

Research Article

Effect of Freezing on Quality of Osmotically Dehydrated Banana Slices

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Abstract: The objective of this study was to evaluate the effect of Fast Freezing (FF) and Slow Freezing (SF) pretreatment on the osmotic dehydration of banana. An untreated sample (UT) was used as a control. Freezing pretreated samples (FF and SF) showed a high moisture loss after 3 h soaking time, which was lowered than the untreated sample (4 h soaking time). The variation of drying time at 70°C from 4 to 6 h was studied. The physicochemical (moisture content, pH, titratable acidity, hardness, total sugar, ascorbic acid, color) and sensory properties of fast freezing, slow freezing and untreated sample were determined. The drying process significantly ($p < 0.05$) lowered moisture content and ascorbic acid of bananas, as well as increased in hardness and total sugar. The pH and titratable acidity were no significant differences ($p > 0.05$) among all samples at any drying time. An increase in the L^* value of all samples was evident with increasing drying time, while slow freezing sample had the highest b^* value ($p < 0.05$). The sensory results revealed that freezing pretreated banana slices were acceptable equally to the untreated sample. The longer drying time caused slightly decreased ($p < 0.05$) in scores of sweetness and overall acceptability of both freezing pretreated banana slices.

Keywords: Banana, drying, freezing, osmotic dehydration, pretreatment

INTRODUCTION

Banana (*Musa* ABB group cv. kluai namwaa), a tropical fruit which mainly cultivates in South East Asian countries such as Thailand and Philippines, is popular for its taste and flavor, high energy, constipation alleviation and nutritional properties, as a source of vitamin A and C, potassium, calcium, sodium and magnesium. Regarding ripe banana contains about 80% moisture, it is categorized as a highly perishable fruit with short shelf life storage at 20°C (<7 days). As a consequence, it is necessary to extend the shelf life of the fruit by many methods including drying, preserving, osmotic dehydration and using a modified atmosphere packaging (Siddiq *et al.*, 2012). Under this preservation, the osmotic dehydration can be used to obtain a high quality product. It is initially started with partial removal of water from fruits and vegetables by immersing in a concentrated solution of osmotic agents such as sugar and salt. This is a pretreatment process before air drying to decrease water content. The method is conceptual in water/solutes diffusion from and into the material through a semipermeable membrane. Two crossed flows: a water outflow, from the fruit to the solution and a solute inflow from the solution into the fruit is occurred simultaneously (Lewicki and Porzecka-Pawlak, 2005). In addition there is a third flow of natural solutes such as sugars, organic acids, minerals leaching from the fruit into the solution, which may have an important effect on the sensorial and nutritional

of the product (Waliszewski *et al.*, 1997). Osmotic dehydration being a drying technique with moderate temperature; consequently, it do not affect the characteristics of the semipermeable cellular membranes (Torres *et al.*, 2006). The advantages of osmotic dehydration are evident in minimizing heat damage to the flavor and aroma and nutritional content, preventing color changes by enzymatic and non-enzymatic browning, lowering the water activity and reducing the loss of volatile compounds (Alakali *et al.*, 2006).

In the case of banana, osmotic dehydration could be an interesting preservation method to attain a better-quality dehydrated product. Many researchers have reported the factors affecting mass transfer rate of osmotic dehydration process which are composition and concentration of the osmotic solution, temperature, soaking time, size and geometry of the fruit, fruit to solution ratio, degree of agitation of the solution and quality of final product (Chavan *et al.*, 2010). Generally, a longer treatment time in high concentration of sucrose was the most important effect on weight reduction and water loss but it could be attributed to the softening of the banana slices, which is difficult to handle and unsuitable for further drying (Renu *et al.*, 2012). Some researchers have studied an approach to reduce the processing time such as chilling, freezing, blanching to increase the rate of osmotic mass transfer. Normally, freezing is the method of preservation. It could be utilized to establish the long term preservation

of banana prior to osmotic dehydration. Falade and Adalakun (2007) found a rapid increase of water loss and solid gain in freeze-thawed African star apples in relation to fresh star apples at the same immersion time. Bchir *et al.* (2012) studied the influence of freezing on mass transfer during osmotic dehydration of pomegranate seeds. They reported that frozen pomegranate seeds had higher water loss and solid gain approximately 1.4 and 3.5 times, respectively compared to unfrozen pomegranate seeds. Similar results were found in the work of Dandamrongrak *et al.* (2003), showing increasing drying rate and decreasing drying time in bananas treated with freezing and blanching/freezing. Therefore, the pretreatment by freezing before osmotic dehydration would be a potential approach subjecting to not only offer more water loss than osmotic dehydration alone, but also decrease initial moisture of fruit, which are advantageous for extending shelf life and reduction drying time. So far, there is a limited literature studied on the impact of freezing process condition on the quality of osmotic dehydrated banana. Thus, the objective of this study was to evaluate the effect of freezing as a pretreatment before osmotic dehydration on the drying efficiency and to optimize the drying time required to produce finished products with the best sensorial quality.

MATERIALS AND METHODS

Materials: Unripe bananas (cv. kluai namwaa) (30 mm diameter x 100 mm length) were purchased from a local market in Bangkok city. The fruits were selected for uniformity in size, maturity based on the peel, flesh color and total soluble solid content. The banana was left at ambient temperature ($30\pm 2^\circ\text{C}$) until the ripe stage (fully yellow peel and 13-17 °Brix of soluble solids). Sucrose (Mitrr Phol, Mitr Phol group, Thailand) was purchased from a local supermarket.

Pre-treatment: The ripe bananas were hand peeled and sliced. The tips from each end of the bananas were discarded. The bananas were cut into radial cylinder with an average thickness of 10 mm. Banana slices were soaked in a sodium metabisulfite solution at 0.1% (w/v) for 10 min to limit microbial spoilage. Bananas were gently washed, drained and then transferred to freezing as a pretreatment process. The bananas were divided into three groups, two groups were pretreated by two freezing procedure before osmotic dehydration as follows: (1) Fast Freezing (FF); bananas were frozen rapidly in an air blast freezer at -34°C for 1 h and then transferred to cold storage at -18°C for 17 h and (2) Slow Freezing (SF): bananas were frozen at -18°C for 18 h in a home freezer refrigerator. Both pretreated bananas were thawed in water for 1 h with intermittent change of water at an interval of 10 min. The last group

Untreated (UT) or control: bananas were loaded directly to osmotic solution without freezing.

Osmotic dehydration: The banana slices from each group were immersed in a sucrose solution at 65°Brix. The ratio of sucrose solution to banana slices was 2:1 (w/w). The samples were kept in the osmotic solution for 4 h; afterwards, the syrup was drained off. Dehydrated banana slices were gently washed in water to eliminate the remained syrup and then blotted with tissue paper. Thereafter, the banana slices were dried in a tray dryer at $70\pm 2^\circ\text{C}$ for 4, 5 and 6 h. The dried banana slices were vacuum packed in low density polyethylene bags and stored at ambient temperature ($30\pm 2^\circ\text{C}$) prior to analysis.

Physicochemical analysis:

pH: The pH of the sample was measured using a digital pH-meter (Model 320, Mettler-Toledo Ltd., Essex, UK) according to AOAC (1995) standard method.

Titrateable acidity: Total acidity of the sample was measured by a titration method with 0.1 N sodium hydroxide using phenolphthalein as an indicator (AOAC, 1995). The result was expressed as gram of citric acid per 100 g of sample.

Moisture content: The moisture content of the sample was determined by a hot air oven method according to AOAC (1995) standard method.

Hardness: Hardness was measuring using a Lloyd texture analyzer (Model LRX, Lloyd Instruments, Hampshire, UK) equipped with a 1000N load cell and a shearing-test cell at 250 mm^{-1} . The hardness (N) of the banana slice was recorded as the force in compression that corresponded to the breakage of sample.

Total sugar: The total sugar content was quantitatively determined by the Lane and Eynon volumetric method using a titration method with Fehling's solution. The result was expressed as gram of glucose per 100 g of sample on dry weight basis (Ranganna, 1986).

Ascorbic acid: Ascorbic acid content was estimated by 2, 6-dichlorindophenol indophenol method. The result was expressed as milligram of ascorbic acid per 100 g of sample on dry weight basis (Ranganna, 1986).

Color: Color of the banana slice was evaluated by a Hunter Lab digital colorimeter (Model ColorFlex, Hunter Associates Laboratory, Reston, VA). Color scales including lightness (L^*) value [0 (black) to +100 (white)], a^* value [- (green), + (red)] and b^* value [- (blue), + (yellow)] were recorded.

Sensory evaluation: Banana slices were evaluated for appearance, color, sweetness and overall acceptability

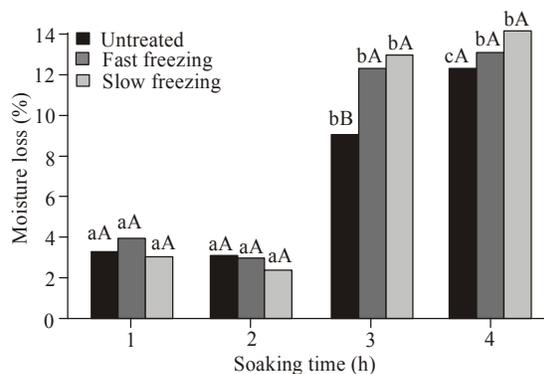


Fig. 1: Effect of freezing pretreatment on moisture loss of banana slices; ^{a, b, c}: Different superscript letters on the bar indicate significant differences ($p < 0.05$) among different soaking times for the same sample; ^{A, B}: Different superscript letters on the bar indicate significant differences ($p < 0.05$) among different samples at the same soaking time; Treatments: FF = banana treated by fast freezing, SF = banana treated by slow freezing, UT = banana without freezing

using a 9-point hedonic scale test (1 = extremely dislike, 9 = extremely like). Twenty-four untrained panelists drawn from Department of Food Science and Technology, University of the Thai Chamber of Commerce (UTCC) were selected based on their interest and product familiarity. Panelists were instructed to cleanse their palates with distilled water before tasting the sample and anytime during the test as needed (Lawless and Heymann, 1998).

Experimental design and statistical analysis: The experimental design was initially evaluated for the moisture loss of banana slices under various treatments including Fast Freezing (FF), Slow Freezing (SF) and Untreated (UT) at four soaking times (1, 2, 3 and 4 h). The three treatments were dried at $70 \pm 2^\circ\text{C}$ for four times (3, 4, 5 and 6 h). The osmodehydrated banana slices were made in duplicate and three samples from each treatment were used for physicochemical analysis. The data were analyzed using SPSS for Window. An Analysis of Variance (ANOVA) was used to evaluate significant difference at level of 5% ($p < 0.05$). Duncan's New Multiple Range Test was used to compare the mean (Cochran and Cox, 1992).

RESULTS AND DISCUSSION

Effect of freezing pretreatment on moisture loss of banana slices: The effects of Fast Freezing (FF) and Slow Freezing (SF) pretreatment on moisture loss of banana slices are presented in Fig. 1. The results showed that an increase in soaking time led to increasing moisture loss of all treatments, possibly due to the functionality of sucrose solution to develop high osmotic potential. During osmotic pressure, water diffuses out quickly from the banana tissue to the

osmotic gradient, whereas sucrose diffuses less rapidly into the banana tissue (Fito *et al.*, 2001). It was also observed that the moisture loss of all samples determined at 1 h and 4 h soaking time were ranged 3.17-3.25% and 12.42-14.20%, respectively. All samples were slow in water removal during the first 2 h; after that, both freezing pretreated samples (FF and SF) showed a higher moisture loss (11.88-12.69%) after 3 h soaking time and tended to be stable through the end of the process. This indicated the osmotic pressure is equilibrated. Although, the result determined in untreated sample was similar to those found in freezing samples, it lowered in rate of moisture loss at 3 h of soaking time ($p < 0.05$). The moisture loss was remarkably increased (12.42%) after 4 h of soaking time and did not significantly differ ($p > 0.05$) compared to the freezing samples. This revealed the effect of freezing pretreatment to enhance water loss rates and high uptake of sugar during osmotic dehydration. As a consequence, freezing pretreated samples were faster to reach the osmotic equilibrium (at 3 h of soaking time) than untreated sample (at 4 h of soaking time), meaning that the freezing is feasible to shorten the time of soaking. It was confirmed by the work of Falade and Adelakun (2007) who reported that freezing-thawed African star apple highly increased in water loss and solid gain within 30 min to 2 h of glucose and sucrose immersion compared the fresh one that required 2-3 hours of immersion. Thus, the soaking time for 3 h was chosen for the next study.

Physicochemical characteristics of the osmodehydrated banana:

Moisture content: The effect of drying time on moisture content of osmodehydrated banana shown in Fig. 2a reveals a gradual decrease ($p < 0.05$) in moisture content of all samples with increasing drying time. The moisture content for all samples after drying for 4 h ranged 22.07-27.67% and lowered to 13.31-19.26% after 6 h drying. This could be attributed to the fact that the decrease of moisture content which is in compliance with the nature of drying characteristics of various researches made for drying of fruit, vegetable and cereals (Gabriela *et al.*, 2004). After drying process, the untreated sample (UT) had the highest moisture content, followed by the Fast Freezing sample (FF) and the Slow Freezing sample (SF) had the lowest. The reduction in moisture content of freezing pretreated samples was found to be faster than untreated sample, possibly due to the freezing process causes a tissue integrity, which allows moisture to be removed more easily (Eshtiaghi *et al.*, 1994). After drying for 5 h, the moisture content found among all samples ranged from 18.09-19.68% was significant ($p > 0.05$). Generally, the basic objective of drying food products is to remove water to a certain level at which microbial spoilage is avoided. The moisture reduction of food lowers to 10 and 20% wet weight basis can prevent bacteria, yeast,

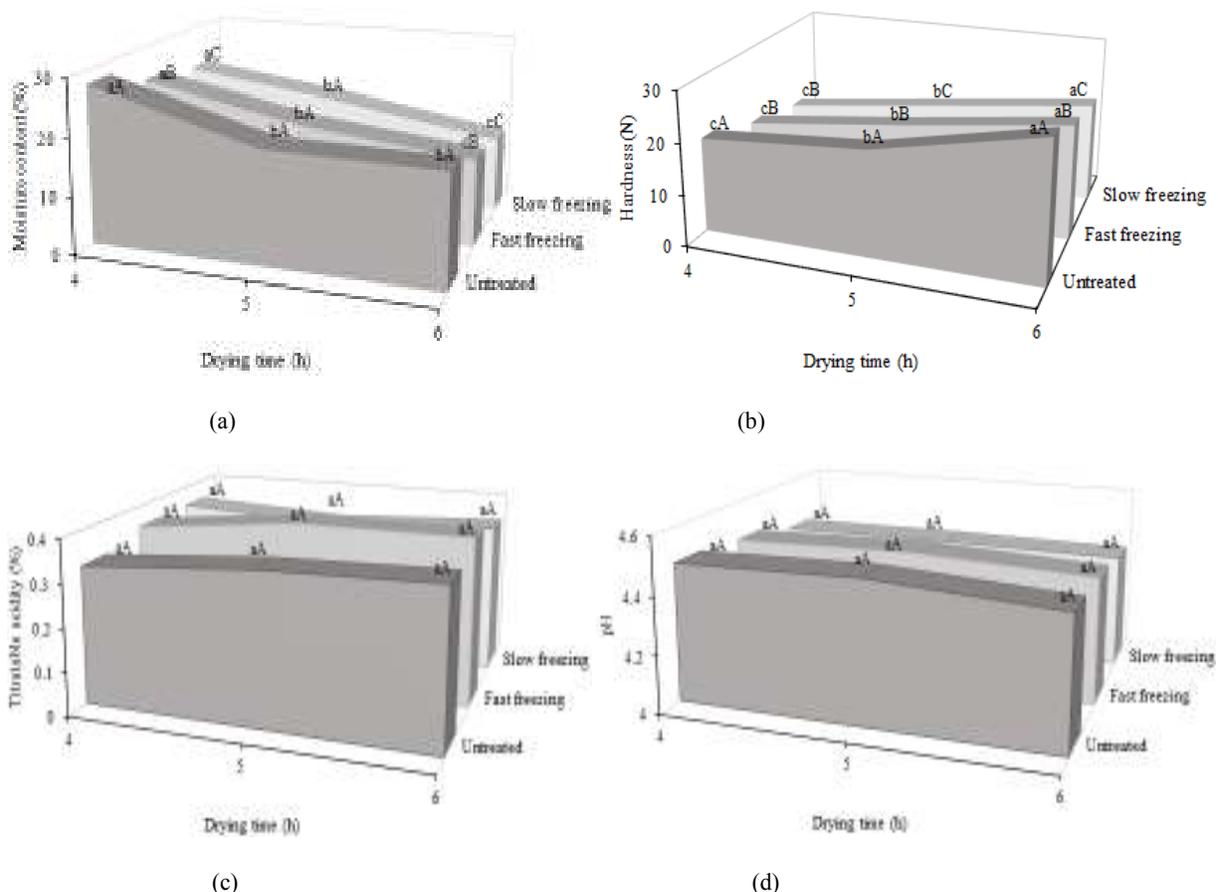


Fig. 2: Effect of freezing pretreatment on physicochemical properties of osmodehydrated banana during drying at 70°C: (a) moisture loss, (b) hardness, (c) pH and (d) titratable acidity; ^{a, b, c}: Different superscript letters on the bar indicate significant differences ($p < 0.05$) among different drying times for the same sample.; ^{A, B, C}: Different superscript letters on the bar indicate significant differences ($p < 0.05$) among different samples at the same drying time

mold and enzyme damage (Jayaraman and Gupta, 2006). Thus the optimal drying time at least 5 h is assured for complete drying and microbial safety in osmodehydrated banana processing.

Hardness: The hardness, represented by the peak force, is illustrated in Fig. 2b. It can be seen that the hardness of untreated sample (UT) and both freezing pretreated samples (FF and SF) were increased ($p < 0.05$) with drying time in the range of 12.05-18.40 N (4 h) and 19.66-27.19 N (6 h), respectively. It was clearly noticed that the moisture evaporation during air-drying caused an enhancement in hardness. The results also revealed that the hardness for all samples were significantly ($p < 0.05$) different at any drying time. The samples treated by freezing had lower peak force values than untreated sample. This can be explained by the reason that during freezing process, the water in the samples partially formed ice crystals which negatively damaged the cellular integrity of the cellular compartments reducing the turgor pressure and firmness values of the samples (Bchir *et al.*, 2012). Furthermore, the hardness

determined in the Slow Freezing sample (SF) was significantly lower ($p < 0.05$) than the fast Freezing Sample (FF). The finding revealed that the slow freezing process caused the banana texture softer than that with fast freezing process. This reflected the banana structure was greatly damaged by slow freezing process, which was attributed to the formation of large ice crystals outside the cell leading to destroy the cellular integrity of the cell wall. In contrast, the fast freezing encourages the formation of small ice crystal both inside and outside of the cell, these causing less damaged in cellular structure (Kerr, 2004).

pH and % acidity: Figure 2c and d show the results of pH and titratable acidity of osmodehydrated banana slices with drying time. There was no significant difference ($p > 0.05$) for pH and titratable acidity among all samples at any time.

Ascorbic acid: Ascorbic acid results of osmodehydrated bananas are presented in Fig. 3a. After drying process, the amount of ascorbic acid content in

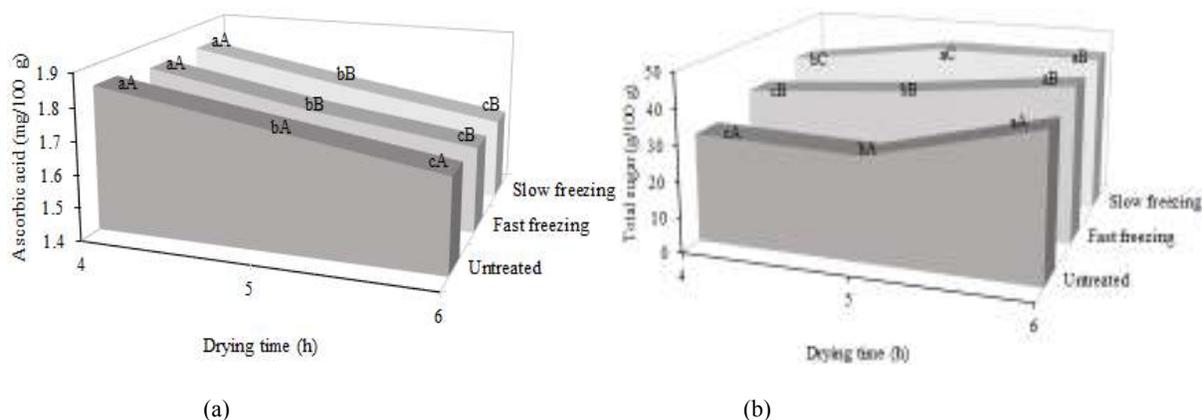


Fig. 3: Effect of freezing pretreatment on ascorbic acid and total sugar of osmodehydrated banana during drying at 70°C: (a) ascorbic acid and (b) total sugar; ^{a, b, c}: Different superscript letters on the bar indicate significant differences ($p < 0.05$) among different drying times for the same sample.; ^{A, B, C}: Different superscript letters on the bar indicate significant differences ($p < 0.05$) among different samples at the same drying time

untreated sample (UT) and both freezing pretreated samples (FF and SF) were lower than fresh banana (14 mg/100g). The ascorbic acid content gradually decreased with increasing drying time for all samples. After 6 h drying, the ascorbic acid content in all samples ranged 1.65-1.68 mg/100g. It was noted that the loss of ascorbic acid could be explained by the leaching of ascorbic acid from the product into the osmotic solution because ascorbic acid is highly soluble in water. Another reason may be the oxidation of ascorbic acid to dehydro-ascorbic acid during drying process (Devic *et al.*, 2010). The lowest of ascorbic acid content was observed in the freezing pretreated samples. From the results suggested that, increasing the water loss caused an increased leaching of ascorbic acid during osmotic dehydration process.

Total sugar: Figure 3b shows the total sugar content of osmodehydrated banana with drying time. The total sugar content increased with the increase in drying time ($p < 0.05$) in untreated sample (UT) and both freezing pretreated samples (FF and SF). Longer drying time increased the sweetness of osmodehydrated banana, which might be due to drying process causes the water to evaporate from the products, consequently concentration the sugar content in the banana. The total sugar content was significantly ($p < 0.05$) different among the samples at any drying time. Except at 6 h drying, there was no significant ($p > 0.05$) difference in total sugar content between two different freezing pretreatment samples. Both freezing pretreatment samples (FF and SF) had the higher total sugar than untreated sample (UT). These data could possibly explained by the cell structure of frozen banana which was damaged by the freezing pretreatment. The damaged membrane loses their semi-permeability functions, thus increasing the sugar migration into banana tissue. These results are in accordance with the

previous finding of Kowalska *et al.* (2008) showing that the use of freezing before osmotic dehydration increased the percentage of solid gain. Bchir *et al.* (2012) found that freezing before osmotic dehydration provided 3.5 times greater sugar gained than an untreated sample.

Color: Changes in color of the osmodehydrated banana parameter L^* , a^* and b^* are presented in Fig. 4. These results indicated that after drying process, there were increases of L^* value (lightness) and b^* value (yellowness) ($p < 0.05$), but no change of a^* value (redness) ($p > 0.05$) observed in untreated sample (UT) and both freezing pretreated samples (FF and SF). The L^* values were significantly different ($p < 0.05$) in all samples at any time. The slow Freezing Sample (SF) showed the lowest L^* when compared with other samples, indicating a darker color as its high total sugar content is related to browning reactions during hot-air drying. The Maillard reaction is mainly responsible for browning development in osmodehydrated bananas. In addition, the degradation of ascorbic acid may be a reason which involves in the formation of brown color. Moreover, the b^* value of slow freezing sample was significantly higher ($p < 0.05$) than other samples throughout drying time. The more yellow may be associated with the loss of water, subjecting to concentrate carotenoid content in the cellular tissue. This was in agreement with the results of Heredia *et al.* (2009) who reported that water loss could increase β -carotene and lycopene in cherry tomato. This finding exhibited that the banana treated by freezing was appeared to have a light yellow color, while the banana without pretreatment became pale.

Sensory evaluation: The sensory evaluation of the osmodehydrated banana is given in Fig. 5a to d. The results showed that there was no significant differences

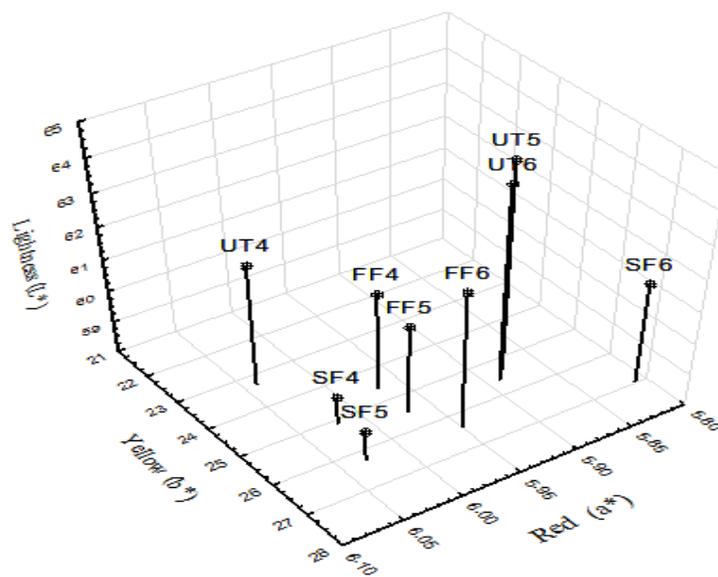


Fig. 4: Effect of freezing pretreatment on L^* , a^* and b^* value of osmodehydrated banana during drying at 70°C ; FF4, FF5 and FF6 = banana treated by fast freezing with drying at 4, 5 and 6 h, respectively; SF4, SF5 and SF6 = banana treated by slow freezing with drying at 4, 5 and 6 h, respectively; UT4, UT5 and UT6 = banana without freezing with drying at 4, 5 and 6 h, respectively

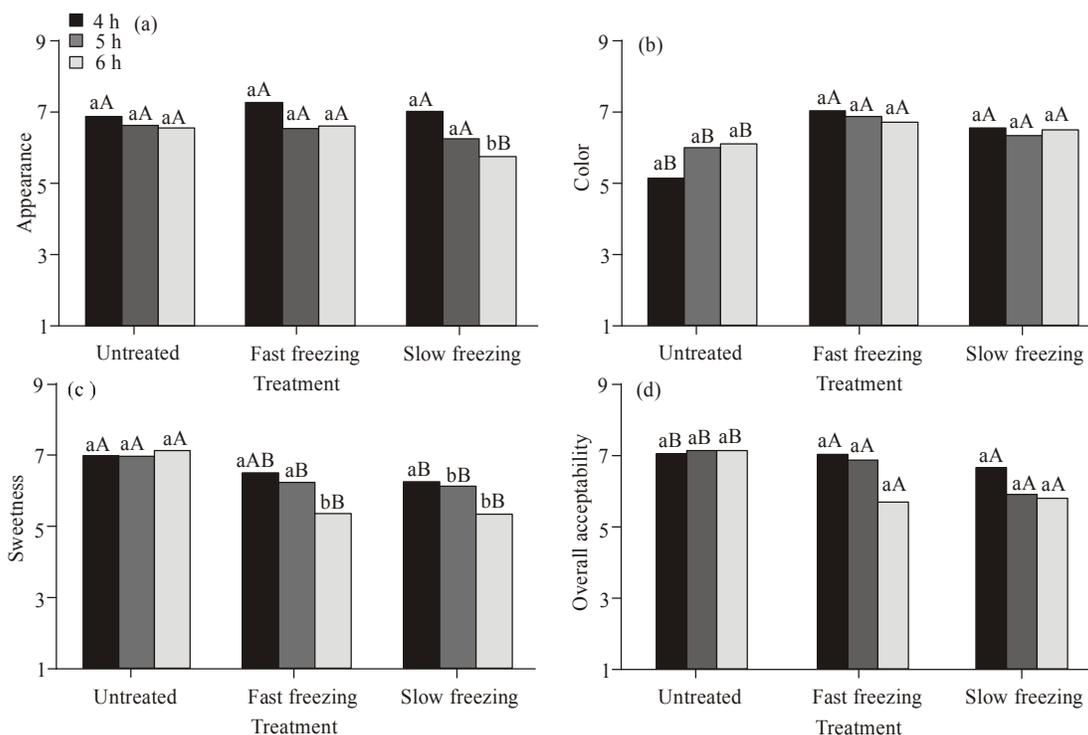


Fig. 5: Effect of freezing pretreatment on sensory attributes of osmodehydrated banana during drying at 70°C : (a) appearance, (b) color, (c) sweetness and (d) overall acceptability; a^* , b^* : Different superscript letters on the bar indicate significant differences ($p < 0.05$) among different drying times for the same sample; A^* , B^* : Different superscript letters on the bar indicate significant differences ($p < 0.05$) among different samples at the same drying time

($p > 0.05$) in appearance among untreated and both freezing pretreated samples during drying period. Except after 6 h drying, the slow freezing sample decreased in appearance score from 7.05 (4 h) to 5.85

(6 h). The possible reason might be due to the sucrose syrup remained on the surface of the sample. The color scores of Fast Freezing and Slow Freezing samples (FF and SF) were significantly ($p < 0.05$) higher than

untreated sample (UT), implying that most panelists preferred the yellow color of the freezing pretreated samples. Most panelists rated the sweetness of freezing pretreated samples (FF and SF) in lower scores ($p < 0.05$) than untreated sample (UT). Although the banana treated by freezing pretreatment was higher in sweet taste, as confirmed by the higher total sugar content in Fig. 3b; nevertheless, panelists felt that the sweetness was over the desirable criteria. It was appeared that overall acceptability of all samples was greatly influenced by the sweetness attribute. However, after 5 h drying, no significant difference ($p > 0.05$) in overall acceptability was observed between untreated (7.05) and fast freezing samples (6.85). Comparing the results obtained from sensory evaluation, it is possible to affirm that sweetness was the most sensorial attribute affecting this product preference. The optimal drying time for the banana treated by fast freezing procedure was found at 5 h.

CONCLUSION

The freezing pretreatment of banana prior to osmotic dehydration was effective to reduce the soaking time at least 1 h compared to untreated sample. The process of freezing, osmotic dehydration followed by drying at 70°C was able to improve the quality of air drying banana slices in term of the color, shrinkage texture. The application of fast freezing as a pretreatment of osmodehydrated banana slices was more accepted than the slow freezing and the optimal condition was found to be 3 h soaking time and 70°C drying temperature for 5 h. Most panelists prefer the yellow color of the banana treated by fast freezing but the panelists felt that the sweetness was over the desirable criteria. Therefore the further research need to use the sucrose solution less than 65°B and optimization the drying time in order to find the best quality products that will be accepted by the consumers.

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