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Study on the Vacuum Pressure and Drying Time of Freeze-drying Method to Maintain the Quality of Strawberry (*Fragaria virginiana*)

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ABSTRACT

This study aims to examine freeze drying techniques and the effect of freeze drying techniques on the quality of freeze-dried strawberries. The material used are strawberries obtained from farmers in Lembang, West Bandung Regency, Bandung. The fruit having postharvest age of 14-15 days after the beginning of fruit formation. Freeze drying was carried out using Buchi type Lyovapor L-200 freeze dryer. The research stage consists of sample preparation, freezing, freeze drying, and quality observation. Freezing was carried out for 110 to 120 minutes until the temperature of the fruit reaches temperature of -12 °C to -15 °C. Freeze drying was carried out at temperature of -46 °C for 12 hours, 24 hours, and 36 hours. The experimental design used in this experiment was a complete randomized factorial design. The first factor was vacuum pressure (0.5 mBar and 0.1 mBar) and the second factor was drying time (12 h, 24 h and 36 h). The experiment was conducted with 2 repetitions. Observed quality parameters include drying rate, moisture content, weight loss, hardness, total dissolved solids, rehydration ratio and favorability/hedonic value. The results showed that the vacuum pressure, drying time and their interaction had a significantly effect on the rate of drying, moisture content, weight loss, hardness, total dissolved solids, rehydration ratio, color and texture of the fruit, but had no significantly effect on taste and aroma. Freezing drying at a vacuum pressure of 0.1 mBar and 36 hours drying time produces the best quality of freeze-dried strawberries with hedonic score of 5 (like) based on the panelists' assessment.

1. INTRODUCTION

Strawberry (*Fragaria virginiana*) is fruit with high economic value but perishable and is highly susceptible to pests and diseases. Strawberry is rich in carbohydrates, Ca, P, Fe, vitamins A, B1, C and water. The content of vitamin C in strawberry is more than that of citrus fruits, which is around 25 – 120 mg/100 g. Strawberry is rich in phenolic compounds such as anthocyanins, flavonols and cinamic acid (Cheng & Breen, 1991). According to Olias *et al*. (2000) post-harvest problems of fruits include mechanical, physiological and disease damage.

The main factors in maintaining the quality of strawberries are the right harvest time and good post-harvest handling. Therefore, strawberries require special handling at harvest and post-harvest. Strawberries are usually packaged in transparent or white plastic containers. According to Paulus (1990) packaging using PVC plastic can reduce the attack index of Botrytis and maintain good fruit quality. This packaging serves to increase CO_2 levels by 10.5% to control fungal damage. Strawberries can be stored for up to six days at temperatures between 0 – 40 °C. After six days, the fruit will lose the components of aroma, taste and other important characteristics (De Souza *et al*., 1999). Drying at low temperatures and modifying the atmosphere by increasing CO_2 levels can suppress fungal growth, senescence, and extend the shelf life of fruit (Manning, 1996). High levels of CO_2 can cause off-flavor (Ke *et al*., 1994).

Freeze drying is one of the drying methods with advantages in maintaining the quality of the drying product. Freeze drying is the process of removing frozen water from a product through sublimation, which is carried out at low temperature and pressure (Fajri, 2002). Freeze drying has been recognized and recognized as a drying method that can provide the best drying product quality compared to other drying methods (Liapis & Bruttini, 1995). The freezing process in freeze drying will determine the final product being dried. Liapis & Bruttini (1995) said that the freeze-drying process involves three stages, namely freezing below -10 °C or lower, primary drying to remove water and solvents in a frozen state by sublimation, and secondary drying to remove sublimated moisture or water. bound in the dry layer.

Freezing rate according to King (1971) is divided into three groups, namely slow freezing (less than 2 cm/hour), medium freezing (2-3 cm/hour), and fast freezing (more than 3 cm/hour). Slow freezing will cause the formation of large ice crystals arranged in the intercellular space with large pore sizes where the resulting pore size will be directly proportional to the temperature used in the freezing process (Heldman & Singh, 1981).

In the freeze-drying process there are three layers of the material, namely the frozen layer on the inside of the material, the dry layer on the surface of the material and the transition layer which is the sublimation surface. During the freeze-drying process, the sublimation surface will move to the inside and the dry layer on the outside will be thicker (Kreith & Bohn, 1986). This process can occur if the vapor pressure and surface temperature of the ice where sublimation takes place are below the triple point, i.e. under a pressure of 4.58 torr (603 Pa) and a temperature of 0.01°C. In the freeze-drying mechanism, the resulting water vapor is sucked up and condensed so that it does not wet the product (Figure 1). The working principle of the freeze dryer is to lower the temperature and then lower the pressure with a vacuum pump (Jakubczyk & Jaskulska, 2021). After the pressure is reached, the heating air is flowed into the drying chamber from the exhaust heat of the condenser.

The advantages of freeze-dried products include having a structure that does not shrivel so that it allows fast rehydration, high flavor retention (because drying takes place at low temperatures), viability, and high reconstitution of living cells in freeze-dried products. Freeze-drying is known to extend the shelf life of foods by preventing microbial growth and slowing lipid oxidation. Freeze drying is also applied to long-term drying of food for preservation purposes on an industrial scale. However, the drying time is longer and more expensive than conventional drying methods (Shofian *et al.*, 2011). Therefore freeze drying is more widely used to dry foods that are difficult to dry, such as coffee, onions, soups, certain seafood, fruits and medicines (Liapis & Bruttini, 1995).

Strawberries are perishable and have a short shelf life. Efforts to overcome these problems are through improving post-harvest handling and processing to increase added value. Most of the postharvest handling of strawberries is carried out conventionally so that the quality loss is very high. Postharvest technology is needed to maintain product quality, including through the application of freeze drying technology. This study aims to examine the effect of freeze-drying process parameters on the drying rate and changes in the quality of strawberries and determine the best freeze-drying process parameters to maintain the quality of strawberries.

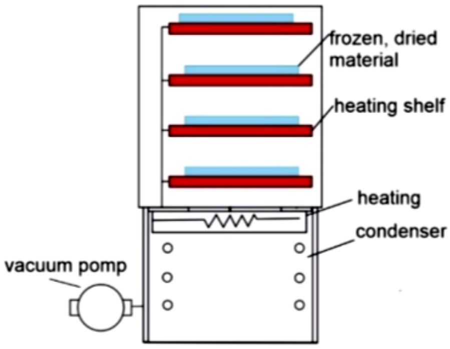

Figure 1. General schematic of freeze dryer system (Jakubczyk & Jaskulska, 2021)

2. MATERIALS AND METHODS

2.1. Materials

The main material used was strawberries (Figure 2) at the age of 14-15 days after the initial fruit formation (HSPB) obtained from a strawberry plantation in Lembang, West Bandung Regency, Bandung. Fresh strawberries were first sorted to separate defective fruit and fruit with uniform size and fruit weights ranging from 10-13 g were selected. The selected fruit was then washed, drained and divided into several aluminum containers according to the treatment of 15 pieces each (Figure 2). The fruit samples were then frozen using a freezer at a temperature of -12 °C to -15 °C.

The equipments used in this study included a freezer to freeze fruit, a freeze dryer Buchi type Lyovapor L-200 with a capacity of 6 kg, a digital thermometer to measure temperature, a rheometer model CR-300 DX-L to measure fruit hardness, a refractometer to measure total dissolved solids, electronic scales to measure fruit weight, and water heaters to measure the rehydration ability of fruit. The stages of the research were shown in Figure 3.

Figure 2. Fresh strawberries used in the experiment

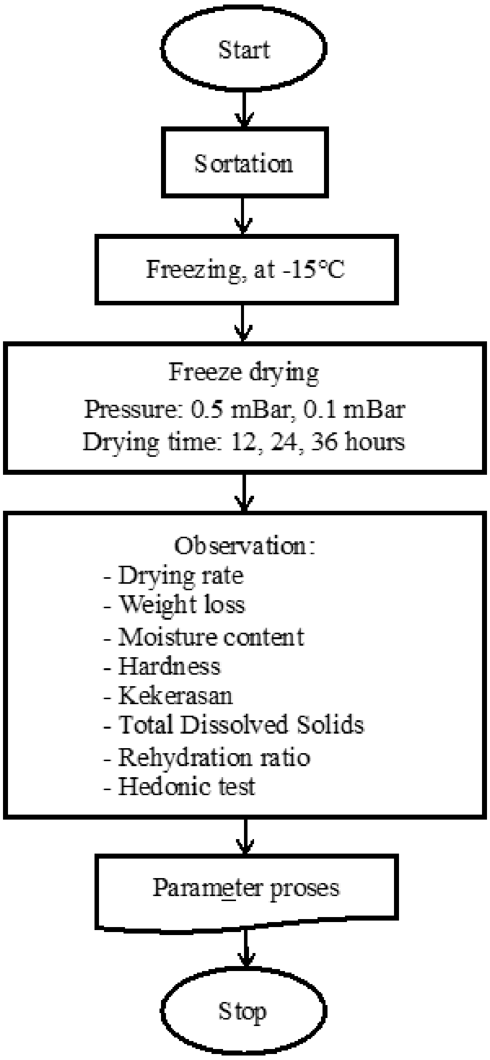

Figure 3. Flow chart of freeze drying experiment for strawberry

2.2. Design of Experiment

The experimental design used was a factorial design that was completely randomized (factorial CRD). The first factor is the vacuum pressure (0.5 mBar and 0.1 mBar) and the second factor is the drying time (12 hours, 24 hours and 36 hours). Each treatment was repeated 2 times. The responses observed were drying rate, moisture content, weight loss, hardness, total dissolved solids, rehydration ratio, organoleptic. The experimental design model is presented in Equation (1).

$$Y_{ij} = \mu + A_i + B_j + (AB)_{ij} + \varepsilon_{ij} \quad (1)$$

where, Y_{ij} is the observed value of the i^{th} pressure and the j^{th} drying time, μ is general mean, A_i is the effect of pressure at i^{th} level, B_j is effect of drying time at j^{th} level, $(AB)_{ij}$ is the interaction effect of factor A (pressure) at the i^{th} level and factor B (drying time) at the j^{th} level, ε_{ij} is experimental error, *i* = 1, 2; *j* = 1,2, 3; and *k* = 1, 2.

The data obtained were analyzed using analysis of variance (ANOVA) at a significance level of 5%. If the ANOVA results show a significant effect, then it was continued with the significant difference test of Duncan Multiple Range Test (DMRT) at the 5% level.

2.3. Analysis and Measurements

2.3.1 Drying Rate

The drying rate was calculated by dividing the difference in sample mass and the drying time (Equation 2).

$$\frac{dM}{dt} = \frac{M_o - M_t}{t} \qquad (2)$$

where *dM/dt* is drying rate (g/h), M_o is initial mass (g water/g strawberry), M_t is final mass (g water/g strawberry), and *t* is drying time (h).

2.3.2 Moisture Content

Analysis of fruit moisture content was carried out using the oven method. The fruit slices were weighed about 20 g and then dried in an oven for 24 hours at 105 ^oC. The percentage of moisture content on a wet basis (M_{bb}) is calculated using Equation (3).

$$M_{bb} = \frac{W_a}{W_a + W_d} x100\% \qquad (3)$$

where W_a is the weight of water in the material (g) and W_d is absolute dry weight (g).

2.3.3 Weight Loss

Fifteen (15) homogeneous samples for each treatment were weighed using a digital scale. Weight loss was obtained by comparing the reduction from the initial weight of the observation and is expressed in percent (%) as given in Equation (4).

$$W_L = \frac{W_o - W_t}{W_o} x100\% \qquad (4)$$

where W_L is weight loss (%), W_o is initial weight (g), and W_t is final weight (g) of the sample.

2.3.4 Hardness

Hardness was determined using a Rheometer Model CR-300, with a maximum load of 10 kg, a compression depth of 15 mm, and a probe diameter of 5 mm. Strawberry fruit was measured 2 times at different positions with a probe velocity of 15-20 mm/min. Strawberry hardness value was observed on the rheometer display and was expressed in kgf unit.

2.3.5 Total Dissolved Solids

Total dissolved solids were determined using a digital refractometer (Atago). Strawberry fruit was crushed by grinding it first to take the liquid, then placing it on a digital refractometer prism which has been stabilized at laboratory temperature. Before and after readings, the refractometer prism was cleaned with distilled water. The total dissolved solids value was shown on the refractometer display in °Brix unit.

2.3.6 Rehydration ratio

The rehydration ratio of the sample was measured by adapting the method provided by Giri and Prasad (2007). The dried sample was measured initially, then immersed in water at 100 °C with a ratio of 500 ml water for one gram of dry sample. The soaked samples were weighed every 2 minutes until the weight was stable. The rehydration ratio (R_r) was calculated based on Equation (5).

$$R_r = \frac{W_2}{W_1} \quad (5)$$

where R_r is the rehydration ratio (%), W_1 is initial weight (g), and W_2 is sample weight after rehydration (g).

2.3.7 Hedonic Test

Samples for the hedonic test were presented randomly and during assessment the panelists should not compare between the samples presented. The number of untrained panelists involved in the assessment were 15 people and they were presented test samples one by one so that they would not compare one sample with another. Assessment of the hedonic test was conducted spontaneously. The rating scale used in this test was 7 scale.

3. RESULTS AND DISCUSSION

3.1. Rate of Freeze Drying

Prior to drying, the strawberries were frozen at a temperature of -12°C to -15°C. This freezing temperature meets the minimum temperature requirements for agricultural product materials to avoid tissue collapse which can cause freeze-drying process failure due to melting of frozen products before drying (Liapis & Bruttini, 1995). Freezing of strawberries is done for 100-120 minutes. Fellows (1988) stated that the factors that affect the rate of freezing include the thermophysical properties of the material, the freezing method, the temperature difference between the product and the freezing medium, and the heat transfer mode. The initial mass of the material used is 150-160 g with a thickness of 2.1 cm and produces an average rate of freezing of strawberries of 1.71 cm/hour. According to King (1971) this value belongs to the slow freezing rate, where the time required is more than 30 minutes for 1 cm of frozen product. Slow freezing rate affects ice crystal formation. Slow freezing will form large ice crystals so that the product has a coarse pore structure. This causes the product to more easily drain water vapor so that the time required for the sublimation process will be faster.

After the freezing process, further drying is carried out at a temperature of -46°C. The drying rate shows the amount of water that is evaporated per unit of time. Freeze-drying rates of strawberries at various vacuum pressures and drying times are presented in Table 1. The results of analysis of variance showed that vacuum pressure and drying time significantly affected the drying rate. The lower the pressure, the higher the drying rate. On drying for 36 hours, the resulting drying rate of 2.89 g/hour for a pressure of 0.5 mBar and 3.73 g/hour for a pressure of 0.1 mBar. DMRT significant test showed that the interaction of pressure treatment and drying time showed a significant difference. The drying rate has a relationship with the adequacy of time in the drying process. A high drying rate tends to speed up the drying time to produce the desired moisture content.

The drying rate is the ratio between the mass of water that has evaporated and the time required during the drying process. According to Tambunan (2005), the factors that affect the drying time are the rate of freezing as the initial freeze-drying process and the surface temperature of the material. The fast freezing rate causes a long drying process and the low surface temperature of the material causes a longer drying time as well.

Table 1. Average drying rate of strawberries at different vacuum pressure and drying time

Treatment		Drying rate (g/h)
Vacuum pressure (mBar)	Drying time (h)	
0.5	12	5.47 ± 0.18 b
	24	3.46 ± 0.18 d
	36	2.89 ± 0.12 e
0.1	12	8.40 ± 0.16 a
	24	4.98 ± 0.16 c
	36	3.73 ± 0.01 d

Note: Values followed by the same letter in the same column show no difference at the 5% level of significance based on the DMRT test

3.2. Freeze Dried Strawberry Quality

During the freezing process of the fruit there is a reduction in the mass of water and other chemical components in the tissue. This also causes chemical and biochemical reactions inside cells (Chiralt *et al*., 2001). Analysis of the quality of freeze-dried strawberries is presented in Table 2. The results from ANOVA showed that the vacuum pressure and drying time had a significant effect on moisture content (*MC*), weight loss (W_L), hardness, and total dissolved solids (TDS).

Table 2. Quality characteristics of dried strawberries

Treatment		*MC* (%wb)	W_L (%)	Hardness (kgf)	TDS (°Brix)
Vacuum-pressure (mBar)	Drying time (h)				
0.5	12	43.9 ± 3.4 a	42.5 ± 2.1 d	8.17 ± 0.18 a	6.38 ±0.55 f
	24	23.9 ± 2.6 c	54.0 ± 2.8 e	4.99 ± 0.12 c	9.46 ± 0.77 d
	36	15.9 ± 0.2 d	67.5 ± 3.5 bc	2.05 ± 0.14 e	11.95 ± 0.97 b
0.1	12	31.5 ± 1.1 b	63.0 ± 1.4 c	6.45 ± 0.38 b	7.27 ± 0.74 e
	24	13.5 ± 1.7 e	73.0 ± 2.8 b	4.16 ± 0.32 d	10.13 ± 0.57 c
	36	9.6 ± 1.1 f	81.5 ± 2.1 a	1.05 ± 0.17 f	13.51 ± 0.38 a

Note: Values followed by the same letter in the same column show no difference at the 5% level of significance based on the DMRT test

3.1.1. Moisture Content

The average initial water content ranged from 62.2% wb to 63.1% wb. Freeze-drying at various vacuum pressures and drying time resulted in the moisture content of freeze-dried strawberries ranging from 9.6 %wb to 43.9%wb. The lower the pressure and the longer the drying time, the lower the moisture content of freeze-dried strawberries. This happens because the lower the pressure and the longer the drying time, the more water molecules that evaporate from the strawberries and the free water on the surface of the material can be easily evaporated during the drying process so that the water content in the material is getting lower. The lower the pressure and the longer the drying time also result in the greater of heat energy in the air so that the amount of mass of liquid that is evaporated from the surface of the freeze-dried strawberries increases.

Freeze-dried strawberries with a drying time of 36 hours produced a moisture content of 15.9% and 9.6%, respectively, for a vacuum pressure of 0.5 mBar and 0.1 mBar. This is consistent with the value of weight loss in the fruit, where drying time for 36 hours for a vacuum pressure of 0.5 mBar and 0.1 mBar resulted in the highest weight loss, namely 67.5% and 81.5%, respectively. Moisture content has a correlation with weight loss because both are affected by water loss from the inside of the material (Kafiya *et al*., 2018).

3.1.2. Weight Loss

Weight loss has a correlation with water content because both are affected by water loss from the inside of the material (Kafiya *et al*., 2018). The process of removing water from a frozen product takes place through sublimation, which occurs at low temperature and pressure (Fajri, 2002). Therefore, the product resulting from the freeze-drying process is dry and porous without any shrinkage.

ANOVA test showed that the vacuum pressure and drying time had a significant effect on weight loss. At a vacuum pressure of 0.5 mBar, the weight loss reached 67.5% in the sample with a drying time of 36 hours, while at a vacuum pressure of 0.1 mBar, drying at the same time resulted in a weight loss of 81.5%. This shows that freeze drying at lower pressures and longer drying times results in greater weight loss.

3.1.3. Hardness

Hardness is one of the internal quality parameters that determine the freshness and quality of horticultural products. Marlina *et al*., (2014) stated that fruit hardness is influenced by cell turgor pressure, structure, and polysaccharide composition of the cell wall. In the freeze drying process there is a freezing process that can increase the hardness value of the fruit if the frozen water cannot be completely sublimated during drying.

The pressure and time of drying had a significant effect on the firmness of the fruit. The longer the drying time and the lower the pressure, the lower the fruit hardness. The highest fruit hardness value occurred at a drying time of 12 hours, which was 8.17 kgf and 6.45 kgf for a vacuum pressure of 0.5 mBar and 0.1 mBar, respectively. This happens because the frozen water before drying has not been completely sublimated so that the porous nature of the strawberries has not been formed. This also indicates that the primary drying process in which frozen water and solvent are removed by sublimation has not yet ended. The primary drying stage ends when all layers of frost on the fruit have completely sublimated. According to Tambunan *et al*., (2001), when the sublimation surface reaches the center of the material, it can be used as an indication of the completion of the sublimation process.

The hardness value of dried strawberries decreased with decreasing pressure and increasing drying time. This is caused by the end of the primary drying process on the strawberries so that the frozen water on the fruit has been completely sublimated and causes the material to become porous. The best drying process based on the value of fruit hardness was obtained on drying with a vacuum pressure of 0.1 mBar and a drying time of 36 hours, which was 1.05 kgf where the pores were perfectly formed in the fruit. According to King (1971) freeze drying has advantages when compared to other drying methods, because freeze drying can produce high quality dry products. Freeze drying can maintain the rigid shape of the dried material, causing the material to be porous and not shrink when dry. This situation will cause a rapid and complete rehydration process when the dry product is added with water. This is also supported by Hariyadi (2013) which states that freeze drying technology can maintain the stability of the material structure where shrinkage and shape changes after drying are very small. Freeze-drying with lower vacuum pressure and longer drying time resulted in lower firmness and crunchy texture of the fruit.

3.1.4. Total Dissolved Solid (TDS)

The TDS value indicates the percentage of dissolved material which is then left in the solution as a residue resulting from evaporation or heating. The TDS value is related to the content in the material because it has carbohydrate reserves which are used as energy for the respiration process. The respiration process causes the conversion of carbohydrates into sugar (Winarno, 2010). The purpose of freeze drying itself is to maintain the quality of the fruit. Vacuum pressure and drying time significantly affect the TDS content of freeze-dried strawberries. The highest TDS value was obtained from drying for 36 hours, which was 11.95 °Brix for a vacuum pressure of 0.5 mBar or an increase of 111.5 percent from the initial TPT of 5.65 °Brix. At a vacuum pressure of 0.1 mBar the TDS value increased again to 13.51 °Brix or an increase of 136.2 percent from the initial TDS of 5.72 °Brix. This is due to the condition of the fruit on longer drying has a low water content so that the TDS value is higher. An increase in the TDS value has a positive impact on certain conditions on consumer acceptance. This is because changes in the TDS content in strawberries give the fruit a sweeter taste.

According to Amiarsi & Mulyawanti (2013), the increase in sugar concentration in fruit that occurs during slow freezing causes the physiological process that remodels organic components into sugar to take longer. The ability to maintain the taste of the freeze-dried strawberries is caused by the drying process running well with an indication of the formation of pores in the fruit. This also shows that during the freezing process, strawberries do not experience chilling injury which generally occurs because strawberries are a very sensitive horticultural commodity during handling and storage (Amiarsi & Mulyawanti, 2013). Hariyadi (2013) states that the physical structure of freeze-dried food products can be maintained during the freeze-drying process, and the overall drying process takes place at low temperatures, so the freeze-dried food produced will be able to maintain color, shape, texture, and flavor.

3.2. Rehydration Ratio

Rehydration is the process of moisturizing dry materials (Joardder *et al.*, 2015). Rehydration is the process of reabsorbing water after the material has gone through the process of removing water. Water that has been lost cannot be returned to its original state, because rehydration is not a reversible process to drying. Rehydration rate can be used as an indicator of food quality. Well-dried food will make the rehydration process faster and more perfect (Fellows, 2009). Rehydration carried out on cold drying results has advantages compared to ordinary drying, namely the rehydration time tends to be shorter and the decrease in vitamin and mineral content can be minimized due to low temperatures. According to Lopez-Quiroga *et al.* (2019) the rehydration process is influenced by the characteristics of the pore network formed during cooling and the temperature at which rehydration is carried out. The larger the pores formed and the higher the temperature of the water used for fruit rehydration, the higher the rate of rehydration. Kulshreshtha *et al.* (2009), Kaur and Singh (2014) and Akoy (2014) in their research explain the rehydration ratio in mathematical form as a comparison of the weight of the dried strawberry fruit sample after being rehydrated to the initial weight of the dried strawberry sample.

The greater the value of the rehydration ratio, the better the product. Figure 4 shows that drying with a vacuum pressure of 0.1 mBar and a drying time of 36 hours, the highest rehydration ratio was 1.77, followed by a pressure of 0.5 mBar with a drying time of 36 hours, which was 1.63. This shows that the longer the drying time, the more completely frozen water in the material in the freezing stage will come out of the material so that the pores formed in the material will be more numerous compared to freeze drying in a shorter time. During the rehydration process, dry materials immersed in water or other liquid media will undergo physicochemical changes, such as moisture content, porosity, volume, temperature, gelatinization and texture. Rehydration includes several processes that occur in parallel, including the absorption of water into the dry matter, migration of the liquid medium through the porous channels and dispersal through the solid matrix, swelling at certain points in the solid matrix, and dissolution of dissolved solids by external fluids (Marabi & Saguy, 2009).

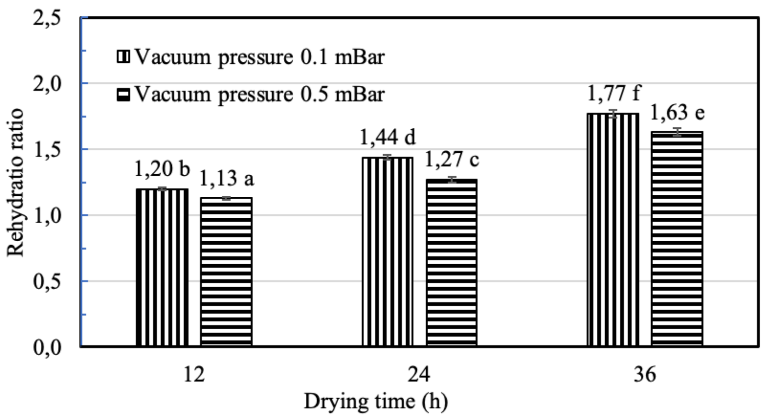

Figure 4. Effect of vacuum pressure and drying time on the rehydration ratio of strawberry

3.3. Hedonic Score for Freeze Dried Strawberries

The hedonic test or preference test was carried out to find out which drying results were most favored by the panelists. The attributes used in the hedonic test include taste, color, aroma, taste, and texture. The average score of panelists' acceptance of freeze-dried strawberries produced from 6 combinations of drying treatments ranged between dislike (2) and like (5). The results of the hedonic test of dried strawberries can be seen in Table 4. The score of preference for the taste of dried strawberries exceeds 4. This indicates that based on sensory evaluation, a score of at least 4 is considered acceptable. The drying method determines the character of the product which will affect the sensory perception and consumer acceptance. Differences in the pretreatment process and changes in material properties during drying will also affect consumer acceptance (Marabi & Saguy, 2009).

The vacuum pressure and drying time did not significantly affect the taste and aroma, but did affect the color and texture. The average value of panelists' preference for taste attributes ranged from 4.60-5.07 which is at the level of like (5). Meanwhile, the aroma attributes ranged from 4.40 to 4.73 or between neutral and like. Drying products at a vacuum pressure of 0.1 mBar and a drying time of 36 hours have the highest level of preference, namely 4.67 (like) for color attributes and 4.75 (like) for texture attributes. These results indicate that drying with lower pressure and longer drying time can increase consumer preferences based on color and texture attributes.

Table 4. Average hedonic test scores of dried strawberries

Pressure (mBar)	Time (h)	Panelist Scores			
		Taste	Colour	Aroma	Texture
0.5	12	5.07 ± 0.70 a	2.73 ± 0.46 c	4.40 ± 0.83 a	1.60 ± 0.51 d
	24	4.67 ± 0.72 a	3.60 ± 0.51 c	4.47 ± 0.52 a	2.60 ± 0.63 c
	36	4.67 ± 0.62 a	4.47 ± 0.52 b	4.67 ± 0.49 a	3.67 ± 0.49 b
0.1	12	4.87 ± 0.49 a	2.80 ± 0.56 bc	4.47 ± 0.52 a	2.13 ± 0.64 cd
	24	4.60 ± 0.74 a	3.93 ± 0.46 b	4.47 ± 0.64 a	3.80 ± 0.77 b
	36	4.67 ± 0.62 a	4.87 ± 0.52 a	4.73 ± 0.59 a	4.73 ± 0.59 a

Note: Values followed by the same letter in the same column show no difference at the 5% level of significance based on the DMRT test

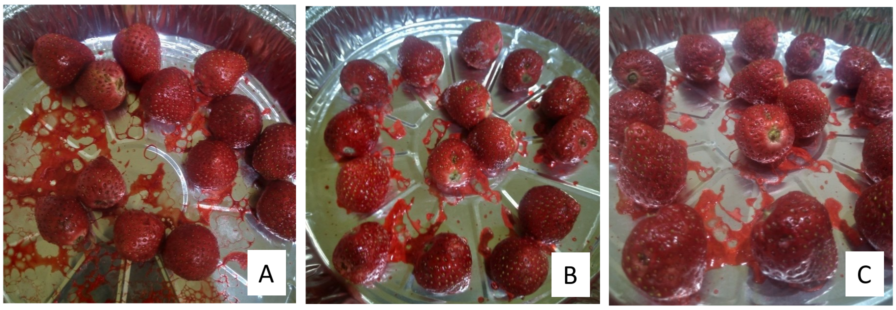

Figure 5. Freeze-dried strawberries at a vacuum pressure of 0.1 mBar with drying time of 12 hours (A), 24 hours (B) and 36 hours (C).

4. CONCLUSION AND RECCOMENDATION

During freeze-drying of strawberries, vacuum pressure and drying time and their interactions significantly affected drying rate, moisture content, weight loss, hardness, total dissolved solids, rehydration ratio, color and texture, but had no effect on taste and aroma. At lower vacuum pressure and longer drying time tends to decrease moisture content, increase weight loss, decrease hardness, increase TDS and increase rehydration ratio. Freeze drying of strawberries at a vacuum pressure of 0.1 mBar and a drying time of 36 hours produced the best freeze-dried strawberries with a moisture content of 9.64%, weight loss of 81%, hardness of 1.05 kgf, 13.51 °Brix and value of rehydration ratio. 1.77. The organoleptic assessment showed that at a vacuum pressure of 0.1 mBar and a drying time of 36 hours produced freeze-dried strawberry products with a better level of panelist acceptance based on the assessment of color and texture and did not affect the taste and aroma. Further research is needed by conducting rapid freezing using the air blast method to produce better freeze-dried product quality. In addition, it is also necessary to study the effect of freeze-drying temperature on the resulting freeze-dried product.

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