Journal of Food and Pharmaceutical Sciences

Original Article

The Effect of Maltodextrin Concentration Variations on the Microencapsulation of Probiotics from Manonjaya Salak Fruit Juice (*Salacca zalacca* (Gaert.) Voss)

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Received: 29 August 2025; Revised: 11 November 2025; Accepted: 12 November 2025; Published: 20 December 2025

Abstract: Probiotic beverages have weaknesses in terms of shelf life related to stability. One way to maintain the stability of probiotic beverages is to encapsulate them into microcapsules using maltodextrin. The objective of this study is to determine the characteristics and effects of varying maltodextrin concentrations F1 (20%), F2 (40%), F3 (60%) on the physical properties of microcapsules from Manonjaya salak fruit (Salacca zalacca) probiotic beverages. This study was conducted experimentally in the production of microcapsules using the freeze-drying method. Data were analyzed descriptively, including organoleptic evaluation, measurement of total lactic acid, pH, lactic acid bacteria (LAB) count, moisture content, and morphological characterization using a Scanning Electron Microscope (SEM). The results of the characteristics of Manonjaya snake fruit juice microencapsulation can be concluded that variations in maltodextrin concentration affect the characteristics of microcapsules where all formulas meet the requirements, except for the results of the water content test between 10–10.33% which does not meet the requirements (≤ 3%). Thus, further research is needed in optimizing the microencapsulation formula of snake fruit juice, such as using a combination of coatings, longer freeze drying optimization time, and evaporation of snake fruit juice.

Keywords: freeze drying; maltodextrin; microencapsulation; manonjaya salak; probiotics.

1. INTRODUCTION

Probiotic drinks are fermented beverages made using lactic acid bacteria that can reduce the amount of toxins produced by intestinal bacteria in the digestive tract [1]. Lactic acid bacteria commonly used in the production of probiotic beverages include *Lactobacillus bulgaricus* and *Streptococcus thermophilus*. *Lactobacillus bulgaricus* produces peptide compounds and amino acids that promote the growth of *Streptococcus thermophilus* by serving as essential nutrients or growth factors [2]. Liquid probiotic drinks generally have a relatively short shelf life compared to other forms of probiotic drinks. Probiotic drinks can last for 24 hours at a temperature of 25–30°C, for 5 days at 7°C, and for 10 days at 4°C [5]. The longer the storage time, the lower the pH of the probiotic drink [6]. As a result, this has a direct impact on the degradation of beverage product quality in the form of physical changes, including changes in color, odor, and viscosity. Hydrolysis or oxidation occurs at low pH levels, therapeutic effectiveness is reduced because active compounds are easily degraded at low pH levels, resulting in decreased bioavailability, and safety risks increase because microorganisms can easily grow. This is why it is necessary to produce microencapsulated probiotic beverages.

Microencapsulation is a method of coating core materials to maintain viability, shelf life, and protection from environmental factors. The use of microencapsulation can protect probiotic bacteria cells from damage caused by processing, storage, pH, and bile salts produced by the digestive tract [7]. Microencapsulation produces microcapsules ranging in size from 1 to 5.000 μm. Microencapsulation consists of a core material, a polymer, and a solvent [8].

Freeze drying is one method used to preserve cultures while maintaining the quality of the dried product. The principle of quality drying is a drying process that lowers the temperature of the product until it becomes solid and loses its water content, causing the product to freeze [9]. During the freeze-drying process, a coating material must be added to protect the probiotic bacteria cells from damage during the freezing and drying process. Maltodextrin is commonly used as an encapsulation coating material. Maltodextrin is a complex carbohydrate derived from oligosaccharides that serves as an energy source for the growth of probiotic bacteria. The advantages of maltodextrin as a coating material include rapid dispersion, high solubility, strong binding capacity, and inhibition of oxidative reactions [7].

One fruit that can be used as a probiotic drink is the Manonjaya salak, which is unique to the Tasikmalaya region. It has a sweet, fresh taste that is not too sour, a crisp texture, and no fibers, and has the potential to be used as a diversified processed product in the form of a probiotic drink. Salak is known for its high carbohydrate content, specifically monosaccharides such as sucrose, fructose, and glucose, which can serve as a nutritional source for the growth of lactic acid bacteria. The monosaccharide content in salak is 10.81% [3].

Based on this background, researchers were interested in conducting research on the microencapsulation of Manonjaya salak fruit probiotic drinks with variations of maltodextrin as a coating layer. The purpose of this study was to examine the effect of maltodextrin variations on the physical properties of salak fruit probiotic beverage microcapsules, including organoleptic testing, pH testing, total lactic acid testing, total lactic acid bacteria testing, moisture content testing, and morphological examination using a scanning electron microscope.

2. MATERIALS AND METHODS

2.1. Materials

The equipment used in this study included autoclave (Gea), incubator (Memmert), Laminar Air Flow, oven, digital pH meter (Smart Sensor), glass tools (Pyrex), colony counter (Health), analytical balance (Fujitsu), hotplate (ika), micropipette (Joanlab), freeze-drying machine (Biobase), and Scanning Electron Microscope (JEOL JSM 6510 LA). The materials used in this study were Manonjaya salak fruit extract, bacterial starter cultures of *Lactobacillus bulgaricus* and *Streptococcus thermophilus* (Lactina), sucrose (Laku), skim milk (NPZM), maltodextrin (ex Lihua), whole milk, Nutrient Agar medium (Merck), PP indicator 1%, NaOH 0.1 N, 0.9% NaCl, oxalic acid, and aquadest.

2.2. Methods

2.2.1. Making Manonjaya Salak Fruit Juice

The flesh of the salak fruit is separated from the skin and seeds, then cut into small pieces and washed with clean water. Next, water is added in a 2:1 ratio with the salak, and 4% sugar is added. Next, the mixture is blended and strained using a sieve. The salak fruit juice is poured into sterile glass bottles and sealed with aluminum foil. The juice is then sterilized using an autoclave at 121°C and 1 atm for 15 minutes [3].

2.2.2. Bacterial Starter Production

One gram of Lactobacillus bulgaricus and Streptococcus thermophilus culture powder was added to pasteurized whole milk at 85°C for 15 minutes, then incubated at 37°C for 24 hours [10].

2.2.3. Formulation of Microcapsules of Probiotic Manonjaya Salak Fruit Juice

The preparation was made in triplicate in 100 ml batches using the following procedure: sterilized Manonjaya salak fruit juice was prepared in a sterile erlenmeyer flask, then 9% skim milk and 7.5% sucrose were added to each bottle. Homogenization was performed, followed by inoculation with 4% *Lactobacillus bulgaricus* and *Streptococcus thermophilus* starter bacteria [11]. After that, the product was incubated at 37°C for 24 hours. Then, maltodextrin was added in varying concentrations of 20%, 40%, and 60%, and stirred until homogeneous [7]. Next, they were dried using freeze drying at a temperature of -56°C for 24 hours, repeated three times. The microcapsules were packaged in vials and stored at room temperature [12].

Table 1. Formulation of Microcapsules of Probiotic Manonjaya Salak Fruit Juice

Ingredients	Concentration (%)			
	F0	**F1**	**F2**	**F3**
Bacterial Starter *Lactobacillus bulgaricus* and *Streptococcus thermophilus*	4	4	4	4
Skim milk	9	9	9	9
Sucrose	7.5	7.5	7.5	7.5
Maltodextrin	0	20	40	60
Manonjaya Salak Fruit Juice ad	100	100	100	100

2.2.4. Organoleptic Test

Organoleptic testing involves observation using the senses. Visual assessment is used to evaluate shape. Taste assessment is conducted using the sense of taste. Smell assessment uses the sense of smell [13].

2.2.5. pH Test

Measurements are taken by dipping the pH meter electrode into the sample solution and allowing it to remain there for a few moments until a stable result is obtained [14].

2.2.6. Total Lactic Acid Test

1 gram of sample was placed in an Erlenmeyer flask and dissolved in 20 mL of CO_2-free water. Add 2 mL of phenolphthalein indicator, then titrate the mixture with 0.1 N NaOH solution. The endpoint of the titration was reached after a constant pink color was formed [13].

$$\text{Total Lactic Acid (\%)} = \frac{V \times N \times 90}{W} \times 100\%$$

W = sample weight (mg)

V = volume of NaOH solution (ml)

N = normality of NaOH solution (0.1 N)

90 = equivalent weight of lactic acid

2.2.7. Total Lactic Acid Bacteria Test

1 gram of sample was placed in 9 mL of sterile physiological NaCl solution (10^{-1} dilution). After homogenization, 1 mL of the 10-1 dilution was taken and added to the next reaction tube containing 9 mL of physiological saline solution (10^{-2} dilution), and so on up to 10^{-5} dilution. Take 1 mL of sample

from each dilution using a micropipette and pour it into a sterile Petri dish, then add 15 mL of sterile nutrient agar medium. The dish is then incubated at 37°C for 48 hours [14].

$$\text{Total Lactic Acid Bacteria Colonies} = \text{Number of Colonies on Plate} \times \frac{Volume\ Plated}{Dilution\ Factor}$$

2.2.8. Moisture Content Test

Weigh the empty, sterilized porcelain dish, then place 1 gram of the sample into it. Next, dry the sample and the porcelain dish in an oven at 105°C for 3 hours, then cool them in a desiccator [15].

2.2.9. Microcapsule Morphology Examination

Morphological examination of the shape and size of microcapsules using a Scanning Electron Microscope (SEM). Samples were placed evenly on aluminum stubs, then vacuumed with argon gas until stable and coated with gold using a sputter coater for 20 seconds. The samples were then placed in an electron microscope to observe the shape and size of the microcapsules [16].

2.2.10. Data analysis

Data analysis was performed to determine the effect of maltodextrin concentration variation on each physical quality test data of salak fruit juice probiotic beverage microcapsules using one-way ANOVA.

3. RESULTS AND DISCUSSION

3.1. Organoleptic Test Results

The microcapsules produced can be subjected to organoleptic testing, which can be seen in Figure 1.

Figure 1. Organoleptic Test Result, (a)F0 (b)F1 (c)F2 (d)F3

Organoleptic testing using human senses by describing the texture, color, aroma, and taste of Manonjaya salak fruit extract probiotic microcapsules as follows:

Table 2. Organoleptic Test Result

Formulation	Organoleptic			
	Texture	**Color**	**Aroma**	**Taste**
F0	A little rough and sticky	Yellowish white	The distinctive smell of yogurt and salak	Slightly sweet and sour, with a hint of salak fruit flavor.
F1	A little rough and sticky	Yellowish white	The distinctive smell of yogurt and salak	Slightly sweet and sour, with a hint of salak fruit flavor.
F2	Smooth and sticky	Yellowish white	The distinctive smell of yogurt and salak	Slightly sweet and sour, with a hint of salak fruit flavor.
F3	Smooth and sticky	Yellowish white	The distinctive smell of yogurt and salak	Slightly sweet and sour, with a hint of salak fruit flavor.

Based on the organoleptic test results shown in Table 2, the texture of F0 produced microcapsules that were slightly coarse and sticky compared to F1 because F0 did not contain maltodextrin. The texture of F2 and F3 produces smoother microcapsules compared to F0 and F1. This is influenced by the use of high maltodextrin concentrations, namely 40% and 60%. The higher the maltodextrin concentration, the smoother the microcapsule texture will be. The sticky texture is caused by the high sugar and water content in salak. In the microcapsule color testing results, all formulas produced a yellowish white color. This is because the addition of polysaccharide molecules in maltodextrin will change the microcapsule formulation into a white-yellowish color, as stated in the Maltodextrin Certificate of Analysis, which can make the product color brighter [5].

The aroma test results from all formulas produced the same aroma, namely the distinctive smell of yogurt and salak. The distinctive smell of yogurt is influenced by the growth of lactic acid bacteria that break down lactose into lactic acid. The lactic acid bacteria responsible for aroma formation are Lactobacillus bulgaricus. In the test results for the taste of the microcapsules, there was an effect from the sugar content in salak and the addition of sucrose. The glucose content in maltodextrin also caused the product to be slightly sweet. The lactic acid bacteria responsible for the formation of the taste are Streptococcus thermophilus [17].

3.2. pH Test Results

The pH test results are shown in Table 3 as follows:

Table 3. pH Test Result

Formulation	pH	Standard
F0	3.81 ± 0.02	3.5 – 4.8
F1	3.85 ± 0.01	
F2	3.87 ± 0.03	
F3	3.88 ± 0.01	

Based on the observations in Table 3, there are differences in pH values among the formulas. The highest pH value was obtained in F3 at 3.88, while the lowest pH value was obtained in F0 at 3.81. pH value is one of the factors that influence the survival of lactic acid bacteria. pH values can indicate the quality of lactic acid bacteria fermentation, categorized as excellent with a pH value around 3.5–4.2, good around 4.2–4.5, moderate around 4.5–4.8, and poor above 4.8 [18].

The addition of maltodextrin causes the pH value to increase with higher concentrations of maltodextrin added. The maltodextrin used has a pH of 5.3, as stated on the Certificate of Analysis Maltodextrin, which can cause an increase in the pH value of the microcapsules. The amount of water bound due to the influence of the charge of proteins can affect the pH value, such that at the isoelectric point (4.4–4.5), the ability of proteins to bind water decreases. The reduced binding of proteins to water causes proteins in milk to coagulate and precipitate due to the release of water from the protein structure [5].

The acidity value in yogurt will cause an increase in lactic acid, which is related to the protein-rich skim milk content as a growth medium for lactic acid bacteria. The protein produced from skim milk, namely casein, can affect the acidity value. Not only that, the sugar content in salak fruit is also utilized by lactic acid bacteria for growth during the fermentation process, thereby forming lactic acid. The more lactic acid that is formed, the lower the pH becomes [19].

Based on the statistical test results, with a p-value <0.0001, there was a significant difference between the treatment groups (F0–F3). This indicates that the addition of maltodextrin statistically affected the pH value of the microcapsules. This was followed by a Tukey HSD test, which showed that adding up to 40% maltodextrin was sufficient to significantly increase the pH of the microcapsules, and that an increase from 40% to 60% no longer made a significant difference. It can be concluded that a concentration of 40% maltodextrin is optimal for increasing and stabilizing the pH of microcapsules.

3.3. Total Lactic Acid Test Results

The total lactic acid test results are shown in Table 4 as follows:

Table 4. Total Lactic Acid Test

Formulation	Total Lactic Acid (%)	Standard
F0	0.78±0.04	0.5% – 2.0%
F1	0.99±0.07	
F2	1.17±0.13	
F3	1.29±0.11	

Based on the results shown in Table 4, the highest total lactic acid value was found in F3 at 1.26%, while the lowest total lactic acid value was found in F0 at 0.78%. Referring to SNI 2981:2009 regarding yogurt, the required range for total lactic acid is between 0.5% - 2.0%.

The total lactic acid produced from Manonjaya salak fruit probiotic microcapsules is directly proportional to the increasing concentration of maltodextrin used. The high sugar content in salak fruit is utilized by lactic acid bacteria as an energy source. Skim milk is used as a nutrient for the growth of lactic acid bacteria, enabling them to grow by breaking down lactose into lactic acid [3]. Lactic acid is a product of carbohydrate metabolism produced by lactic acid bacteria during fermentation. Lactic acid functions to inhibit pathogenic bacteria in the digestive tract. Pathogenic bacteria cannot survive in the acidic environment created by lactic acid. Lactic acid can stimulate peristaltic movements in the digestive tract, thereby enhancing digestion, absorption, fecal elimination, and the expulsion of pathogenic bacteria [20].

Based on the results of the one-way ANOVA statistical test, it was found that variations in maltodextrin concentration had a significant effect on the total lactic acid in microcapsules (F-statistic = 557.79, p-value < 0.0001), with an increasing trend as the concentration increased. The Tukey HSD test showed that all pairs of groups (F0–F3) had statistically significant differences in total lactic acid ($p < 0.05$), with an increasing trend as the maltodextrin concentration increased.

3.4. Total Lactic Acid Bacteria Test Results

The total lactic acid bacteria test results are shown in Table 5 as follows:

Table 5. Total Lactic Acid Bacteria Test Result

Formulation	Total LAB (CFU/mL)	Standard
F0	$3.77x10^7$±0.24	Minimal $1x10^7$ CFU/mL
F1	$4.30x10^7$±0.15	
F2	$4.78x10^7$±0.06	
F3	$5.16x10^7$±0.11	

Total LAB testing is a standard method used to determine the viability or number of live cells in a probiotic product, especially after undergoing processing such as drying when using freeze-drying equipment. Total lactic acid bacteria testing in this study was carried out using the Total Plate Count (TPC) method. The testing was carried out using a Colony Counter on samples with a dilution level of 10^{-5}. In Table 5, the highest total lactic acid bacteria count was obtained in F3 at 5.16×10^7 CFU/mL, while the lowest total lactic acid bacteria count was obtained in F1 at 3.77×10^7 CFU/mL. According to SNI 2981:2009 on yogurt, the minimum required total lactic acid bacteria count in yogurt is $1x10^7$ CFU/mL.

The results of the total lactic acid bacteria test showed an increase in line with the increase in maltodextrin concentration. The addition of maltodextrin in the formulation is known to replace the role of water lost from the bacterial cell structure by forming stable hydrogen bonds with phospholipid groups on the bacterial cell membrane, thereby maintaining the structural integrity of the cell membrane. The use of maltodextrin can protect bacterial cells during the drying process, thereby increasing bacterial cell viability. This technique is crucial to ensure that the resulting probiotic products meet the minimum standards for live microbe counts. Maltodextrin also plays a role in extending the shelf life of dried probiotic products by reducing water content, thereby maintaining microbial stability during long-term storage [21].

The growth of lactic acid bacteria colonies is influenced by the availability of essential nutrients in the fermentation medium, particularly the content of skim milk, salak fruit, and sucrose. Skim milk produces protein that acts as an energy source for LAB growth. Salak fruit acts as a source of carbon and nitrogen that supports the metabolic activity and replication of LAB cells. Sucrose, as a disaccharide, produces energy to support rapid LAB growth and high populations [14].

Based on the results of the one-way ANOVA statistical test, it was found that variations in maltodextrin concentration had a highly significant effect on the total number of lactic acid bacteria (LAB) in microcapsules ($F = 2717.19$, $p < 0.0001$). The higher the maltodextrin concentration, the higher the number of LAB detected. The Tukey HSD test showed that all pairs of groups (F0–F3) had statistically significant differences in the total number of lactic acid bacteria (LAB) ($p < 0.05$), with an increasing trend as the maltodextrin concentration increased. All pairs showed significant differences, meaning that each increase in maltodextrin concentration had a real impact on the increase in the number of LAB.

3.5. Moisture Content Test Results

The moisture content test results are shown in Table 6 as follows:

Table 6. Moisture Content Test Results

Formulation	Moisture Content (%)	Standard
F0	10.33±0.47	≤ 3%
F1	10.00±0.00	
F2	10.00±0.00	
F3	10.00±0.00	

Moisture content is defined as the amount of water contained in a material that affects the stability, shelf life, and microbial activity in the product. Moisture content testing was conducted by oven drying for 3 hours, showing differences in moisture content results with increasing maltodextrin

concentration in the Manonjaya salak fruit probiotic. In Table 6, the highest moisture content value was obtained at F0 at 10.33%, while the moisture content values at F1, F2, and F3 were the same at 10%. Referring to SNI-4320-2004 regarding powder in moisture content testing, the required limit is ≤ 3%.

Maltodextrin is a carbohydrate derivative produced by the partial hydrolysis of starch, which is widely used as a coating agent in probiotic microcapsule formulations. Its hydrophilic, water-soluble, non-reactive properties, and high total solids content make maltodextrin effective in forming a protective matrix for probiotic cells during the freeze-drying process [5]. Maltodextrin's ability to increase the total solids in a mixture during the drying process reduces the amount of water that can be evaporated. Thus, the higher the concentration of maltodextrin added, the lower the moisture content produced. This compound has a relatively low molecular weight (less than 4000) and a simple chemical structure, making it easier to release water during the drying process [22].

In Table 6, the water content values of probiotic microcapsules coated with different maltodextrin concentrations show relatively similar values. This is because at certain concentrations, maltodextrin's ability to bind and retain water reaches a saturation point, so that adding maltodextrin beyond this limit no longer results in significant differences in water content when the concentration is already sufficiently high, e.g., >10–15%. Additionally, all samples were stored under the same environmental conditions, with low hygroscopic properties, and no water absorption from the air occurred, so the water content tended to be the same [23].

Another factor that can affect the high water content in microcapsules is that fruit juice must be evaporated first before being mixed with the coating material for the microencapsulation process. The aim is to reduce the initial water content so that the microcapsules have a low final water content. In this study, the fruit juice was not evaporated beforehand, resulting in excessively high water content in the coating solution and suboptimal drying, thereby requiring a longer drying process. In this study, evaporation was not carried out beforehand because it was only preliminary research. For further research, it is necessary to evaporate the salak fruit juice before making probiotic drinks.High water content in probiotic microcapsules accelerates biological and chemical degradation reactions such as hydrolysis and enzyme activity, which can cause probiotic cell death during storage, soften the maltodextrin matrix, cause the microcapsules to lose their structural integrity, and make the microcapsules sticky. Probiotic growth can also be contaminated by pathogenic microorganisms that thrive in high-moisture environments [24].

Based on the results of the one-way ANOVA statistical test, it was found that variations in maltodextrin concentration had a significant effect on the water content of microcapsules ($F = 326.70$, $p < 0.0001$), with the highest water content in F0 (0%) and a steady decrease in F1–F3. The Tukey HSD test showed that the water content of microcapsules in F0 (0% maltodextrin) was significantly different from F1, F2, and F3, while F1–F3 were not significantly different from each other. F1, F2, and F3 had statistically similar moisture content, indicating that adding maltodextrin from 20% to 60% no longer significantly reduced moisture content.

3.6. Microcapsule Morphology Examination

The microstructure of a microcapsule material can be observed using a Scanning Electron Microscope (SEM). Microcapsules coated with various types of encapsulation materials such as maltodextrin can be analyzed to determine the surface characteristics and size of the microcapsules, as shown in Figures 2 and 3.

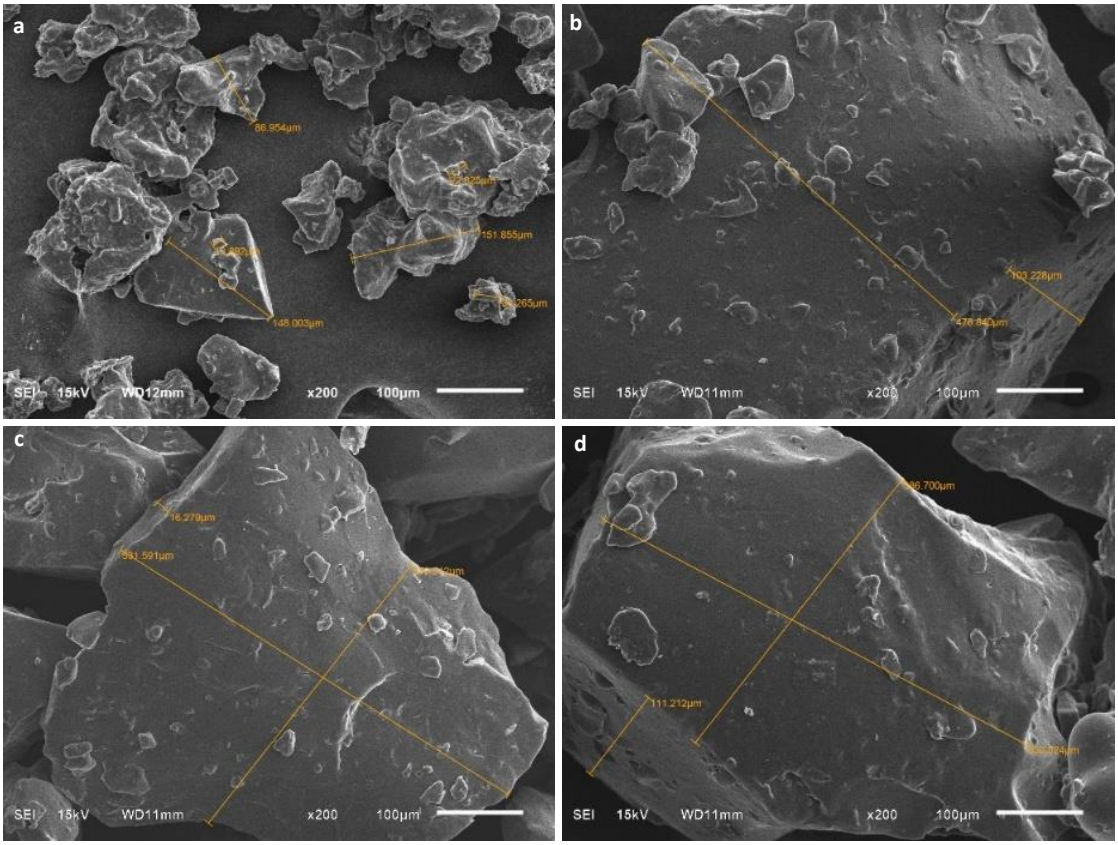

Figure 2. Microstructure Morphology of Microcapsules at 200x Magnification (a) F0 Without Maltodextrin (b) F1 20% Maltodextrin (c) F2 40% Maltodextrin (d) F3 60% Maltodextrin

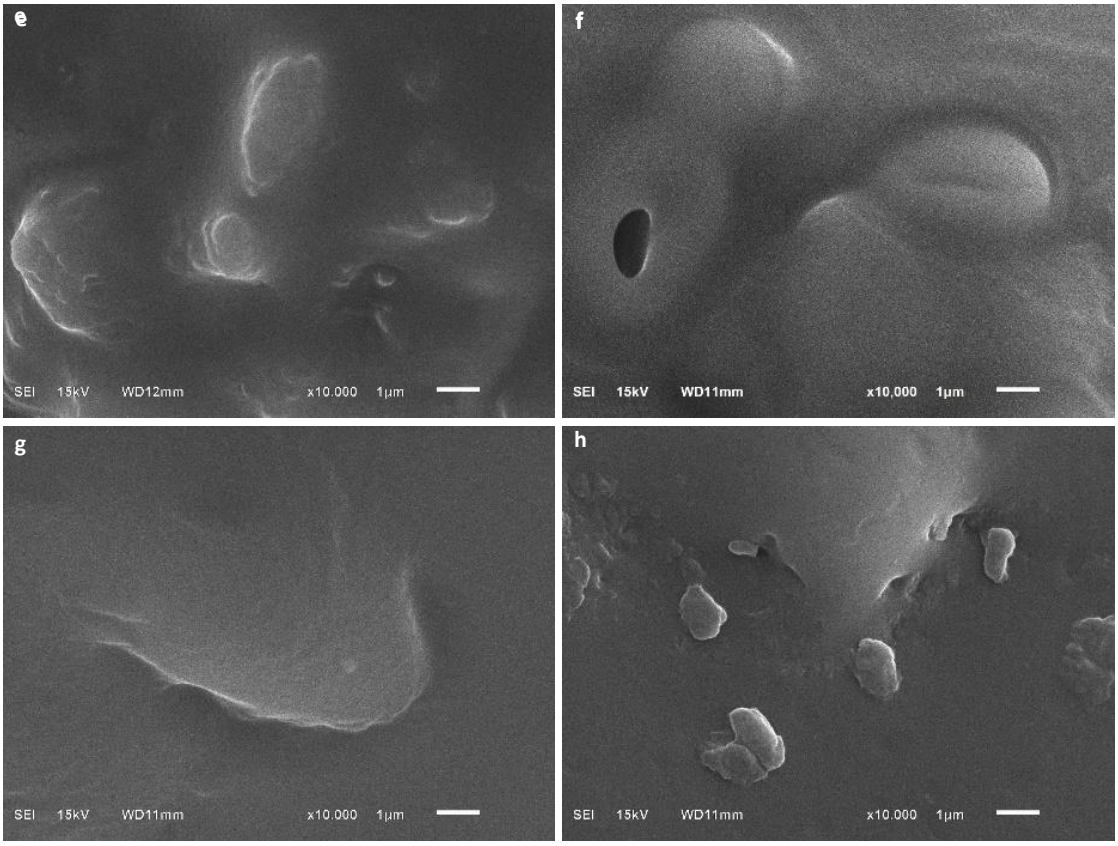

Figure 3. Microstructure Morphology of Microcapsules at 10.000x Magnification (e) F0 Without Maltodextrin (f) F1 Maltodextrin 20% (g) F2 Maltodextrin 40% (h) F3 Maltodextrin 60%

Microencapsulation techniques aim to compare microcapsules that are not coated with maltodextrin and those coated with maltodextrin at concentrations of 20%, 40%, and 60%. Based on the research results, it was found that examining the shape and morphology of microcapsules coated with maltodextrin successfully encapsulated the probiotics. SEM showed that the microcapsules produced were generally spherical in shape, either perfectly spherical or spherical with some indentations, and had a smooth surface without cracks [25]. SEM was used to characterize the morphology of microencapsulated probiotics, demonstrating the effectiveness of microencapsulation using the freeze-drying method. Referring to research on microcapsule size observed using a Scanning Electron Microscope (SEM), the required size is 1–1000 μm [26].

In the F0 results without the addition of maltodextrin coating material at 200x magnification, the particles showed more varied and irregular shapes, round with wrinkled and rough surfaces, separate particles, hollow, and black holes. The resulting particle shapes appeared clumped, forming uneven aggregates, causing clumping and uneven shapes. The structure of microcapsules without a coating can result in probiotic cells without an outer layer, exposing them directly to the external environment, including air, light, humidity, and temperature during the freeze-drying process, which can accelerate cell degradation. The particle size produced is highly variable (approximately 18 μm to 151 μm). At 10,000x magnification, the particles appear elongated and oval in shape, most likely the exposed cell wall structure of the probiotic itself, which is not coated by a protective layer, allowing the probiotic cells to be freely exposed to the external environment, which is highly susceptible to degradation during processing and storage [27]. Unencapsulated probiotic cells exhibit a smooth, open surface without structural protection, making them more susceptible to damage from environmental conditions such as stomach acid and high temperatures. Simulation results showed that the viability of unencapsulated probiotic cells decreases significantly, leading to total loss after exposure to gastrointestinal conditions, primarily due to low tolerance to acidic environments. In contrast, encapsulated cells exhibit significantly higher resilience, with survival rates reaching 84%. Microcapsules without protective structures are more susceptible to damage at high temperatures or in acidic environments, while well-structured microcapsules enhance stability and protection against acidic conditions [28].

In the F1 results (20% maltodextrin), it can be seen at 200x magnification that the microcapsules tend to appear rough and uneven, with small pores or holes visible on the outer layer. This occurs because maltodextrin has a tendency to form layers with microcracks during drying. The presence of these pores or gaps is one of the factors that can reduce the stability of probiotic cells during storage, as it increases the likelihood of direct contact between bacteria and environmental factors such as oxygen, air, high temperatures, and other external stresses. Additionally, small particles are observed adhering or scattered on the capsule surface, likely originating from undissolved maltodextrin residues or imperfectly coated probiotic cells. This indicates potential imperfections in the encapsulation process. The microcapsules are not perfectly spherical but irregular and somewhat sharp. This reflects that maltodextrin tends to form fragile and brittle structures if not combined with other encapsulation agents that enhance physical stability. The measured particle size shows a length of approximately 478.84 μm and a height of approximately 103.23 μm. At 10.000x magnification, there were no large pores or noticeable cracks. This indicates that the use of maltodextrin at a concentration of 20% was able to form a denser and more evenly

distributed capsule matrix compared to microcapsules without coating or with lower coating concentrations [29].

In the F2 results (40% maltodextrin), at 200x magnification, the microcapsules exhibited a smoother surface compared to F1; however, small cracks and shallow indentations were still visible, scattered across the surface. This indicates that the wall structure is not completely compact and is still susceptible to external environmental influences such as humidity and air. Small fragments or microscopic particles are scattered across the surface of the capsule. These could be maltodextrin deposits or probiotic cells that are not fully enclosed. The presence of micro-pores or fine cracks could also accelerate oxygen diffusion and reduce viability during storage. The microcapsule shape is not perfectly spherical but irregular and angular. This shape also reflects an uneven wall hardening process. The microcapsule size produced has a maximum particle length of ± 531.59 μm, other particle widths of ± 378.51 μm, and an edge thickness of ± 16.28 μm. At 10,000x magnification, the microcapsules appear to have an irregular shape and are slightly rounded at the ends, resembling droplets. Their surfaces appear relatively smooth, and no large pores are visible. Therefore, microcapsules coated with a 40% maltodextrin concentration show that the surface provides adequate protection against the external environment [28].

In the F3 results (60% maltodextrin), with 200x magnification, the microcapsule surface appears smoother and flatter than F1 and F2. The microcapsule surface does not show many large pores or open gaps, indicating that maltodextrin with a concentration of 60% is capable of forming a relatively compact capsule wall layer. The capsule surface shows few cracks or damage, although small particles are attached. This indicates the formation of a more stable capsule wall, possibly due to more controlled freeze-drying conditions or a more homogeneous maltodextrin solution. The size of the microcapsules produced has a maximum length of ± 553.82 μm, a horizontal width of ± 386.70 μm, and a vertical width of ± 111.21 μm. At 10,000x magnification, the microcapsules appear rounder and more compact compared to those with 20% and 40% maltodextrin concentrations. This indicates that increasing the maltodextrin concentration helps form a more uniform capsule structure. Thus, probiotic microcapsules with a 60% maltodextrin concentration exhibit a more stable morphological structure, with a relatively smooth surface and minimal large porosity. Particle size exceeds 500 μm, which can provide longer-lasting protection for probiotic cells. This structure indicates that maltodextrin is capable of forming an effective capsule wall for encapsulating probiotic cells [30].

4. CONCLUSION

Variations in maltodextrin concentration affect the physical properties of Manonjaya salak fruit probiotic microcapsules in formulas 1, 2, and 3, with the best statistical results in the pH test being in F2. Meanwhile, in the total lactic acid and total lactic acid bacteria tests, increasing maltodextrin concentration statistically increased the lactic acid and total lactic acid bacteria levels, making F3 the most optimal. In the moisture content test, F1 was statistically effective in reducing moisture content but did not meet the requirements. In morphological observations using SEM, F3 was the most optimal, as seen from its smoother, flatter surface with minimal large pores and cracks, as well as a more stable and uniform capsule wall. Overall, all formulas met the physical microcapsule test requirements, except for the moisture content test, so further research is needed to improve deficiencies such as the combination of coating agents and evaporation of salak fruit juice before microencapsulation.

Funding: This research received no external funding.

Acknowledgments: The author would like to thank the research members

Conflicts of interest: The authors declare no conflict of interest.

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