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Response surface optimization of time and pressure for freeze-drying mango slices

*Suherman, S., Hadiyanto, H., Trianita, A.P., Hargono, H., Sumantri, I., Jos, B. and Alhanif, M.

Department of Chemical Engineering, Faculty of Engineering, Universitas Diponegoro, Jl. Prof. Soedarto, S.H., Tembalang, Semarang, Indonesia, 50275

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Abstract

Mango is the second most-produced fruit in Indonesia, and the quantity of mangoes produced reached 2,624,791 tons at the end of 2018. This fruit is prone to rotting and getting wasted. Therefore, innovation is required to preserve mangoes by processing them into dehydrated food products using drying techniques. Freeze drying is still considered an efficient method to de-hydrate the water content in a product under mild process conditions, and it is mostly applicable to highly sensitive products. This study aims to determine the optimum processing parameters of drying time (13, 15, 17 hrs) and pressure (25 Pa, 30 Pa, and 35 Pa) to maintain the product quality of mango slices by using a response surface methodology. The results showed that the moisture contents are in accordance with SNI standards (less than 31%) with optimum moisture content (MC) values of 6.574%, total phenolic content (TPC) of 10.476 mg GAE/g, rehydration capacity (RC) of 2.852, colour (ΔE) of 87.373, hardness of 1312.959, the cohesiveness of 0.549, and Springiness of 3.446 unit. This study also revealed that the optimum conditions of freeze-drying were at the time (t) 13 hrs and pressure (P) 25 Pa. It can, therefore, be concluded that freeze-drying can prevent changes in the structure of mango and help retain its good quality.

1. Introduction

As a tropical country, Indonesia has many diverse natural resources, especially in terms of the diversity of available tropical fruits, one of which is mango. Mango is the second most-produced fruit in Indonesia, and the quantity of mangoes produced reached 2,624,791 tons at the end of 2018 (BPS-Statistics Indonesia, 2018). Mango has a variety of types, for example, Golek mango, Cengkir (Indramayu) mango, Arum Manis mango, Honey mango, Apple mango, and Gedong Gincu mango. In Indonesia, most of the mangoes (80.70%) are produced in various provinces in Java and Sumatra (Kumoro *et al*., 2020). The price of mangoes decreases during the big harvest. Meanwhile, the export of mangoes increases each year when compared to the import value of mangoes, which means there is more demand and higher selling prices. However, taking into consideration that mango is a tropical fruit with high moisture and a large amount of mango production and demand, lots of mangoes get rotten quickly due to a lack of proper handling after harvesting. Therefore, further innovation can increase the selling value of mangoes and maintain their quality (Rozana *et al*., 2016; Izli *et al*., 2017; Salazar *et al*., 2018).

There are quite a lot of processed mangoes in the market, such as mango chips, candy mango, and others in Indonesia. Still, these products can reduce the nutritional value of mango and change the structure of the material. Thus, it is necessary to create processed mango products that can maintain the stability of the structure of materials and nutrients as well as more efficient products. The processing of mangoes into dehydrated food with the working principle of removing the water content in the material through the method of drying involves proper drying using below freezing temperatures. Dehydrated food products are dried to prevent microbial degradation, growth of microorganisms, prevent enzymatic reactions, and extend shelf life (Alhanif *et al*., 2021). This method can be utilized mainly in foods with high water content and excellent nutritional content when consumed, such as mangoes. One of the best techniques to produce dehydrated food products is through freeze-drying technology using a freeze dryer. Dehydrated food products are fresh products that are dried, have better

*Corresponding author.
Email: *suherman.mz@che.undip.ac.id*

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storage properties, and can be easily used or refreshed (Kaymak-Ertekin and Gedik, 2005; Guine and Barroca, 2011).

Freeze drying, a modern drying process, comprises two stages, namely primary drying and secondary drying. During the drying process, the material is first frozen with a drying temperature below freezing to -50°C. Subsequently, the material is dried through a sublimation process, which contributes to the formation of ice crystals on the surface of the material, where the freeze-drying process can reach up to 50 hrs in general. Freeze drying has been applied to several agricultural products, such as soursop (Ceballos *et al*., 2012), apple (Parniakov *et al*., 2016), ginger (An *et al*., 2016), eggplant (Colucci *et al*., 2018), and mango (Salazar *et al*., 2018), and all research studies have stated that freeze -drying can help retain the physical properties of the dried products. However, the freeze-drying method is not without its limitations, as it requires a long drying time, which translates into high energy costs (Liliana *et al*., 2015). In addition to the drying time, other factors that also affect the product quality during freeze-drying are the operating temperature and pressure. The suitability between variations in conditions between time, pressure, and temperature can affect the quality and water absorption of dehydrated food products, which means optimum operating conditions are required.

Therefore, this research aimed to evaluate the impact of freeze drying on the quality of Gedong Gincu mango and identify the optimum operating conditions of the freeze dryer. The Response Surface Methodology (RSM) is used to find the best time and operating pressure in terms of the results of the analysis of product characteristics and qualities such as moisture content (MC), rehydration capacity (RC), colour, total phenolic content (TPC), texture analysis (TPA), and hedonic test to determine the level of consumer preference for the product, The response of each quality parameter to time and pressure is presented in the form of contour surface response plots in either 2D or 3D.

2. Materials and methods

2.1 Materials characteristic

Unlike other types, the Gedong Gincu mango has a smaller size and is slightly flatter. While most mango varieties in Indonesia have green skin, this mango comes in various colours: green, yellow, or red. The ripe Gedong Gincu mango has reddish skin and a fragrant aroma. The flesh is yellow and fibrous, and it is a bit hard to cut. This mango can be harvested when it reaches the age of 110 days after the flowers bloom. The acidity level of this mango is lower (9.44%) than the Gedong mango (17.89%). Utami *et al.* (2020) reported that the ratio of sugar to acid (0.80) and total solids (7.50°Bx) of this mango was higher compared to the Gedong mango (0.24; 4.17°Bx). The sensory profile of the Gedong Gincu mango is dominated by volatile components with fruity and sweet aromas, and it is preferred based on hedonic test results (Utami *et al*., 2020). The appearance of fresh Gedong Gincu mango was depicted in Figure 1.

Figure 1. Fresh Gedong Gincu mango

2.2 Materials preparation

Fresh Gedong Gincu mango was purchased from the Mango Plantation in Sliyeg Village, Indramayu Regency, Cirebon, West Java, Indonesia. The mango was sorted and then washed using running water to clean it from dirt and other foreign objects. Subsequently, the mango was peeled until the skin separated from the flesh and seeds. Thereafter, the mango was sliced using a knife with an average size of 6 cm × 5 cm × 0.5 cm (length, width, and thickness). Finally, the mango slices were stored in the freezer at -13°C for 24 hrs before being dried in the freeze dryer (Shofian *et al*., 2011).

2.3 Experimental design

To find the optimum freeze-drying conditions, Response Surface Modeling (RSM) was performed using Design Expert ver. 10 software. Central Composite Design (CCD) was selected as the response surface method, with time (t) and pressure (P) as the variables. Eight response variables were investigated in this research, including MC, RC, colour, TPC, hardness, cohesiveness, springiness, and adhesion. Table 1 shows the level of independent variables (time and pressure) during the freeze-drying experiment. There were three levels of codes for independent variables, namely -1 for

Table 1. Level of independent variables during freeze drying.

Notation	Variable	Unit	Symbol	Level				
				-1.41421	-1	0	1	1.41421
x_1	Time	(h)	(t)	12.1716	13	15	17	17.8284
x_2	Pressure	(Pa)	(P)	22.9289	25	30	35	37.0711

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the lowest value, 0 for the middle value, and +1 for the highest value. Nine different experimental runs were performed on an independent variable to investigate their impact against the eight response variables by the CCD method.

The suitability of the regression model (*Lack of it* test) was ascertained for determining the suitability of the regression model obtained from the ANOVA test results on each response variable, with the use of the following hypotheses:

H0: The regression model is suitable (there is no lack of it)

H1: The regression model is not suitable (there is a lack of it)

If the ANOVA test results in the regression model yielded a p-value that is higher than the significance level ($\alpha = 0.05$), then there is no reason to reject H0, which means that the regression model is suitable. Conversely, H0 will be rejected if the p-value is less than the significance level ($\alpha = 0.05$).

2.4 Freeze drying process

After 24 h of storage inside the refrigerator, the mango slices were placed in a freeze dryer (BUCHI Lyovapor™ l-200), as shown in Figure 2a. The mango slices were placed on drying trays until the entire tray was covered as shown in Figure 2b. Nine freeze-drying runs were performed, with a constant temperature of -32°C at the primary drying process on the shelf then the second process with a heated process at 25°C for 1 min to make a sublimation condition in the shelf and vacuum as the last process to dried mango slices. This study has used a variation of drying time (13, 15, and 17 hrs) and operating pressure (25, 30, and 35 Pa). After the drying runs were completed, the dried mango slices were placed inside the ziplock plastic packaging and stored in a refrigerator (4°C) before quality analysis was conducted.

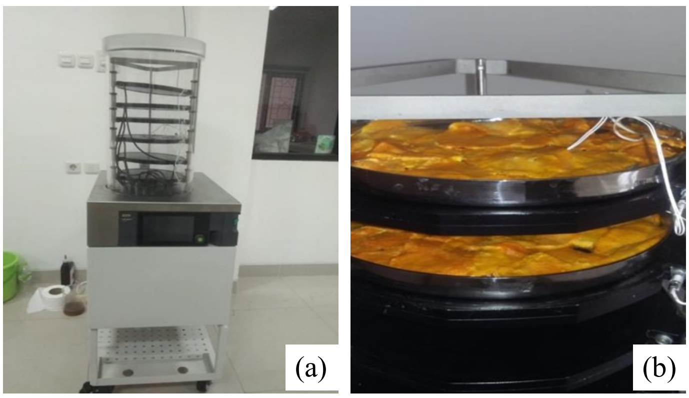

Figure 2. Scheme of the drying process, a) freeze dryer b) mango slices drying

2.5 Quality analysis of freeze-dried mango slices

2.5.1 Sub subheading

The MCs of the mango slices were determined using the oven drying method according to the previous study on agricultural product drying (Alhanif *et al*., 2021). Equation 1 shows the formula of MC. MC stands for moisture content (% wet basis), W_{fm} denotes the fresh mango slices (kg), and W_{dm} denotes the weight of dried mango slices (kg).

$$MC = \frac{(W_{fm} - W_{dm}) \times 100}{W_{fm}} \quad (1)$$

2.5.2 Rehydration capacity

The rehydration capacity (RC) analysis was performed based on the suitable analysis method for dried fruit products, according to the findings of the research study conducted by Marques et al. (2007). This analysis began by measuring the initial weight of freeze-dried mango slices. Subsequently, freeze-dried mango slices were submerged in the water for 15 mins and then drained above an aluminium sieve for 15 mins. Thereafter, the weight of the mango slices after water soaking was measured. RC (R_d) is defined as the weight ratio of rehydrated mango sample and dry mango sample, as seen in equation (2). W_t is the weight of mango slices after rehydration (kg) while W_0 denotes the initial weight of mango slices before rehydration (kg).

$$RC = \frac{W_t}{W_0} \quad (2)$$

2.5.3 Colour analysis

To analyze the colour of freeze-dried mangoes, CS-210 Digital Colourimeter Colour Meter Analyzer (Made in China) was used. Colour testing was conducted according to the method presented by Salazar *et al.* (2018). The parameters of colour testing consisted of a* (red-green dimension), b* (yellow-blue dimension), and L* (luminosity). Total colour testing (*ΔE*) was determined using equation (3). Subscripts $_f$ and $_0$ denote the initial and final sub-indication of the mango slices, respectively.

$$\Delta E_{ab} = \sqrt{(L_f^* - L_0^*)^2 + (a_f^* - a_0^*)^2 + (b_f^* - b_0^*)^2} \quad (3)$$

2.5.4 Total phenolic content

The total phenolic content (TPC) was assayed using the Folin-Ciocalteu reagent, following Singleton's method, slightly modified by Caballero-Galván *et al.* (2018). TPC analysis was performed using 150 µL of freeze-dried mango slices extract mixed with 2.4 mL of distilled water, 150 µL of Folin-Ciocalteu solution (1 N), and 300 µL of sodium carbonate (20% w/v). It took two hrs to get the reaction during the testing process, and the

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absorbance was determined by a spectrophotometer with a wavelength of 765 nm.

2.5.5 Texture analysis

The texture analysis (TPA) of the freeze-dried mango slices was performed using a Brookfield CT-3 Texture Analyzer following the appropriate texture test methods on food products (Ansari *et al*., 2014). The texture test criteria include hardness, cohesiveness, springiness, and adhesion. The analysis was performed by setting the texture analyzer and choosing the desired test parameter. Subsequently, the mango slices were placed above the plate and then the probe pressed the mango slices twice to obtain the value of hardness 1 and 2, cohesiveness, springiness, and adhesion using a cylindrical probe with a constant velocity 1 mm/s and compression reach until 75% from the first high position. The value was shown on the monitor of the texture analyzer.

2.5.6 Hedonic analysis

The hedonic analysis was carried out with several testing parameters, including texture, colour, taste, and aroma of the resulting product. This study used ten trained panellists with a food technologist background who have passed through the sensory analysis tested and practical in Food Technology Department, Universitas Diponegoro, Indonesia. The panellists gave a rating based on the level of liking to the product with the following criteria: (1) dislike very much, (2) dislike, (3) rather like (4) like, and (5) like very much.

2.6 Data analysis

Data processing was performed by the RSM method using computer-based software (Design-Expert version 10.0) through the linear regression analysis method using two predictors, namely time (x_1) and pressure (x_2), with the equation model shown in equation (4) as follows:

$$y = a + b_1x_1 + b_2x_2 \quad (4)$$

Where y is the effect of response variables on x_1 and x_2, respectively. Furthermore, RSM analysis was performed to determine the relationship between independent variables and response variables, and the final results are shown in 2D or 3D. The first-order equation model is used to determine the response of variables, as shown in equations (5) and (6), respectively.

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \varepsilon \quad (5)$$

$$\hat{y} = \beta_o + \sum_{i=1}^{k} \hat{\beta}_i x_i + \sum_{i=1}^{k} \hat{\beta}_{ii} x_i^2 + \sum_{i} \sum_{i} \hat{\beta}_{ij} x_i x_j, i < j \quad (6)$$

The p-value can be determined from equation (6). If the value is less than 5%, then the equation model is considered suitable. Therefore, a result can be obtained by the equation model, where the value of x_i is known. RSM was also used to find out the value of independent variables that are influenced by response variables, and the values are displayed in the form of response surface plots. The optimum conditions can be determined based on the coefficients obtained, including the values of a, b_1, and b_2, which are then displayed in the regression equation (Salazar *et al*., 2018).

3. Results and discussion

3.1 The effect of operating conditions on the quality of freeze-dried mango slices

Table 2 shows the impact of nine different freeze-drying runs on RC and TPC (mg GAE/g). In this study, the overall value of the MC was 6.46% with MC before drying being around 80.5 - 85% and the mass of mango samples before drying was 293 g and 15 – 19.5 g after drying for every sample, which fulfilled the Indonesian standard for dried fruit products (less than 31% w.b.) (BSN, 1995).

Furthermore, in the RC analysis, the lowest value obtained was 2.47 at running 2 and the highest value at 3.63 at running 8, with the average value of RC being 3.08. The average RC value found in this experiment is lower than similar mango freeze-drying research. Marques *et al*. (2009) found that the RC of freeze-dried mango is 3.89, whereas Salazar *et al*. (2018) found that the RC value is 3.30. The results obtained in the study were compared with the research performed by Salazar *et al*. (2018) about the freeze-drying of mango. They found that RC values were in the range between 3.3 and 3.8% within 15 mins and with the possibility of maximum RC in dried mango slices (DMS) around 4.9%. High and low RC values are influenced by the porosity of the material, which is formed where, during the freeze-drying process, there is a rate of movement between the material water coming out through the surface pores of the material to form a pore cavity and making the material slightly shrunk, which contributes to high and low productivity. High porosity can cause high rehydration power such that the freeze-drying process is used as a reversible process and can maintain the colour and taste of the product (Marques *et al*., 2007).

In the TPC analysis, the lowest value was obtained at running 8, with the value of 2.03 mg GAE/g, and the highest value was obtained at running 6 with 19.53 mg GAE/g, and the average TPC value was 9.59 mg GAE/g. The decreased TPC value can be attributed to the freeze-drying operating conditions used, one of which is the type of freeze-drying method used. The freeze-drying speed will have an impact on the total phenol content of dried fruit, which will reduce the total amount of phenol content from 793 mg/100 g (dry weight) during fast freezing and decrease the total value of phenol content from 815 mg/100 g (dry weight) on slow freeze-drying (Reyes *et al*., 2010). The phenomenon that occurs is associated with the rate of movement of nutritional components, one of which is the content of phenols from the material out through the pores of the material following the flow of water content that comes out of the material for the phenol content to decrease.

Table 2. Results of quality analysis of MC, RC, and TPC

Run	Results of Analysis		
	MC (% w.b.)	RC	TPC (mg GAE/g)
1	6.84	3.23	4.01
2	7.01	2.47	9.61
3	5.5	3.33	8.37
4	6.17	3.00	5.70
5	7.13	3.60	13.13
6	7.13	2.62	19.53
7	6.91	2.56	12.96
8	5.46	3.63	2.03
9	5.95	3.27	10.93
Average	6.46	3.08	9.59

3.1.1 Moisture content

Figure 3a shows the impact of drying time and operating pressure during freeze-drying on the MC of dried mango in the form of the surface response and contour graph obtained from the optimization. In the MC contour plot, it can be perceived that the colour of the contour plot from the left is red while the colour turns blue in the right direction, which indicates that there is a reasonable impact towards the minimum blue point. Therefore, it can be seen that the longer the drying time, the lower the MC value obtained. In addition, the higher the drying pressure, the higher the MC value. The response surface model has a distribution of MC values with values ranging from 6 to 7%, with an optimum point of 6.574%. The initial MC of fresh mango is 82.9% wet basis. The results obtained have decreased the value of MC, thereby ranging from 5.46 to 7.13%, where the lowest MC value is obtained in samples with a drying time of 17 hrs and operating pressure of 25 Pa.

Meanwhile, the highest value of water content was found in samples with a drying time of 13 hrs and operating pressure of 35 Pa. The value of MC obtained is not much different from the results of the research study conducted by Salazar *et al*. (2018). In the latter research, the MC of dried mango using a freeze dryer was reduced from 83.75 to 1.93%. Marques and Freire (2005)

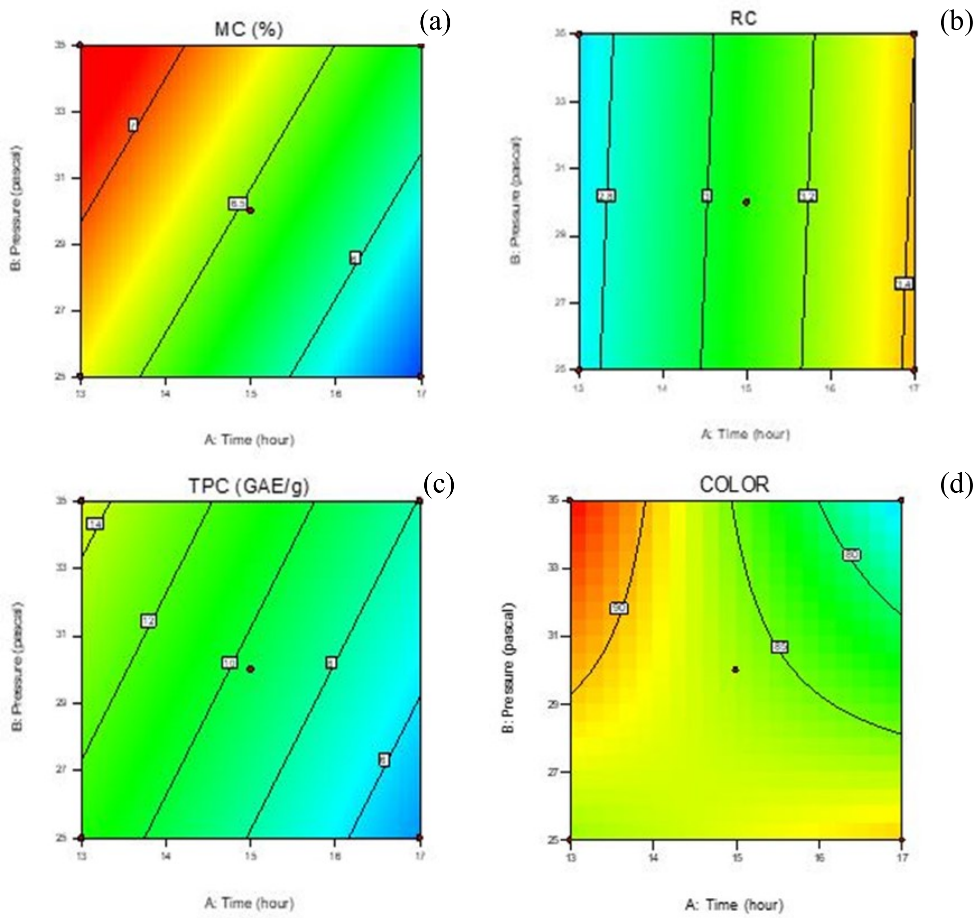

Figure 3. The effect of drying time and operating pressure on (a) moisture content, (b) rehydration capacity, (c) total phenolic content (d) colour parameters.

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reported that the MC of freeze-dried mango was constant at 2.2%. In the MC results obtained in this study, it can be perceived as a whole that the longer the drying time, the lower the MC value and vice versa. Likewise, the higher the pressure under drying conditions, the lower the MC value. This is the occurrence of mass flow transfer from foodstuff to foodstuff due to the influence of freeze-drying operating conditions. Freeze-dried fruit will have a low MC value, which can prolong the shelf life of the product, thereby making the freeze-dried fruit product highly stable (Raghavan and Venkatachalapathy, 1999).

Thus, the operating conditions of freeze-drying greatly affect the value of MC obtained where a longer drying time leads to a lower MC value and higher pressure in terms of freeze-drying while the final MC becomes higher. This is due to the presence of water in the material, which is difficult to remove. Thus, moisture continues to be trapped in the material.

3.1.2 Rehydration capacity

Figure 3b shows the surface response and contour of the results of the optimization of the freeze-drying of mango to the RC value. By using the response surface model, the distribution of RC values is at the midpoint of the figure with values ranging from 2.8 to 3.4% RC with an optimum point of 2.8%. In RC plots, the contours and response surface obtained from the bottom left are light blue and they are orange in the upper right corner, which indicates that there is a response impact on the maximum point. It can be seen that the longer the drying time, the higher the RC value from the results of the colour formed. Meanwhile, if the drying pressure is lower, then the feeding pressure of the RC value will be lower. The factors that can affect the RC of the product are based on the speed of the freeze-drying rate. The quality of freeze-dried products can be affected by the speed and ease of reconstitution or rehydration (Liliana *et al*., 2015). In addition, the RC can also be affected by the method of the rehydration process and the use of temperature, time, and agitation conditions (Arriola-Guevara *et al*., 2006).

3.1.3 Total phenolic content

Figure 3c shows the surface response and contour of the results of the optimization of freeze-dried sliced mango to the TPC values. The response surface model shows that the colour analysis value distribution is located at the midpoint of the figure with values ranging from 8 to 10 mg GAE/g colour analysis value with an optimum point of 10.476 mg GAE/g. In TPC, the colour contour plots formed from the upper left direction are green while in the right direction showed dark blue, which indicates that there is a response effect to reach the minimum point in blue. Thus, it is known through these results that the longer the drying time of food, the lower the value of TPC, and there is no significant impact on the results obtained at the drying pressure.

The results of the TPC study showed that there was a reduction in the amount of phenol content in the freeze-dried mango. This finding is in alignment with the findings of similar research performed by Shofian *et al*. (2011), in which they reported that there was a reduction of TPC by 23% during the freeze-drying of mangoes. According to Salazar *et al*. (2018), some enzymes affect the reduction of the TPC of mango, namely polyphenol oxidase (PPO) and peroxidase (POD) enzymes. In addition, the results of the research conducted by Macias (2013), which compared the value of phenol content in strawberry fruit using different types of drying, such as Hot Air Drying (HAD), Swell-drying (SD), and Freeze-drying (FD), obtained the value of phenol content from drying results with using a higher FD, which is 18.41% higher when compared to other types of drying. However, in general, the value of low or high phenol content still has sufficient antioxidants. The existence of a low phenol content still allows for antioxidant activity (Murakami *et al*., 2004; Buchner *et al*., 2006).

3.1.4 Colour

Figure 4a-d shows the colour analysis of freeze-dried mango slices from nine different runs. The overall value of L* a* b* was found to be positive (+). The positive L* value indicates that the yellow colour is more dominant. The positive value of indicator b* means that the overall mango sample is predominantly yellow. Meanwhile, the value of indicator a* is also positive, thereby indicating that the colour of freeze-dried mango is more dominantly red than green, in which the value of b* should be negative. From the ΔE value, it can be perceived that a fairly drastic decrease begins at the sample with a drying time of 17 hrs with all variations of pressure. These results can be attributed to a longer time in the drying process, which is 17 hrs with high pressure of 35 Pa, thereby causing the MC to remain high enough compared to the low pressure such that it affects the colour of the food. Therefore, it can be perceived in the results of the study that the longer the duration for which the freeze-drying process is carried out, the ΔE value decreases to a greater extent. These results are compared with the results of previous studies conducted by Salazar *et al*. (2018) wherein the result of the ΔE value is 22.59. These results are similar to the findings of Kaewdam and his colleagues (2013), wherein drying the "nam dok mai" type of mango with a freeze dryer resulted in a value of ΔE that ranges from 4.37 to 13.94 with each colour

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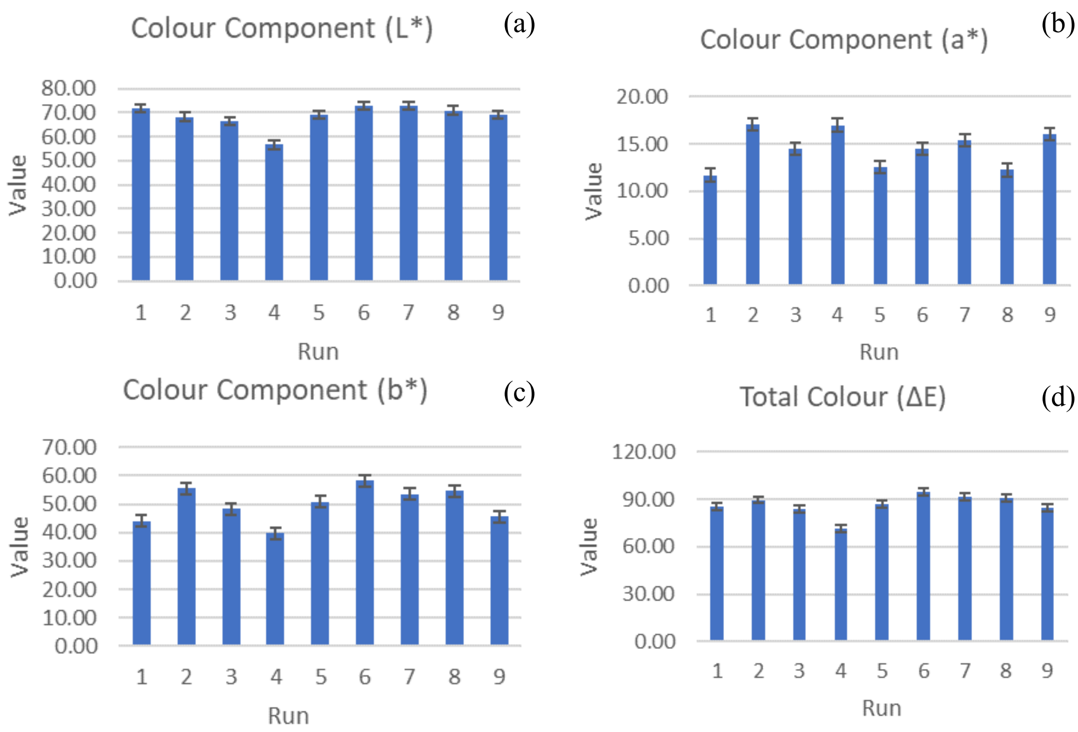

Figure 4. Colour component for (a) L*(Luminosity), (b) a*(red-green dimension), (c) b*(yellow-blue dimension), (d) ΔE (total colour analysis)

parameter characteristic of L* a* b* being 78, 92, 3.53, and 38.42.

On the other hand, in the freeze-dried mango sample, there is a pressure influence factor, that is, the higher the pressure used in the drying operation, the more is the colour affected. The phenomenon that occurs in samples that experience colour changes is the influence of time and operating pressure where a longer period and the higher pressure will make the content of B-carotene as a colour giver on the mango sample decrease and cause the sample colour to become darker when compared to the primary drying process, which uses latent heat to execute the sublimation process. This is confirmed by the results of the research conducted by Shofian *et al*. (2011), which highlights that 8.16% of the B-carotene content was lost after the freeze-drying process was executed. According to Cui *et al*. (2008), as much as 95.4% of the B-carotene content was lost due to the freeze-drying process of carrots in his research.

Figure 3d showed the colour response of polynomial models, which describes the impact of drying time and operating pressure on the colour value (ΔE) of freeze-dried mango. The value distribution was found at the midpoint of the image with values ranging from 85 to 90 colour analysis values with an optimum point of 87,374. The formation of dark red was observed on the left and right, which indicates that there was a response to the maximum point of dark red. Therefore, it can be seen that the longer the drying time, the higher the colour value, namely the colour change, and the higher the drying pressure, the higher the colour value. A darker colour is produced in the mango due to the drying process with a relatively long time when compared to others. The other factor involved in the MC in the material is still quite high. This was supported by research performed by Salgado *et al*. (2017), which stated that high water content in food could reduce the level of brightness of the product.

3.2 The effect of operating conditions on the texture of freeze-dried mango

Table 3 shows the results of TPA on freeze-dried mango slices based on texture test criteria, including hardness, cohesiveness, springiness, and adhesion. It was gathered from hardness analysis that freeze-dried mangoes with a drying time of 13 hrs and at 25 Pa, 30 Pa, and 35 Pa have higher hardness than the other samples, with a value of 2370.13, 3047.25, and 2027.88 gF, respectively. In contrast, the lowest hardness values were identified in samples with a drying time of 15 hrs and at all operating pressures. Freeze drying at 13 hrs and 30 Pa gave the highest hardness value at 3047.25 gF, whereas the lowest hardness value was found during freeze-drying at 15 hrs and 25 Pa at 313.50 gF. The lower the hardness value, the softer the texture of the freeze-dried mango slices. Conversely, the higher the hardness value, the harder and tighter the texture of the freeze-dried mango slices. These findings are in alignment with the results found by Salgado *et al.* (2017), in which they stated that the hardness value of mango, as per the results of his research, by drying the mangoes where the level of hardness is low when at low temperatures and high hardness at high temperatures.

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That is due to the presence of glucose, xanthan gum, and glycerin content, which can affect the level of dry mango hardness and result in high material density, porosity size, and high hardness value. Processed foodstuffs will change properties and undergo different texture quality measurements based on each ingredient (Engelen, 2018).

Table 3. Results of texture analysis.

Run	Results of Analysis			
	Hardness (gF)	Cohesiveness	Springiness (mm)	Adhesion (mJ)
1	2370.13	0.32	2.95	0.47
2	3047.25	0.28	2.40	0.26
3	2027.88	0.43	2.70	0.19
4	313.50	0.78	0.78	0.27
5	340.88	0.67	0.67	0.63
6	619.88	0.46	0.46	0.56
7	1514.50	0.32	0.32	0.31
8	2460.75	0.26	2.90	0.69
9	1159.63	0.37	3.25	0.55
Average	1539.38	0.43	1.82	0.44

gF, gram force

The following texture criterion was cohesiveness in which the analysis value obtained was within a range of values from 0.255 to 0.775. The lowest cohesiveness value was found in samples with 17 hrs with a pressure of 30 Pa. Meanwhile, the highest cohesiveness value was found in samples with a time of 15 hrs with a pressure of 25 Pa. The cohesiveness value was used to determine the existence of a combination of texture and structure of the material. According to the results of the study, if cohesiveness is higher, then the surface and structure of the material formed are excellent.

In addition, there are springiness criteria, where the lowest value is at the drying time of 17 hrs, with a pressure of 25 Pa. The highest value was obtained in the sample with a drying time of 17 hrs with a pressure of 35 Pa. However, overall, the lowest average value was achieved in 15 hrs with an average value of 0.63167 mm wherein each experiment with a pressure of 25 Pa, 30 Pa, and 35 Pa gets a range of springiness values between 0.775 and 0.445 mm. The existence of high values can indicate the level of elasticity obtained, as the higher the springiness value of the product or foodstuff, the more resilient the food product and vice versa in case the lower springiness value depends on the lack of the level of plasticity of the product or foodstuff.

In the research results of adhesion analysis, the lowest and the highest values were identified in each experiment. The lowest value, that is, 0.16 mJ, was obtained in a sample with a time of 13 hrs with a pressure of 35 Pa while the highest value amounted to 0.685 mJ at a time of 17 hrs with a pressure of 30 Pa. Higher adhesion value makes the sample more sticky and less compatible with dry-based food products, whereas the lower the value of adhesion, the better is the texture formed despite the lack of high stickiness in the food product. Therefore, the best result of adhesion in this study is the lowest adhesion value at 13 hrs with a pressure of 25 with an adhesion value of 0.19 mJ. Some characteristics, such as cellular components, biochemistry, water content, and cell wall composition in fruits and vegetables, can affect their texture. This can be produced from the texture at the end of the product (Ansari *et al*., 2014). This is reinforced by the opinion of the study conducted by Guine and Barroca (2011), which reported that the presence of external factors can affect product characteristics such as changes in texture by extension on the quality of the final product.

3.2.1 Hardness

Figure 5a shows the surface response and contour of the results of the optimization of freeze-dried, dried sliced mango to the hardness value of the material. With the response surface model above, they form the response at the minimum point where the distribution of hardness values is in the middle point in the image with values ranging from 500 g to an optimum point of 1312,466 g. The contour plot of the hardness analysis results in the formation of dark blue in the middle of the surface plot with the left and right sides of green indicating that there is a response to the minimum point caused by almost all surfaces of dark blue. Alternately, it can be said to be dominant towards dark blue. Therefore, it can be seen that a longer time will make the hardness value higher while a lower time will make the hardness value lower. On the other hand, with respect to the drying, in terms of the pressure carried out on the hardness value, there is no significant impact marked with the green colour on the contour, and surface plots received a response. The value of hardness in the evaluation of the characteristics of dried fruit is not much different from the similar assessment of characteristics, namely crispness and crunchiness. In the study conducted by Macias (2013), strawberry slices were dried with a freeze dryer, wherein the level of crispness or hardness is higher than the strawberries dried in HD; however, the results are better than SD.

3.2.2 Cohesiveness

Figure 5b shows the surface response and contour of the results of the optimization of freeze-dried sliced mango in relation to the cohesiveness value of the material. The response surface model formed a response at the maximum point where the distribution of cohesiveness values is at the midpoint of the image with values ranging from 0.5 to 0.6 with an optimum point of 0.550. The colours formed on the left and right sides are

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green with orange dominant on the surface, thereby indicating the response to the maximum point. Therefore, it can be perceived that the drying time with the highest value towards the maximum point at the time of 15 hrs and the lower drying pressure will affect the cohesiveness value, which will be higher when marked with red and indicates the maximum point. The results obtained in this study are not much different from the findings of the research conducted by Hajnal *et al.* (2012) in dried apricots, where the cohesiveness values ranged from 0.2 to 0.3 mJ.

3.2.3 Springiness

Figure 5c shows the surface response and contour of the results of the optimization of freeze-dried sliced mango in relation to the springiness value of the material. The response surface model above formed a response at the maximum point where the springiness value distribution is at the midpoint of the image with values ranging from 3.4 to 3.6 mm with an optimum point of 3.446 mm. The dominant colour, red, tends to be dark, which means there is a response to the maximum point. Thus, it can be perceived that the maximum point occurs at a drying time of 14 to 16 hrs with a pressure of 25 to 30 Pa. At the time of drying, there is no significant effect, whereas the lower the pressure of drying pressure, the higher the springiness value and toward the maximum point. The existence of the maximum point can be influenced by the phenomenon that occurs in the drying of mango freeze on the texture value, especially cohesiveness. The phenomenon that occurs is that the cell wall of mango slices decreases or gets damaged, thereby resulting in shrinkage. These results are not much different from the study conducted by Macias (2013), in which the occurrence of shrinkage and cell walls have been damaged after being dried with HAD and FD with strawberry slices. Processing significantly influences the cell structure in dried fruits and vegetables (Guiné and João, 2011; Macias, 2013).

3.2.4 Adhesion

Figure 5d shows the surface response and contour of the results of the optimization of freeze-dried sliced mango in relation to the adhesion value of the material. The response surface model above formed a saddle response graph where the distribution of adhesion values is at the midpoint of the figure with values ranging from 0.4 to 0.5 mJ with an optimum point of 0.406 mJ. The results of the contour and surface plot adhesion values can be perceived from the dominant green formed with blue on the left and dark red on the right, thereby indicating the response to the maximum point. Thus, it can be seen that the longer the drying time, the higher the adhesion value, whereas the higher the drying pressure of the meal, the lower the adhesion value. The adhesion value obtained is not much different from the results of

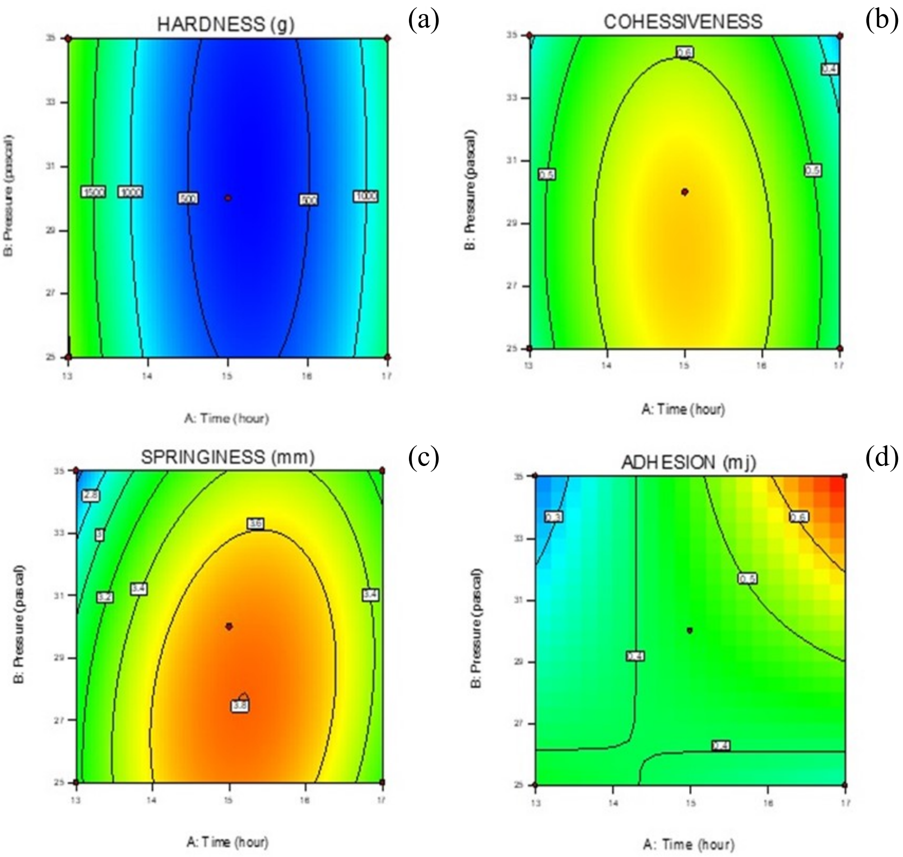

Figure 5. The effect of drying time and operating pressure on (a) hardness, (b) cohesiveness, (c) springiness, (d) adhesion of mango slices.

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the study conducted by Hajnal *et al*. (2012), wherein dried apricots analyzed by adhesion or adhesiveness had values ranging from 0.56 to 2.45 mJ.

3.3 Optimization of mango freeze drying

Table 4 shows the results of the comparison between experimental data measurements with prediction calculation data using the model. It can be seen that y_1, y_2, y_3, y_4, y_5, y_6, y_7, and y_8 show the value of the measurement results with calculations and prediction models that are not much different. The coefficient value of each variable was displayed in the form of a regression equation, which was formed along with statistical analysis that is Analysis of variance (ANOVA) where the p-value, R^2, and Adjust R^2 can be determined. The results of ANOVA and equation response variables can be perceived in Table 5.

In Table 5, the R^2 and p-value of each response variable can be seen and matched with the initial hypothesis in the study design to determine whether or not there is a model fit. The results of R^2 in each response ranged from 0.4 to 0.9. The lowest R^2 value is in the TPC response of 0.4802, whereas the R^2 value is found in the hardness response of 0.9612. The suitability of the model is marked by the value of R^2, which increasingly adheres to the value of 1. This is not much different from the findings of the research conducted by Salazar *et al*. (2018), the value of R^2 in his study drying the "nam dok mai" type of mango with a freeze dryer score 0.9 for MC, RC, colour, and TPC responses. Similar to the results of the research study conducted by Macias (2013), obtaining an R^2 value from the results of his research drying strawberries with HAD, SD, and FD is 0.7226 (72.26%).

In the MC variable, p-value 0.0010 more than 0.05 degrees of freedom was a significant model and rejected H0, which means the model was unsuitable. In the RC variable, the p-value was 0.0781 more than 0.05, which accepted H0 so the model was suitable. In the TPC variable, the p-value was 0.1405 more than 0.05, which was accepted H0 so that the model was suitable. In the colour variable, the p-value was 0.0440 less than 0.05, which rejected H0. This means the model was unsuitable. The texture variable (hardness) p-value 0.0090 is less than 0.05 rejected H0, which means that the model is unsuitable. In the texture variable (springiness), the p-value was 0.0825 less than 0.05, which accepted H0, which means the model was suitable. In the texture variable (cohesiveness), the p-value was 0.1221 more than 0.05, which is H0, which means the model was suitable. In the texture variable (adhesion), the p-value was 0.1286 more than 0.05, which was accepted H0, which means the model was suitable.

The optimization conditions can be perceived in Table 6, where we can find out the optimum condition values for each response variable. The optimum value obtained at MC is 6,574, RC is 2,852, TPC is 10,476, colour is 87,374, hardness is 1312,466, cohesiveness is

Table 4. CCD design experimental data results.

Run	Independent Variable		Response Variable								Note
	x_1	x_2	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	
1	15	30	6.84	3.23	4.01	85.37	340.88	0.67	3.75	0.63	I
			6.44	3.07	9.58	86.42	340.88	0.66	3.75	0.44	II
2	12.1716	30	7.01	2.47	9.61	89.62	3047.30	0.28	2.40	0.26	I
			7.25	2.60	14.27	92.23	3284.25	0.24	2.38	0.29	II
3	17.8284	30	5.50	3.33	8.37	83.62	2460.80	0.26	2.90	0.69	I
			5.65	3.55	4.89	80.60	2381.51	0.21	2.84	0.58	II
4	17	35	6.17	3.00	5.70	71.25	1159.60	0.37	3.25	0.55	I
			6.21	3.40	7.94	75.11	1333.88	0.34	3.12	0.71	II
5	15	37.0711	7.13	3.60	13.13	86.67	619.88	0.46	2.95	0.56	I
			6.91	3.06	11.94	84.03	498.88	0.52	3.16	0.50	II
6	13	35	7.13	2.62	19.53	94.46	2027.90	0.43	2.70	0.19	I
			7.34	2.73	14.56	94.34	1978.56	0.39	2.55	0.25	II
7	13	25	6.91	2.56	12.96	91.77	2370.10	0.32	2.95	0.47	I
			6.69	2.75	11.23	86.72	2038.17	0.43	3.15	0.42	II
8	17	25	5.46	3.63	2.03	90.57	1514.50	0.32	3.00	0.31	I
			5.56	3.42	4.60	89.50	1406.18	0.44	3.23	0.36	II
9	15	22.9289	5.95	3.27	10.93	84.46	313.50	0.78	3.95	0.27	I
			5.99	3.09	7.22	88.82	592.15	0.63	3.66	0.37	II

I = measurement results, II = the results of calculating the prediction model, x_1 = time, x_2 = pressure, y_1 = MC, y_2 = RC, y_3 = colour, y_4 = TPC, y_5 = hardness, y_6 = cohesiveness, y_7 = springiness, y_8 = adhesion.

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Table 5. ANOVA and final equation of response parameter.

Response	Final Equation in Terms of Actual Factors	Model	p-value	R^2	Adj R^2
MC	8.76785 – 0.28409t + 0.064969P	Linear	0.0010	0.8988	0.8650
RC	0.65679 + 0.16664t - 2.58274E-003P	Linear	0.0781	0.5725	0.4300
TPC	24.42863 - 1.65710t + 0.33378P	Linear	0.1405	0.4802	0.3069
Colour	-120.21757 + 14.45158t + 7.91607P - 0.55026tP	2FI	0.0440	0.7677	0.6283
Hardness	76560.52236 - 9495.04914t - 247.39783P - 0.31750tP + 311.49969t^2 + 4.09275P^2	Quadratic	0.0090	0.9612	0.8966
Cohesiveness	-13.62822 + 1.68092t + 0.12269P - 1.37500E-003tP - 0.054844t^2 - 1.82500E-003P^2	Quadratic	0.1221	0.7662	0.3766
Springiness	-28.85694 + 3.97232t + 0.18214P + 0.012500tP - 0.14219t^2 - 6.75000E-003P	Quadratic	0.0825	0.8626	0.6337
Adhesion	5.21392 – 0.33650t + 0.18417P + 0.012875tP	2FI	0.1286	0.6172	0.3875

0.550, springiness is 3,446, and adhesion is 0.406, where the optimum conditions of freeze-drying operation are at the time (t) 13 hrs and pressure (P) 25 Pa. In a similar study, Salazar *et al*. (2018) dried mangoes with a freeze dryer and produced optimum conditions at -1°C, 560 mTorr pressure, and a freezing rate of 0.4°C/min. Furthermore, in a similar study conducted by Marques *et al*. (2007), the results of optimization of mango drying conditions with a temperature of -30°C, a pressure of 0.001330 Pa and a drying time of 12 h were observed. In a similar study but with a different type of material conducted by Seeranguryayar *et al*. (2017), dates were dried with a freeze dryer and optimum conditions were obtained at a temperature of -40°C and a pressure of 42 Pa within 72 hrs. In addition to dates, Chinese gooseberry fruit dried with a freeze dryer highlighted the results of research conducted by Wang *et al*. (2008), which states that the optimum conditions are at a temperature of -20°C with a time of 20 hrs and, 20°C for a time of 5 hrs through two stages of the freeze-drying process with a pressure of 10 Pa.

Table 6. Optimization of freeze-dried operations results

x_1	x_2	y	Optimum Conditions
------ h ------	------ Pa ------		
13	25	1	6.574
		2	2.852
		3	10.476
		4	87.373
		5	1312.959
		6	0.549
		7	3.446
		8	0.406

x_1 = time, x_2 = pressure, y_1 = MC, y_2 = RC, y_3 = colour, y_4 = TPC, y_5 = hardness, y_6 = cohesiveness, y_7 = springiness, y_8 = adhesion.

Optimization results can differ due to the influence of the use of variations in operating conditions, including time, temperature, pressure, and the rate of drying and freezing. In addition, the influence of the type of material used significantly affects the optimum results of a condition, including the structure or shape of the material to be dried (liquid/powder/solid).

3.4 Hedonic

Figure 6 displays the results of the accumulation of assessment data of the ten trained panellists' preference levels for freeze-dried mango samples. Overall, the most dominant level of the characteristics of the freeze-dried mango sample preferred in terms of appearance, where the level of appearance is the highest compared to the characteristics of other hedonic test parameters, is 3.67, which means panellists favour it. Thereafter, the level of appearance followed by the second sample aroma level was favoured by the panellists with an average value of 3.56. Subsequently, the last order is the parameter level in terms of texture and taste, with the same average value of 3.44, which means the panellists rather like it.

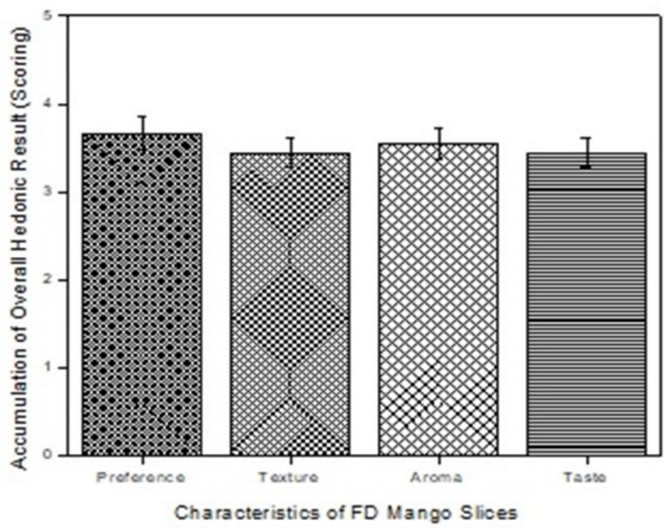

Figure 6. Hedonic test results of dried mango

According to Huirem and Shakya's study (2015), the level of panellists' preferences is based on several parameters of consumer acceptance, including visual or appearance components, colour, aroma, taste, product worthiness, and consumer buying interest by scaling or scoring with ten panellists, in their research.

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4. Conclusion

Freeze drying is a modern drying technique that uses temperatures below freezing to -50ºC, which has the advantage of preventing changes in the structure and chemistry of materials. This drying technique has been widely applied to produce food products based on dehydrated food. Freeze-dried mangoes produced in this study included dehydrated food products, which can be refreshed like fresh mangoes for consumption. The quality and quality of the resulting product are analyzed for characteristics. In this study, the characteristics formed on the value of MC, RC, TPC, colour, and texture (hardness, cohesiveness, springiness, and adhesion). The MC value of the mango product produced is under SNI 3710-2018, that is, less than 31%. The best results in the analysis of RC characteristics, TPC, and texture parameters all indicate that fast-drying time with low pressure has the best results. In addition, the optimization results obtained the best time in the operating conditions when the freeze-drying time of mango slices is 13 hrs with a pressure of 25 Pa. The final product quality analysis carried out in this study with a hedonic test analysis (preference), where the appearance and aroma parameters of the product were the most superior characteristics of freeze-dried mango products, was favoured by panellists. It can be concluded that freeze-drying is a technique that is good enough to prevent changes in the structure of the material and maintain product quality. These results are needed for further research to determine the porosity of the material structure as well as the existence of shelf-life product analysis.

Conflict of interest

The authors declare no conflict of interest.

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References

Alhanif, M., Kumoro, A.C. and Wardhani, D.H. (2021). Mass Transfer, Energy Utilization, Physical and Nutritional Properties Evaluations During Drying of Papaya (*Carica papaya L.*) Seeds at Low to Moderate Temperatures. *Arabian Journal for Science and Engineering*, 47, 6245–6267. https://doi.org/10.1007/s13369-021-06226-x

An, K., Zhao, D., Wang, Z., Wu, J., Xu, Y. and Xiao, G. (2016). Comparison of different drying methods on Chinese ginger (Zingiber officinale Roscoe): Changes in volatiles, chemical profile, antioxidant properties, and microstructure. *Food Chemistry*, 197 (Part B), 1292–1300. https://doi.org/10.1016/j.foodchem.2015.11.033

Ansari, S., Maftoon-Azad, N., Farahnaky, A., Hosseini, E. and Badii, F. (2014). Effect of moisture content on textural attributes of dried figs. *International Agrophysics*, 28(4), 403–412. https://doi.org/10.2478/intag-2014-0031

Arriola Guevara, E., García Herrera, T., Guatemala Morales, G.M., Nungaray Arellano, J., González Reynoso, O. and Ruíz Gómez, J.C. (2006). The Behavior of Freeze-Dried Hass Avocado During the Rehydration Process. *Revista Mexicana de Ingeniera Qumica*, 5(Suppl. 1), 51–56.

BPS-Statistics Indonesia. (2018). Statistik Buah-buahan dan Sayuran Indonesia, p. 107. Jakarta, Indonesia: BPS-Statistics Indonesia.

BSN (Badan Standarisasi Nasional.). (2018). SNI 3710-2018-Buah kering. Jakarta, Indonesia: BSN.

Buchner, N., Krubein, A., Rohn, S. and Kroh, L.W. (2006). Effect of thermal processing on the flavonols rutin and quercetin. *Rapid Communications in Mass Spectrometry*, 20(21), 3229–3235. https://doi.org/10.1002/rcm.2720

Caballero-Galván, A.S., Restrepo-Serna, D.L., Ortiz-Sánchez, M. and Cardona-Alzate, C.A. (2018). Analysis of Extraction Kinetics of Bioactive Compounds from Spent Coffee Grounds (Coffea arábica). *Waste and Biomass Valorization,* 9, 2381–2389. https://doi.org/10.1007/s12649-018-0332-8

Ceballos, A.M., Giraldo, G.I. and Orrego, C.E. (2012). Effect of freezing rate on quality parameters of freeze dried soursop fruit pulp. *Journal of Food Engineering*, 111(2), 360–365. https://doi.org/10.1016/j.jfoodeng.2012.02.010

Colucci, D., Fissore, D., Rossello, C. and Carcel, J.A. (2018). On the effect of ultrasound-assisted atmospheric freeze-drying on the antioxidant properties of eggplant. *Food Research International*, 106, 580–588. https://doi.org/10.1016/j.foodres.2018.01.022

Cui, Z.W., Li, C.Y., Song, C.F. and Song, Y. (2008). Combined microwave-vacuum and freeze drying of carrot and apple chips. *Drying Technology*, 26(12), 1517–1523. https://doi.org/10.1080/07373930802463960

Engelen, A. (2018). Analysis of texture, water content, colour and sensory analysis on making chips of kelor leaf. *Journal of Agritech Science*, 2(1), 10–15.

Guine, R.P.F. and Barroca, M.J. (2011). Influence of freeze-drying treatment on the texture of mushrooms and onions. *Croatian Journal of Food Science and Technology*, 3(2), 26–31.

Guiné, R.P.F. and João, M. (2011). Food and Bioproducts Processing Effect of drying treatments on texture and colour of vegetables (pumpkin and green pepper). *Food and Bioproducts Processing*, 90 (1), 58–63. https://doi.org/10.1016/j.fbp.2011.01.003

Hajnal, V., Szalay, L., Németh, S., Ficzek, G., Bujdosó, G. and Tóth, M. (2012). Changes in the fruit texture parameters and composition of apricot cultivars during ripening. *Acta Alimentaria*, 41(Suppl. 1), 73–82. https://doi.org/10.1556/AAlim.41.2012.Suppl.7

Huirem, B. and Shakya, B.R. (2015). Thin layer drying kinetics of kiwifruits (var. monty). *International Journal of Scientific Engineering and Technology Research,* 4, 1736–1746.

Izli, N., Izli, G. and Taskin, O. (2017). Influence of different drying techniques on drying parameters of mango. *Food Science and Technology*, 37(4), 604–612. https://doi.org/10.1590/1678-457x.28316

Kaewdam, S., Nitatwichit, C., Varith, J. and Jaturonglumlert, S. (2013). Mathematical model of freeze drying on mango. *Journal of Agricultural Research and Extension*, 30(Suppl. 3), 56–67.

Kaymak-Ertekin, F. and Gedik, A. (2005). Kinetic modelling of quality deterioration in onions during drying and storage. *Journal of Food Engineering*, 68 (4), 443–453. https://doi.org/10.1016/j.jfoodeng.2004.06.022

Kumoro, A.C., Alhanif, M. and Wardhani, D.H. (2020). A critical review on tropical fruits seeds as prospective sources of nutritional and bioactive compounds for functional foods development: A case of Indonesian exotic fruits. *International Journal of Food Science*, 2020, 4051475. https://doi.org/10.1155/2020/4051475

Liliana, S.C., Diana, P.V.M. and Alfredo, A.A. (2015). Structural, physical, functional and nutraceutical changes of freeze-dried fruit. *African Journal of Biotechnology*, 14(6), 442–450. https://doi.org/10.5897/ajb2014.14189

Macias, M.A. (2013). Comparatives studies of different drying process of strawberry hot air drying freeze-drying and swell-drying: application on the biological compounds preservation. France: Université de La Rochelle, PhD Thesis.

Marques, L.G. and Freire, J.T. (2005). Analysis of freeze-drying of tropical fruits. *Drying Technology*, 23(9–11), 2169–2184. https://doi.org/10.1080/07373930500212438

Marques, Luanda G., Ferreira, M.C. and Freire, J.T. (2007). Freeze-drying of acerola (*Malpighia glabra* L.). *Chemical Engineering and Processing: Process Intensification*, 46(5), 451–457. https://doi.org/10.1016/j.cep.2006.04.011

Marques, Luanda G., Prado, M.M. and Freire, J.T. (2009). Rehydration characteristics of freeze-dried tropical fruits. *LWT - Food Science and Technology*, 42(7), 1232–1237. https://doi.org/10.1016/j.lwt.2009.02.012

Murakami, M., Yamaguchi, T., Takamura, H. and Matoba, T. (2004). Effects of Thermal Treatment on Radical-scavenging Activity of Single and Mixed Polyphenolic Compounds. *Journal of Food Science*, 69(1), 7–10. https://doi.org/10.1111/j.1365-2621.2004.tb17848.x

Parniakov, O., Bals, O., Lebovka, N. and Vorobiev, E. (2016). Pulsed electric field assisted vacuum freeze-drying of apple tissue. *Innovative Food Science and Emerging Technologies*, 35, 52–57. https://doi.org/10.1016/j.ifset.2016.04.002

Raghavan, G.S.V. and Venkatachalapathy, K. (1999). Shrinkage of strawberries during microwave drying. *Drying Technology*, 17(10), 2309–2321. https://doi.org/10.1080/07373939908917685

Reyes, A., Bubnovich, V., Bustos, R., Vásquez, M., Vega, R. and Scheuermann, E. (2010). Comparative study of different process conditions of freeze drying of "Murtilla" berry. *Drying Technology*, 28(12), 1416–1425. https://doi.org/10.1080/07373937.2010.482687

Rozana, R., Hasbullah, R. and Muhandri, T. (2016). Response of Drying Temperature on Drying Rate and Quality of Dried Candied Mango (*Mangifera indica* L.). *Jurnal Keteknikan Pertanian*, 4(1), 59–66. https://doi.org/10.19028/jtep.04.1.59-66

Salazar, N.A., Alvarez, C. and Orrego, C.E. (2018). Optimization of freezing parameters for freeze-drying mango (*Mangifera indica* L.) slices. *Drying Technology*, 36(2), 192–204. https://doi.org/10.1080/07373937.2017.1315431

Salgado, N., Giraldo, G.I. and Orrego, C.E. (2017). Influence of the extrusion operating conditions on the antioxidant, hardness and colour properties of extruded mango. *LWT - Food Science and Technology*, 86, 209–218. https://doi.org/10.1016/j.lwt.2017.07.049

Seerangurayar, T., Manickavasagan, A., Al-Ismaili, A.M. and Al-Mulla, Y.A. (2017). Effect of carrier agents on flowability and microstructural properties of foam-mat freeze dried date powder. *Journal of Food Engineering*, 215, 33–43. https://doi.org/10.1016/j.jfoodeng.2017.07.016

FULL PAPER

Shofian, N.M., Hamid, A.A., Osman, A., Saari, N., Anwar, F., Dek, M.S.P. and Hairuddin, M.R. (2011). Effect of freeze-drying on the antioxidant compounds and antioxidant activity of selected tropical fruits. *International Journal of Molecular Sciences*, 12(7), 4678–4692. https://doi.org/10.3390/ijms12074678

Utami, M., Wijaya, C.H., Efendi, D. and Adawiyah, D.R. (2020). Physicochemical characteristics and sensory profile of Gedong mango at two different maturity levels. *Jurnal Teknologi dan Industri Pangan,* 31(2), 113-126. https://doi.org/10.6066/jtip.2020.31.2.113

Wang, H., Zhang, S. and Chen, G. (2008). Glass transition and state diagram for fresh and freeze-dried Chinese gooseberry. *Journal of Food Engineering*, 84(2), 307–312. https://doi.org/10.1016/j.jfoodeng.2007.05.024

