result for ratio 1:60 (w/v)

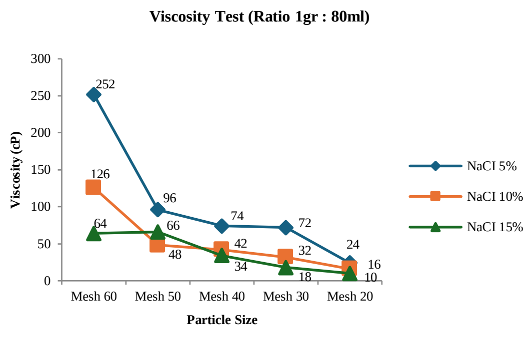

Figure 4 Viscosity result for ratio 1:80 (w/v)

Identification of Viscosity Results on the Addition of Isopropyl Alcohol

The selected formulation added with isopropyl alcohol is at a particle size of 40 mesh, 5% NaCl concentration, and a ratio of 1:40 (w/v). The viscosity result of the selected formulation can be seen in Figure 2 which shows a viscosity of 800 cP. This result is still above the maximum verge for forming cavitation bubbles, which is 200 cP (Golykh et al. 2020). Thus, there is a need for a viscosity control process which can be achieved by adding isopropyl alcohol. This addition aims to reduce the viscosity level in the sample to proceed toward the viscosity of water 1 cP. Another benefit of adding isopropyl alcohol is that it can bind water molecules during the cavitation process, so that porang flour does not easily dissolve and prevents gel formation or viscosity. The ratio test was carried out at a ratio (porang flour: NaCl solution: isopropyl alcohol) with concentrations of 3.33%, 2.85% and 2.5%.

In trials of formulations with concentrations of 3.33%, 2.85% and 2.5%, the viscosity level decreased ultimately to <10 cP. However, at concentrations of 3.33% and 2.85%, gel formation and concentration were still visible in the sample. In comparison, at a percentage of 2.5%, the viscosity level was less visible and was no longer concentrated. In the process of adding isopropyl alcohol solution, it was proven that there was a decrease in the viscosity level in porang flour. It is due to isopropyl alcohol having the property of binding ability to water molecules in porang flour, so that glucomannan, which initially forms a viscosity more quickly, can be controlled by adding isopropyl alcohol to produce a viscosity level of <10 cP. Consequently, the best formulation for the next experimental stage is a mesh size of 40: NaCl 5%: isopropyl alcohol at a concentration of 2.5%.

The property of isopropyl alcohol that can bind water molecules is also evident in salak seed flour with the addition of 95% isopropyl alcohol at a ratio of 1:17 (w/v) resulting in glucomannan levels of up to 40.19% (Anindita et al. 2016). It was also applied to porang flour with the addition of 95% isopropyl alcohol at a 1:19 (w/v) ratio which produced glucomannan levels of up to 45.167% (Setiawati et al. 2017). A positive correlation between anti-solvent isopropyl alcohol and porang flour causes this process. The more anti-solvent added to porang flour, the more water will be attracted by the anti-solvent, resulting in the viscosity of the flour decreasing drastically.

The use of isopropyl alcohol as an anti-solvent is more conducive and profitable than other types of alcohol, such as ethanol and methanol. Isopropyl alcohol is more non-polar than ethanol and methanol when viewed from the value of the dielectric constant (Anindita et al. 2016). The great non-polar nature of the solvent will decrease the solubility of glucomannan in water solubility caused by water molecules being attracted by isopropyl alcohol. In addition, isopropyl alcohol is safe and non-toxic to food when compared to methanol.

Selected Formulation Experiment on Swirling Flow Microbubble Cavitation

At this stage, experiments were carried out on the selected formulation with a particle size of 40 mesh, 5% NaCl concentration, and a ratio of 1:20:20 (w/v/v) or at a concentration of 2.5%. It was conducted to prove the effectiveness of the cavitation bubbles on the response of glucomannan in porang flour with an air flow rate (*Qg*) of 3 lpm, a flow rate (*Ql*) of 10 lpm, and a time of 15 minutes. The specification for a swirling flow nozzle type hydrodynamic cavitation tool uses a nozzle hole of 7mm in a vertical position with parallel inlet and outlet channels. The nozzle is plexiglass with an outer diameter of 80 mm and a height of 160 mm. It consists of a vortex chamber for liquid entry and an air hole for air gas flow (Alam et al. 2020).

The result produced from this experiment has a glucomannan content of 55%, viscosity of 3660 cP, water content of 9%, and calcium oxalate of 97.2 mg /100g from the initial KO 205.2 mg/100g with a percentage of 52.63%. The residual calcium oxalate in porang flour contradicts with the standard for human body tolerance, explicitly 71 mg/100g (Sefa-Dedeh and Agyir-Sackey 2004). Therefore, the resultant flour is not safe for consumption. Furthermore, the yield of calcium oxalate at this experimental stage still does not meet SNI 7938:2020, that is 30 g/100g.

The formation of microbubbles with this technique can be enhanced by a high vortex flow in the vortex space inside the nozzle (Alam et al. 2020). According to the law of conservation of momentum, eddy fluid flow produces a relatively high-pressure gradient due to an increase in the tangential velocity of the fluid about the nozzle axis. In the nozzle axis area, the fluid pressure reaches a minimum value. In contrast, the tangential velocity and fluid turbulence level reach a maximum value, so the gas input pressure is minimal with low energy consumption (Levitsky et al. 2016). This technique can produce microbubbles of <40 µm, where generation time has no significant effect on the size of the microbubbles (Alam et al. 2020).

The *QI/Qg* ratio dramatically influences the level of fineness and the number of bubbles produced (Levitsky et al. 2016),), and the more and finer the bubbles produced, the faster the degradation process in the sample will be. Specific fluid flow rates and air flow rates can affect the size of the cavitation bubbles (Sheng et al. 2021);(Fu et al. 2009);(Levitsky et al. 2016). The high *Ql/Qg* value causes the diameter of the cavitation bubbles to become smaller and can result in higher operating pressures (Alam et al. 2022);(Alam et al. 2021). The hydrodynamic cavitation technique for producing microbubbles has several advantages such as less energy used, relatively low cost, faster cell wall breakdown process, and the fact that it can be applied on an industrial scale.

CONCLUSION

The results of this study indicate that the factors of particle size, the concentration of NaCl, and the ratio significantly affect the reduction in the viscosity of porang flour. The larger the particle size, the higher the NaCl concentration and the lower the viscosity level, which can reach up to 10 cP. The results of adding isopropyl alcohol to the ratio (mesh size 40: 5% NaCl: isopropyl alcohol) at a concentration of 2.5% can produce a viscosity level of up to <10 cP with a gel level in the sample that is less visible and less concentrated.

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