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Original Research Article

Banana Powder Production via Foam Mat Drying

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Abstract: Banana puree is one of the main commercial banana products available in the market worldwide. However, like other purees, banana puree deteriorates quite rapidly and gets a chilling injury when refrigerated. Therefore, this study focused on the dehydration of banana puree using a foam mat drying (FMD) technique to prolong its shelf life. It involved whipping the banana puree to form foams with the help of whey protein concentrate (WPC) and carboxymethyl cellulose (CMC) as the foaming agent and foam stabilizer, respectively. The study evaluated the effect of different foaming agent percentages (5, 7.5, 10, 12.5 and 15%) and drying temperatures (50, 60, 70 and 80°C) on the production of the foam mat dried banana powder. Besides that, the drying curves of banana puree using FMD and oven drying methods were compared. The banana powders produced were also analyzed in terms of the foam density, moisture content, solubility, color (browning index) and flowability (caking strength). Based on the findings, the FMD technique has proven to produce a good quality banana powder better than the control sample especially at a higher foaming agent concentration (15%) and drying temperature (80°C). By using the FMD technique, the banana puree has the capacity to be dried three times faster compared to the conventional oven drying method to form a more stable banana powder.

Keywords: banana; drying; foam mat drying; fruit powder; fruit puree

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1. Introduction

Banana (*Musa acuminate*), one the most popular fruit around the world, offers a quick boost of vitality and is a good source of vitamins C, B6, and potassium (Sampath Kumar *et al.*, 2012). Although most of the banana fruits are consumed fresh, this fruit can also be processed for different food applications such as snacks, desserts and beverages. Banana puree, as one of the main products of the banana, is the basis used in many bakeries, confectionery and beverages produce including ice cream, cakes, biscuits, yoghurt, smoothies and sorbet. Unfortunately, banana puree has a short shelf-life, since it can easily be oxidized and spoil to microbial activities. In order to overcome this shortcoming, drying of the banana puree is an alternative to extend its shelf-life.

The dehydration or drying process takes place when water vapor is taken away from its surface into the surrounding space, resulting in a dried material with an extended shelf life and reduced water activity of food products. During drying, the moisture content of the sample can be brought down to a low level to avoid microbial spoilage and undesirable enzymatic reactions (Vasudevan *et al.*, 2020). Through the dehydration process, the banana puree can be dried and further converted into powder form.

The banana powder has the potential to be commercialized in the market, since it is more convenient compared to the fresh puree in terms of long shelf-life, reduced volume or weight, simpler storage and handling and can be easily reconstituted for usage in varieties of banana-based products. However, some difficulties in producing the powder are expected, mainly due to the high sugar content and the stickiness characteristic of the banana puree. Without suitable processing approaches, the drying for the puree will take a long time and the produced powder may turn to be very hygroscopic and easily agglomerate. This will cause a caking problem, especially during the handling and storage of the bulk powder.

In order to solve this issue, suitable processing approaches to produce the banana powder should be considered, especially during the drying process. One of the emerging dehydration process technique, suitable for heat-sensitive, high sugar content and viscous foods, is the foam mat drying (FMD) technique. The FMD technique involves the transformation of products from a liquid state to a stable foam, followed by air drying (Affandi *et al.*, 2017). The formation of the foam structure in this technique requires the existence of a foaming agent, mostly protein-based substances and a foam stabilizer, mostly polysaccharide-based substances. This technique can be used for large scale production of fruit powders because of its suitability for all types of fruit puree, rapid drying at a lower temperature, retention of nutritional quality, easy reconstitution and cost-effective for producing easily reconstitute fruit powders (Brar *et al*., 2020; Sangamithra *et al.*, 2015). By considering these advantages, the foam mat drying (FMD) technique has the potential to be applied to produce the banana powder. However, more explorations are needed to refine the process. Hence, the aim of this study is to determine the effect of foaming agent percentage and drying temperature on the quality attributes of the banana powder produced via foam mat drying (FMD) technique.

2. Materials and Methods

2.1 Sample Preparation

Banana of the Cavendish variety was bought from convenience stores (Sri Serdang, Selangor, Malaysia). The bananas were peeled and blanched by placing them in boiling water for 1 min to inactivate the polyphenoloxidase, which triggers the generation of dark pigment (Yap *et al.*, 2017). The blanched banana was then mashed to produce banana puree and was considered as the raw ingredient in the foam mat drying procedure.

2.2 Foam Mat Drying (FMD) Technique

Foam mat drying (FMD) procedure consist of the mixture of (1) banana puree; (2) whey protein isolate (WPI) as the foaming agent (80% protein content); (3) carboxymethyl cellulose (CMC) as the foam stabilizer; and (4) distilled water. The ingredients were weighed based on the modified formula from Abbasi and Azizpour (2016) are shown in Table 1.

Table 1. The formulation for foam mat drying of banana puree.

Ingredients	**Formula**	
Banana puree	100 g	
Foaming agent (WPI)	5–15%	Based on the weight of the banana puree
Foam stabilizer (CMC)	8%	
Water	85%	

WPI, CMC and distilled water were whipped using a kitchen mixer (ELB-ESMB9925SS, Elba, Malaysia) at a maximum speed of 1150 rpm for 50 minutes prior to the addition of the banana puree. Mixing was continued for another five minutes at the same speed. The foamed mixture as illustrated in Figure 1(a) was removed from the mixer and further analyzed for foam density determination.

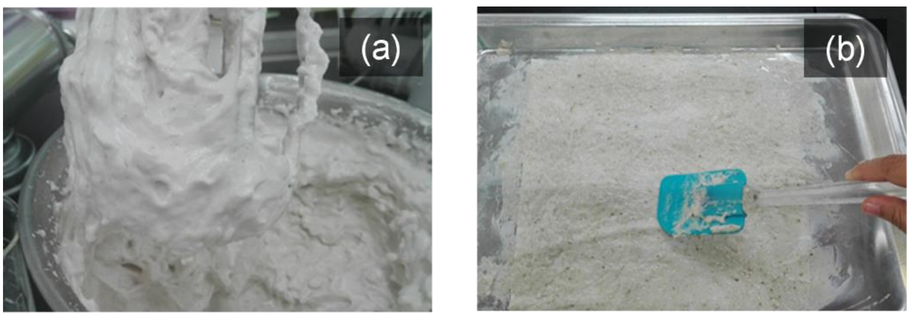

Figure 1. The foamed banana puree mixture: (**a**) after the wiping process, (**b**) during spreading on a tray.

The foam mixture produced was then spread uniformly with a thickness of 3.0 ± 0.02 mm on a metal tray, which the base has been covered with parchment baking paper as illustrated in Figure 1(b). The banana mat layer was placed in the hot air oven (UN55, Memmert, Germany) for the drying process. Once the drying process was completed, the dried mat was removed from the metal tray and grounded by a mixer grinder (MX-AC210SW, Panasonic, Japan) prior to sieve by a 100 µm screen mesh. The produced banana powder was stored in an air-tight container at room temperature and was used for the subsequent analyses for the evaluation of the powder quality.

2.3 Experimental Procedures

This study was performed in 3 phases. Phase 1 was an observation on the effect of foaming agent percentage of 5, 7.5, 10, 12.5 and 15% in the formulation of the foam mixture, on the quality of the foam and powder produced. For this phase, the drying process was fixed at 80°C for 7 hours. The investigation in the study was further extended in Phase 2 to investigate the impact of drying temperature at 50, 60, 70 and 80°C on the attributes of the produced FMD banana powder. The drying process was performed for seven hours and the formulation of the mixture was fixed using a 10% foaming agent. In phase 3, a comparison was done on the drying curve between FMD and conventional oven drying technique by observing the free moisture (X) removal until it reaches equilibrium.

2.4 Analyses

2.4.1 Determination of foam density

The foam density was determined according to Bag *et al.* (2011), where 50 ml of the foam was poured into a 50 ml graduated cylinder at room temperature. The samples were weighed, and foam density was calculated according to Equation 1.

$$\text{Foam density} = \frac{\boldsymbol{weight\ of\ foam}\ (\boldsymbol{g})}{\boldsymbol{volume\ of\ foam}\ (\boldsymbol{cm^3})} \tag{1}$$

2.4.2 Determination of moisture content

The moisture content of the banana powder was determined by using a moisture analyzer (MX-50, A&D Weighing, Japan).

2.4.3 Determination of solubility

The solubility of the banana powder was determined by using a dissolution tester (D-63512, Pharma Test, Germany). Banana powder of 2.5 g was placed in a vessel filled with

250 ml distilled water inside a temperature-controlled water bath. The dissolution tester was operated at 250 rpm and at 45°C, where the time (in min) for the powder to dissolve was recorded.

2.4.4 Determination of color

The color properties of the banana powder were determined using a portable spectrophotometer (CR-10, Konica Minolta, Japan). The calibration of the device was performed using a white and black calibration plate prior to the analysis. The color properties were recorded in terms of lightness (L*), redness (a*) and yellowness (b*) values, in order to measure the browning index (BI), based on Equation 2 (Nasser *et al.*, 2017);

$$BI = \frac{[100\ (x - 0.31)]}{0.17} \tag{2}$$

where *x* was calculated based on Equation 3;

$$x = \frac{a^* + 1.75\ x\ L^*}{(5.645\ \times\ L^*\ +\ a^*\ - 3.012\ \times\ b^*)} \tag{3}$$

2.4.5 Determination of flowability

The flowability of powders can be measured by using a powder flowability analyzer probe (TTC, USA) attached to a texture analyzer (TA.XTPlus, Stable Micro Systems, UK). The flowability of the powder was determined by running a caking test. All samples were fixed at 70 mL volume for each experiment. The blade travels down and upwards through the powder column at a nominal speed of 50 $mm.s^{-1}$.

2.4.6 Determination of drying curve

The drying curve of the samples was determined according to the free moisture, *X* of the sample as the function of drying time. The free moisture, *X* of the sample was calculated based on Equation 4.

$$X = X_t - X^* \tag{4}$$

where X_t was the moisture content at a time (t) was calculated using (Equation 5) and X^* was equilibrium moisture content (kg equilibrium moisture kg dry $solid^{-1}$):

$$X_t = \frac{W - W_s}{W_s} \tag{5}$$

where W is the weight of the wet solid in (kg) and W_S is the weight of dry solid in (kg).

3. Results and Discussion

3.1 Effect of Different Percentages of Foaming Agent

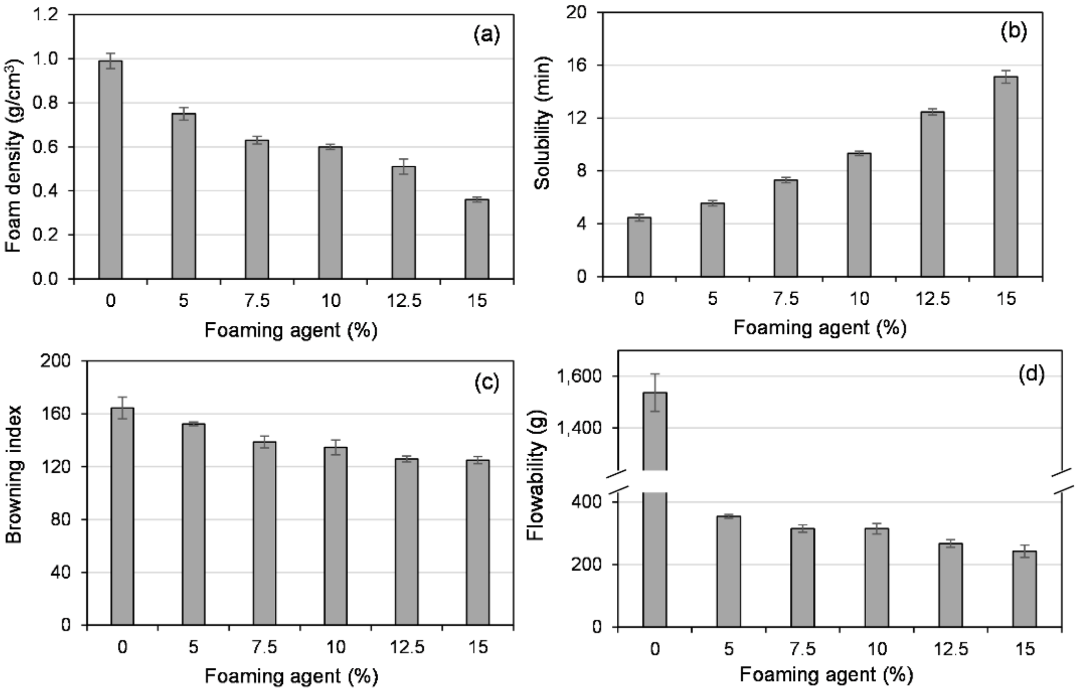

Figure 2. Effect of different percentage of the foaming agent on: (**a**) foam density; (**b**) solubility; (**c**) browning index; and (**d**) flowability of the samples

Different percentages of the foaming agent (WPC) i.e. 5, 7.5, 10, 12.5% were being added to the banana puree to observe their effects on the produced samples. Figure 2(a) shows the effect of different percentages of the foaming agent on the resulted foam density. The density of the foam decreases significantly with the increment of the WPC concentration. A 63% reduction has been achieved at 15% foaming agent compared to the control sample, (at 0% foaming agent). This clear trend is due to the reduction of the interfacial tension at the air or liquid interface with the increment of WPC concentration and subsequently reduces the surface tension of the foam structure (Dachmann *et al.*, 2018). Hence, more entrance of air into the foam structure is expected and subsequently resulting the density to reduce (Affandi *et al.*, 2017). Lower foam density of the mat will facilitatefacilitates better moisture removal during the drying process.

The solubility duration of the banana powder produced at different percentages of foaming agent is displayed in Figure 2(b). The time to solubilize the powders increased significantly with the rise of the concentration of WPC, in which powder with 15% WPC required 3-fold longer time to solubilize compared to the control powder. Hence, t high WPC content in the FMD powder resulted to the powder with a low solubility rate. This has been affected by the change in the microstructure of the FMD mixture due to its reduction of hygroscopic behavior (Cano-Chauca *et al.*, 2005). Hygroscopic is the property of absorbing the water and is mostly low if the powder is in an amorphous state (Cano-Chauca *et al.*, 2005). It is expected that higher WPC in the formula increases the amorphous behavior of the produced banana powder, thus reducing the hygroscopic character and the solubility rate of the powder. Besides, the solubility rate might be also due to the pore structure of the powders. FMD samples have been reported to have high porosity and stretched pore shape with skeletal-like structure compared to a compact and less porous structure of a non-foamy sample (Sangamithra *et al.*, 2015).

Figure 2(c) exhibits the browning index (BI) of the banana powder at different percentages of foaming agent and a control sample. As shown in the figure, the effect of WPC on the browning index exhibited a decreasing trend. The structure of WPC is made of protein, so by increasing the amount of WPC in the formula, the amino acids existing in its chemical composition reduces the sugar in the system, which lead to a lesser browning effect during the drying process (Wilson *et al.*, 2014). Besides, the existence of CMC in the FMD powders is believed to affect the lower BI value compared to the control sample. The CMC, which acts as a foam stabilizer, has a hydrophilic structure that can contribute to the reduction of humidity of the mixture and subsequently affect the Maillard-reaction during the drying process (Abbasi & Azizpour, 2016).

The flowability of the banana powder, characterized by its loose particulate solids, treated with different percentages of foaming agent and a control sample is displayed in Figure 2(d). The flowability of the banana powder was determined based on its caking strength of the powders using a texture analyzer. Caking strength is a measurement to evaluate the potential of the particular powder to form cake based on the force required to cut through the cake formed after the compaction, which would determine the strength of the cake (Shah *et al.*, 2008). The greater the strength, the higher the tendency of the powder to form hard cake, which is not easy to disperse. Thus, the tendency of the powder to be involved in caking is high. Based on the result obtained in Figure 2(d), the control-powder has a significantly stronger caking strength than any of the FMD powders. It can be proven that the caking strength of the banana powder is decreasing as the concentration of WPC increased. This finding has proven that the existence of the foaming agent and its concentration level have a significant effect on lowering the caking problem of the banana powder resulted from reduction of hygroscopicity of the powder (Seerangurayar *et al.*, 2017). The hygroscopicity characteristic produces a sticky powder. The stickiness can lead to the rise of the cohesiveness, powder-caking and increase the adhesion to the surface of the powder. Thus, low hygroscopicity behavior leads to a decrease in the caking strength and an increase in the flowability.

Based on the findings in this study, higher foaming agent concentration led to a better foam density and powder's solubility, browning index and flowability, however, other factors such as the cost of the raw materials and protein allergenicity effect should also be evaluated for a more feasible banana powder production.

3.2 Effect of Different Drying Temperatures

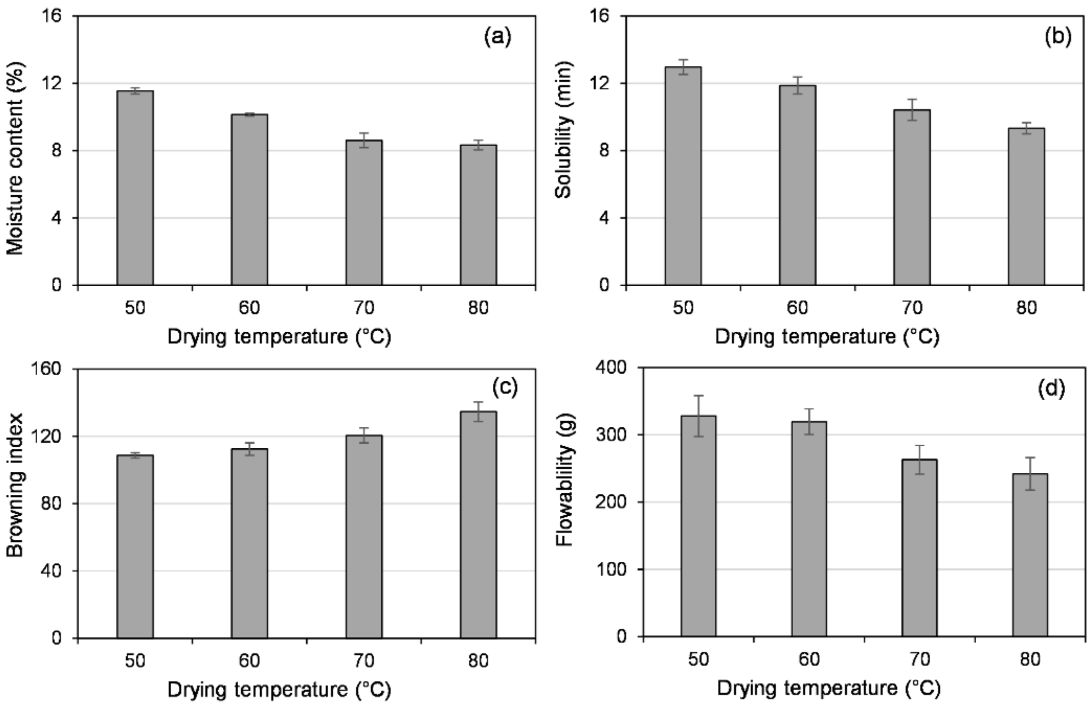

Figure 3. Effect of different drying temperatures on: (**a**) moisture content; (**b**) solubility; (**c**) browning index; and (**d**) flowability of the produced powders

For the purpose of further exploration in this research, this study has chosen a 10% foaming agent in the formulation to proceed with the determination of the effect of different drying temperatures of the FMD technique. The drying temperature was varied at 50, 60, 70 and 80ºC and the characteristics of the FMD powder produced were evaluated.

Figure 3(a) shows the effect of different drying temperatures on the moisture content of the produced powder at a fixed drying time of six hours. As expected, the lowest drying temperature of 50ºC produced powder with the highest moisture content, 27% higher compared to the sample dried at 80°C. Higher drying temperatures have resulted to more moisture removal within the sample. This is because the higher amount of heat generated in the oven creates a relatively larger vapor pressure difference between the internal and the surface of the sample, which leads to more rapid moisture removal, hence, forming a sample with lesser moisture content.

Based on Figure 3(b), the powder produced at higher drying temperature required lesser time to dissolve in water. This might be related to the reduction of moisture content in the sample as shown in Figure 3(a). The lower the moisture content in the samples, the powder became less sticky and has lesser contact with water (Franco *et al.*, 2016). Besides, the reduction of the solubility time might also be due to the increment of denatured protein in the powder at the higher drying temperature, since the foaming agent used in this study was categorized as protein. Meanwhile, Figure 3(c) exhibits the browning index (BI) of the banana powder at different drying temperatures. An increment of the drying temperature leads to a higher browning index. The BI value for powder dried at 80°C was 134.61 compared to the BI of 108.67 of the powder dried at 50°C. This trend is due to the Maillard-reaction that was accelerated at a higher drying temperature because the heat both increases the rate of chemical reactions and increase the evaporation of water in the samples. Nevertheless, the BI value for the sample dried at 80°C is still low compared to the control sample with 164.43 BI value, as per illustrated in Figure 2 (c).

The flowability of the banana powders dried at different temperatures is shown in Figure 3(d). The finding shows a decreasing trend of the flowability of the powder as the drying temperature increases. The flowability of the powder is related to the caking behavior as what has been discussed in the previous section and can be associated with the moisture content in the sample. Higher moisture content in the banana powder would lead to higher caking strength. This can be proven by similar trends in Figure 3(d) with Figure 3(a) that shows the decrement of the moisture content of the powder as the drying temperature increases. Low moisture content leads to a lower tendency for the powder to form crystalline bond caking. The crystalline bonds are formed between particles when the material is soluble and high on the water source.

Based on Figure 3(a) to (d), it is clear that at a higher drying temperature, the powder being produced has good attributes in terms of moisture content, solubility rate and flowability, although a slight increment of the browning index occurred. However, the operating cost and drying duration may still need to be considered further to choose the best drying temperature for the foam mat drying technique of banana powder.

3.3 Drying curve of FMD and conventional oven drying method

A comparison of the drying curve between the FMD-treated and control samples has been performed as exhibited in Figure 4. The FMD treated-sample was prepared with 10% of WPC, while the control sample was the untreated banana puree dried using the conventional oven drying method. Both samples were dried at 80ºC. The moisture removal of both samples was observed at a certain time interval (every 1 hour) based on the weight loss of each sample until they reach constant weight.

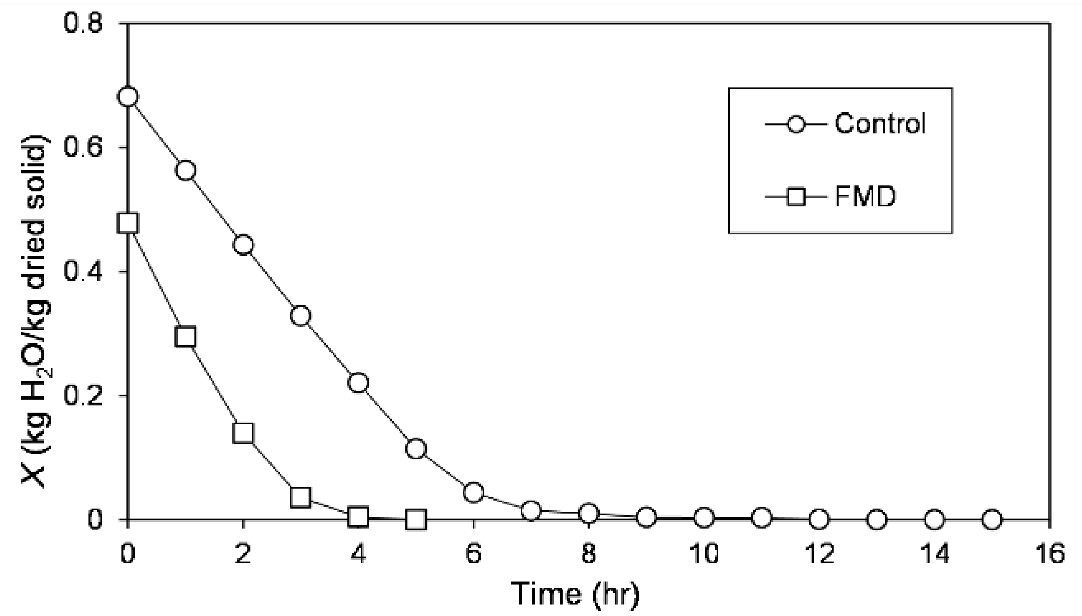

Figure 4. Drying curve of free moisture, X against drying time for FMD and control samples at 80°C

As shown in Figure 4, the addition of foaming agent has reduced the initial free moisture of the FMD sample compared to the control sample. The FMD treated sample exhibited a steep drying curve indicating massive loss of free moisture during the first three hours before it approached the zero-equilibrium value after five hours. The control sample exhibits a gradual decline of free moisture loss in six hours before approaching equilibrium after 15 hours. These findings further support the FMD concept where better moisture removal is expected from a porous structure of the FMD treated-sample during the drying process. The moisture removal from the control sample, which was a plain banana puree, required a longer time to achieve since the sample was denser and stickier. In comparison, the drying process of the FMD treated-sample required a drying time of three times shorter than the control sample, proving that the FMD technique can accelerate the drying time compared to the conventional method.

4. Conclusion

In this study, the banana puree has been successfully converted into powder by using the foam mat drying (FMD) technique. The density of the puree foam decreased significantly with the increase in the foaming agent concentration. High foaming agent percentage (15% WPC) and drying temperature (80°C) produced powder that has better attributes in terms of moisture content, solubility rate, browning index, and flowability. However, other factors including the cost of the raw materials and operation as well end product's protein allergenicity effect should also be considered before the optimal processing approaches can be decided. By using the FMD technique, the drying time of the banana puree to form banana powder can be reduced up to three times compared to the conventional oven drying method.

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