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Research Article

Effects of binder content and drum filling degree on cassava pearl granulation using drum granulator

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Abstract

The purpose of this research was to study the effects of binder content and filling degree on cassava pearl granulation. A stainless steel drum granulator with 30 cm diameter and 20 cm length was used. The drum rotational speed was 30 rpm. During granulation, samples were taken at 4, 8, 12, 16 and 20 minutes and granule density, hardness, sphericity, mass mean diameter and size distribution were measured. In order to investigate effect of binder content on cassava pearl granulation, the binder content was varied at 37, 38, 39 and 40% (wet basis). The results indicated that binder content affected granule growth of cassava pearl but did not affect density, hardness and sphericity. The growth of cassava pearl was very sensitive to binder content. Increasing binder content decreases granule growth. Cassava pearl obtained from 37% binder content gave the highest growth rate with the maximum mass mean diameter of 2.13 mm. Moreover, this treatment also gave the highest mass fraction of 2.4 mm particle (commercial size). The value of particle density, hardness and sphericity were in the range of 0.56-0.65 g/cm^3, 0.96-1.25 N and 0.96-0.98, respectively. The filling degree was varied at 20%, 40%, 60% and 80% (v/v). The results showed that density, hardness and sphericity of 2.4 mm cassava pearl were not significantly different (p>0.05) when filling degree increased. Density, hardness and sphericity were in the range of 0.52 - 0.64 g/cm^3, 0.80 – 1.14 N, 0.94 - 0.97, respectively. However, filling degree affected the growth mechanism of cassava pearl. Granulation of cassava pearl using 80% (v/v) filling degree caused a static or non-moving region during the process. In addition, cassava pearl obtained from this treatment gave the lowest mass mean diameter of 1.75 mm and also the lowest mass fraction of 2.4 mm particle. However, mass mean diameter and mass fraction of 2.4 mm particle obtained from 20, 40 and 60% (v/v) were similar. Therefore, the production capacity of cassava pearl granulation by drum granulator could reach up to 60% of drum volume.

Keywords: *Manihot esculenta*, filling degree, processing, Thailand

Introduction

Cassava pearls are normally used as an ingredient in several food items such as Thai dessert, bubble tea and puddings. Cassava pearl granulation is defined as "wet granulation process", as cassava starch is mixed with water which is used as a binder prior to granulation to achieve a moisture content of about 40% (wet basis). Traditionally, wet starch is agglomerated in a cloth cradle which is used as a generator, until larger granules are formed. Following this, the granules are roasted and dried. Using a cloth cradle as a granulator can cause many problems because quality and productivity of cassava pearl produced from cloth cradle depend entirely on human skill. Additionally, it makes it difficult to follow Good Manufacturing Practice (GMP) guidelines and regulations. Therefore, in order to solve these problems and achieve higher productivity, another type of granulator should be considered for cassava pearl granulation. This study will focus on the granulation of cassava pearl using a drum granulator as this equipment gives a product with high density and high sphericity. These characteristics are the desired characteristics of cassava pearl.

The efficiency of wet granulation process using drum granulator depends on many factors including binder content, rotational speed, surface roughness, size of drum, raw material (feed particle size distribution) and drum filling degree. Assavasanti [1] studied the effect of particle size of wet starch feed on cassava pearl granulation using a plastic batch drum granulator. It was found that particle size of wet starch feed strongly affected growth behaviour of cassava pearl. However, the cassava pearl had a low mass fraction of 2.4 mm (commercial size) and low sphericity. In 2005, Radchasom [2] used a galvanized iron drum with different surface roughness for cassava pearl granulation. The drum was operated at various rotational speeds. The result indicated that both surface roughness and rotational speed affected granular flow behaviour, growth rate, density and sphericity of cassava pearl. The effect of drum size on cassava pearl granulation was studied by Suwanamart [3]. The results showed that drum diameter did not affect particle size distribution, granulation rate, density and sphericity. This was the result of constant Froude number in all treatments. Binder content also affected wet granulation process. Iversion *et al*. [4] studied the effect of binder content on the granulation of glass ballotini. Glycerol-water mixture was used as a liquid binder. The granulator was a stainless steel drum with 0.3 m diameter and 0.2 m length. The result showed that binder content affected the granule porosity which decreased with the binder content. Nevertheless, Ramachandran *et al*. [5] investigated the effect of binder content on the granulation of calcite using polyvinyl alcohol in water as a liquid binder. A stainless steel drum with 0.3 m diameter and 0.2 m length was used. The results showed that granule porosity decreased with increasing binder content due to the increase of coalescence between particles. Apart from these factors, filling degree is also one of the most important factors which influences the production capacity of the granulation process using a drum granulator. Effect of drum filling degree on wet granulation process of glass bead was studied by Santomaso *et al* [6]. The drum was filled at three levels of 10, 15 and 25% v/v. The result revealed that the curvature of bed surface and the transition of granular flow depended on filling level. Moreover, Ramachandran *et al*. [5] suggested that different drum loads of calcite caused the different flow patterns. Even though much of this research work showed that binder content and filling degree affected the granulation process and granule qualities, the effects of binder content and filling degree have not been investigated in cassava pearl granulation. Therefore, this research aimed to study the effect of binder content and drum filling degree on cassava pearl granulation.

Materials and Methods

Experimental procedure

The experimental procedure started with feed preparation. Cassava starch was mixed with water to obtain the moisture content of 37, 38, 39 and 40% w/w (wet basis) because the cassava pearl granule can only be produced using this range of moisture content (from preliminary experiment). The mixture was then aged for 12 hours to obtain uniform moisture distribution. Wet starch feed was then screened to select the particle with average size of 0.5 and 1.7 mm. After screening, fine particles with 0.5 mm average size (particles through sieve No. 18) and seed particle with 1.7 mm average size (particles remained on sieve No.14) were mixed with the ratio of 1:1.85 by mass according to Radchasom's work [2]. Wet starch feed was fed into the drum granulator at various filling degrees of 20, 40, 60 and 80% v/v. The drum was operated at 30 rpm rotational speed throughout the experiment. During granulation, samples were taken at 4, 8, 12, 16 and 20 minutes of granulation time. Particle size distribution, mass mean diameter, density, hardness and sphericity of samples were then determined.

Determination of cassava pearl properties

Particle size distribution was examined by using test sieve analysis. After sieving, the fractions remaining in each sieve stack were weighed. The results were presented in the form of mass fraction of total sample retained in, or passing through, each sieve [7, 8]. The values of mass fraction were then used for calculation of mass mean diameter by the method of McCabe *et al* [8]. Density of cassava pearl with the average size of 2.4 mm (commercial size) was determined by using resin displacement method [2, 3]. Particle hardness of cassava pearl was measured using texture analyzer (Stable Micro System, TA.XT.Plus, UK). 50 pellets of cassava pearls were measured for each treatment. Cassava pearl was placed on a planar place and force was then applied to the sample by P/50 probe. A force-time curve was recorded and analyzed. Hardness was determined by measuring the maximum force required to break the sample. The sphericity of 2.4 mm cassava pearl was determined by method of Moshenin [9]. 30 pellets were measured for each treatment.

Results and Discussion

Effect of binder content on cassava pearl granulation

Effect of binder content on particle size distribution and mass mean diameter

Figure 1 shows the particle size distribution of cassava pearl obtained from all levels of binder content. It was found that the profiles of mass fraction predominantly changed from the initial stage to 4 minutes of granulation process. These results revealed similar trends for all levels of binder content. During this period, mass fraction of 0.5 mm or fine particle and 1.7 mm or seed particle decreased. These caused the increase of mass fraction of 2.4 mm particles. Moreover, mass fraction of 3.4 mm particles also slightly increased during this period. This could be explained in that fine particles tended to form into larger particles due to the layering of fine particles onto the surface of well-formed granules [10]. After 4 minutes of granulation, mass fraction of 2.4 mm particles obtained from all levels of binder content were almost constant which indicated that there was no growth. This could be explained by the constant mass fraction of 0.5 and 1.7 mm particles. The result also showed that the highest mass fraction of 2.4 mm particle was obtained from 37% binder content. When binder content increased, the mass fraction of 2.4 mm particle decreased. This indicated that the potential to produce larger granules decreased with increasing binder content.

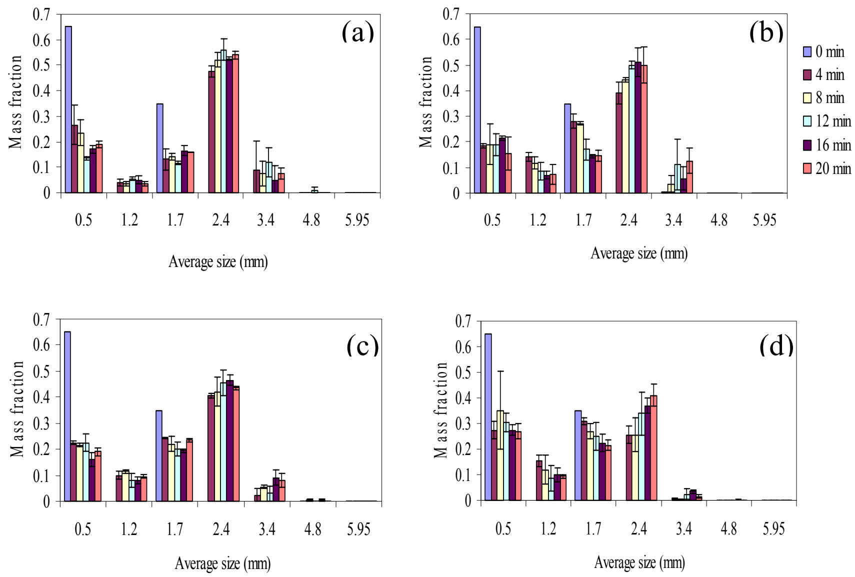


Figure 1. Particle size distribution of cassava pearl obtained from 4 levels of binder content of (a) 37%, (b) 38%, (c) 39% and (d) 40% (wet basis).

Figure 2 shows the mass mean diameter profiles of cassava pearl obtained from all levels of binder content. These profiles described the granule growth of cassava pearl during granulation. From the initial stage to 4 minutes of granulation, mass mean diameter of cassava pearl increased continuously. This can be explained by the increase of mass fraction of 2.4 mm particle as discussed earlier. After 4 minutes of granulation, mass mean diameter profiles of cassava pearl obtained from all treatments were almost constant. These results were consistent with the profiles of particle size distribution (Figure 1) which were almost constant during this period. Nevertheless, it was observed that cassava pearl obtained from 37% binder content exhibited the highest growth rate. Then, the growth rate decreased with increasing binder content. This could be explained in that increasing binder content reduced inter-particle friction due to the lubrication between particles [11]. This caused the resistance of granules consolidation and hence led to the decrease of granule growth of cassava pearl.

The results of particle size distribution (Figure 1) and mass mean diameter (Figure 2) indicate that the increase of binder content of 1% at a time makes an obvious difference to the results. These results were consistent with Ramachandran and co-workers [5] who stated that granule size was very sensitive to binder to solid ratio. Comparing between cassava pearl obtained from all levels of binder content, it can be seen that wet starch feed with 37% binder content gave the highest growth rate of cassava pearl, then the growth rate decreased as the binder content increased. In addition, cassava pearl obtained from 37% binder content gave the highest mass fraction of 2.4 mm particle. In contrast, cassava pearl from 40% binder content gave the lowest mass fraction of 2.4 mm particle. Therefore, the binder content of 37% was used for further investigation.

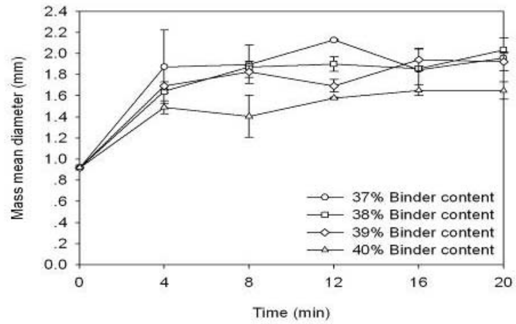
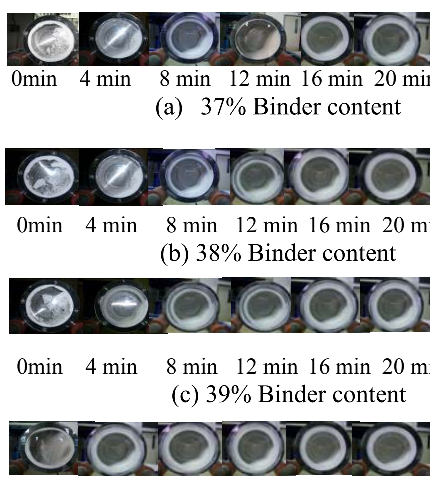


Figure 2. Mass mean diameter of cassava pearl obtained from 4 levels of binder content.

The increase in mass mean diameter values during the first 4 minutes of granulation can be explained by the transition of granular flow pattern in the drum granulator as shown in Figure 3. The flow patterns of cassava pearl obtained from all treatments were cataracting mode during the first 4 minutes of granulation. After 4 minutes of granulation, it was changed to cascading mode. These results were in agreement with the results of particle size distribution which exhibited the rapid growth at the first 4 minutes of granulation and then remained constant. This indicated that the cataracting motion strongly affected particle size enlargement of cassava pearl because of high collision energy between particles [12, 13]. However, mass fractions of 2.4 mm cassava pearl obtained from all treatments were similar. This might be due to the similar cascading motion during 4 to 20 minutes of granulation. At the same motion pattern, collision energy between particles was similar and hence led to the similarity of growth behaviour of cassava pearl.



0min 4 min 8 min 12 min 16 min 20 min
(a) 37% Binder content

0min 4 min 8 min 12 min 16 min 20 min
(b) 38% Binder content

0min 4 min 8 min 12 min 16 min 20 min
(c) 39% Binder content

0min 4 min 8 min 12 min 16 min 20 min
(d) 40% Binder content

Figure 3. Granular flow pattern of cassava pearl during granulation at all levels of binder content of (a) 37%, (b) 38%, (c) 39% and (d) 40% (wet basis).

Effect of binder content on particle density, hardness and sphericity of 2.4 mm cassava pearl

Figure 4 shows the profiles of particle density, hardness and sphericity of 2.4 mm cassava pearl obtained from all levels of binder content. The results revealed that particle density of cassava pearl obtained from all treatments were not significantly different at 95% confident level. This could be explained by the growth behaviour of cassava pearl as mentioned earlier. From 4 to 20 minutes of granulation, mass mean diameter of cassava pearl obtained from all levels of filling degree were almost constant. This indicated that particle consolidation and coalescence did not occur during this period. Mechanisms of consolidation and coalescence promoted the increase of granule growth [5], granule compaction [5] and granule density [14]. Therefore, when consolidation and coalescence did not occur during 4 to 20 minutes of granulation, the values of particle density were constant. It was also found that the result of particle hardness was in agreement with particle density. Granule consolidation and growth directly related to the strength of granule [15]. As these two mechanisms did not occur during 4 to 20 minutes of granulation, the particle hardness was almost constant during this period. When compared between each treatment, the values were not significantly different at 95% confidence level. Also, particle sphericity of cassava pearl obtained from all treatments were similar. One of the most important factors affecting particle sphericity is the granular flow pattern. Granular flow behaviour of cassava pearl obtained from all levels of filling degree were during cascading mode. This flow pattern caused the rotating of granules inside the drum and granule tended to adhere with fine particles. Therefore, this flow pattern generated spherical granules [2-3].

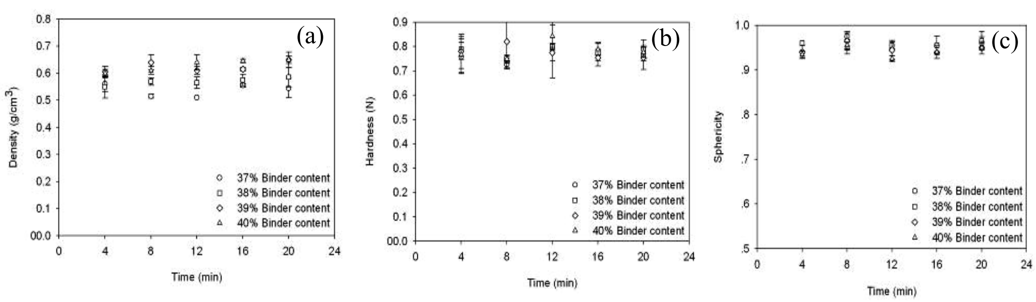


Figure 4. Particle density (a), hardness (b) and sphericity (c) of cassava pearl at various levels of binder content.

Effect of drum filling degree on cassava pearl granulation

Effect of drum filling degree on particle size distribution and mass mean diameter

Figure 5 shows the particle size distribution profiles of cassava pearl at various drum filling degrees. It was found that particle size distribution of cassava pearl obtained from all treatments were similar. At the initial stage to 4 minutes of granulation, mass fraction of 0.5 mm or fine particles and 1.7 mm or seed particles decreased. This led to the increase of mass fraction of 2.4 mm particles. During granulation, fine particles tended to form into larger particles due to the layering of fine particles onto the surface of well-formed granules [10]. After 4 minutes of granulation, mass fraction of 2.4 mm particle was almost constant until the end of granulation process. This indicated that no particle size enlargement occurred during this period. This finding was confirmed by the constant value of mass fraction of 0.5 and 1.7 mm particles after 4 minutes of granulation.

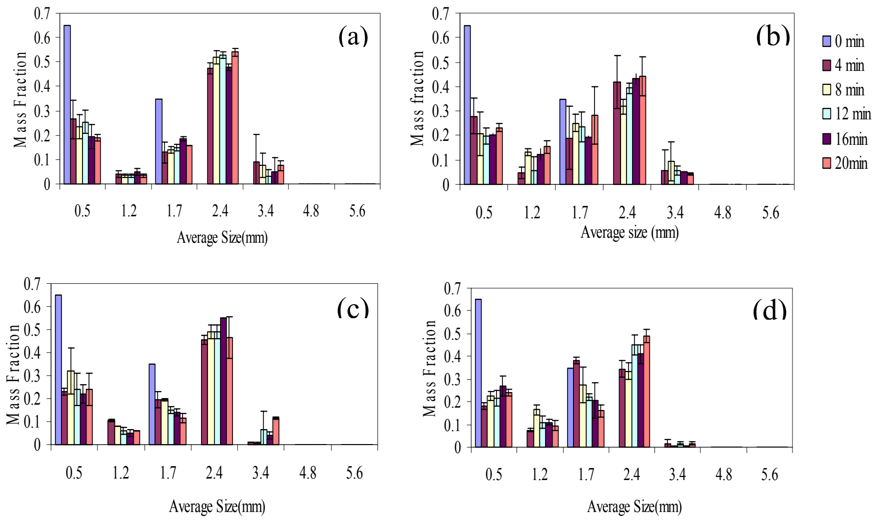


Figure 5. Particle size distribution of cassava pearl obtained from different drum filling degree of (a) 20, (b) 40, (c) 60 and (d) 80% v/v.

Mass mean diameter profiles of cassava pearl obtained from all levels of filling degree are shown in Figure 6. At the first 4 minutes of granulation, mass mean diameter of cassava pearl in every treatment increased predominantly. This was the cause of the increase of mass fraction of 2.4 mm particles. The predominant change of mass mean diameter during this period could be explained as mentioned in the previous section. After 4 minutes of granulation, mass mean diameter of cassava pearl from all treatments were almost constant. These results could be explained by the constant mass fraction of 2.4 mm particle during this period as mentioned earlier. Following comparison between mass mean diameter of cassava pearl from all treatments after 4 minutes of granulation, cassava pearl obtained from 80% filling degree gave the lowest mass mean diameter.

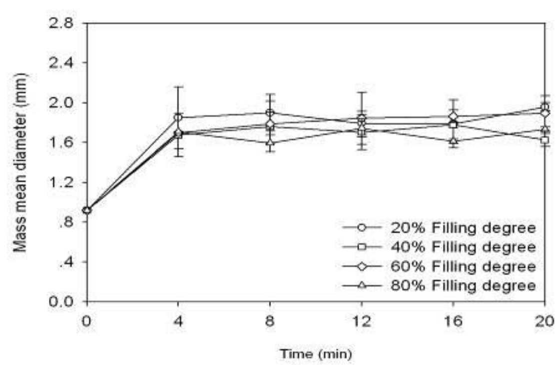


Figure 6. Mass mean diameter of cassava pearl obtained from 4 levels of binder content.

The experimental results also indicated that there was static or non-moving region occurring in the drum filled with 80% (v/v) filling degree as shown in Figure 7. The existence of this static region might cause the lowest mass fraction of 3.4 mm particle obtained from 80% (v/v) filling degree. As the drum filling degree increased, the intermixing between particles decreased [16]. This led to a decrease in the opportunity for particle coalescence and consolidation. These phenomena could be the cause of the decrease of granule growth of cassava pearl obtained from 80% (v/v) filling degree.

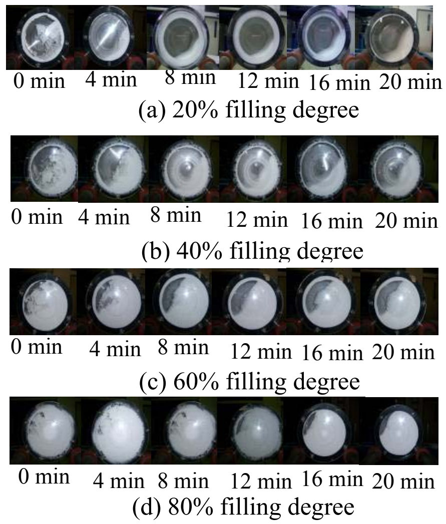


Figure 7. Granular flow pattern of cassava pearl during granulation at the drum filling degree of (a) 20, (b) 40, (c) 60 and (d) 80% v/v.

Effect of filling degree on particle density, hardness and sphericity of 2.4 mm cassava pearl

Effects of filling degree on particle density, hardness and sphericity of cassava pearl can be seen from Figure 8. It was found that particle density, hardness and sphericity of cassava pearl obtained from all treatments were independent of drum filling degree. These were the results from cascading granular motion pattern.

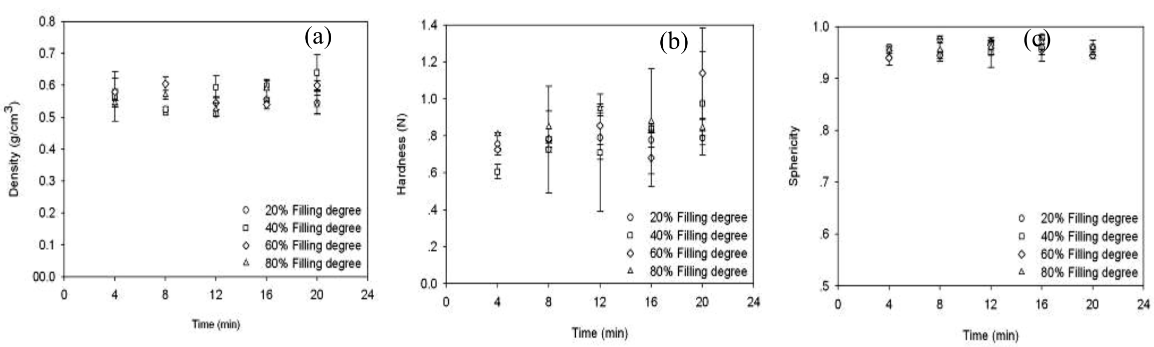


Figure 8. Particle density (a), hardness (b) and sphericity (c) of 2.4 mm cassava pearl obtained from all levels of drum filling degree.

Conclusions

The experimental results indicated that the growth of cassava pearl was very sensitive to binder content. At the initial stage to 4 minutes of granulation, cassava peal obtained from all treatments exhibited the maximum growth rate. After that, growth rate of cassava pearl from all treatments was constant. This could be explained by the transition of granular flow pattern from cataracting to cascading mode. The results also showed that particle size enlargement decreased as the binder content increased. Cassava pearl obtained from 37% binder content gave the highest growth rate and mass fraction of 2.4 mm particle (commercial size). However, binder content did not affect density, hardness and sphericity of cassava pearl. The result of drum filling degree indicated that growth behaviour of cassava pearl is dependent on drum filling degree. At the initial stage to 4 minutes of granulation, the growth of cassava pearl obtained from all treatments increased. After that they were almost constant. Mass mean diameter of cassava pearl obtained from 20, 40 and 60% v/v were similar. On the other hand, the filling degree of 80% v/v gave the lowest mass mean diameter. This was the result from a static region occurring at the centre of the drum which led to the decrease of particle consolidation and coalescence. Finally, the density, hardness and sphericity of 2.4 mm cassava pearl obtained from all levels of filling degree were not significantly different. These results indicated that the production capacity of cassava pearl could be optimized to reach 60% v/v filling degree.

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