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EFFECTS OF FREEZING AND STORAGE PERIODS ON CHARACTERISTICS OF FROZEN SLICED ARUMANIS MANGO[1)]

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ABSTRACT

Mango is a potential tropical fruit in Indonesia. With its abundant productions, the mango can be relied upon to be one tropical fruit that can compete in international markets. However, like other horticultural products, mangoes are easily damaged hence their shelf life is relatively short and thus limits range of the marketing distribution. Freezing is one way to anticipate the damage to mangoes, and thus have a longer shelf-life. The study aimed to determine the effect of period of immersion in liquid nitrogen and frozen storage on the characteristics of frozen sliced Arumanis mango. Rapid freezing research on sliced ripe mango was conducted in a laboratory using a factorial completely randomized design. The factors studied were four dipping periods in liquid nitrogen (0, 30, 40 and 50 seconds) and four levels of storage periods (0, 1, 2, and 3 months). The results showed that 40-second immersion in liquid nitrogen gave the best characteristics of frozen sliced Arumanis mango after storage for 3 months, i.e. with a pH of 4.9, total soluble solid (TSS) 14.07 °Brix, vitamin C 27.66 mg/ 100 g, total acid 0.46, hue 85.09, chroma 39.57, and sorically are preferred by the panelists. The total plate count (TPC) content was 250 colonies/ml, far below the required standard TPC (100,000 colonies/ml).

[**Keywords**: Mangoes, Arumanis, freezing, frozen storage, quality characteristics]

INTRODUCTION

Mango is a potential horticultural commodity in Indonesia. In 2005, mango production reached 1.4 million tons from 176,000 ha harvest area. The mango production centers were in the district of Indramayu, Majalengka, Cirebon, Pemalang, Blora, Situbondo, Probolinggo, Pasuruan, Buleleng, and Karangasem (Anonymous 2007). However, like other horticultural products, the main problem in mango is fragile, easily damaged, so that it has a relatively short shelf-life. This has resulted in high losses during the main harvest and low prices of mangoes. On the other hand, mango is a seasonal fruit, rarely found at certain times so it does not meet the availability of raw materials for industries engaged in the mango processing.

Rapid freezing is one way to anticipate destruction of mangoes hence they have longer shelf-life. This technology is quite simple, not time consuming, and inhibits the growth of microbes such as bacteria, mold, and the spoiler yeasts. Compared with the heating process, this rapid freezing technology requires relatively shorter time. With the boiling point temperature of -195.8°C, liquid nitrogen has the capacity to freeze organic materials more effectively than ammonia and freon-based cooling. In rapid freezing, the rate of heat evaporation is running fastly, so the amount of crystal nucleus formed is abundant and small. In food freezing, the smaller ice crystals can be distributed evenly hence it does not change the tissue structure (Khadatkar *et al.* 2004).

The storage condition is a factor that determines the quality of frozen fruit products. According to Tressler (1968), storage of frozen products at a temperature of -20°F (-29°C) in Europe can maintain the quality of frozen products during storage. Buckle *et al.* (1987) mentioned that frozen storage at a temperature of -18°C or lower will prevent the products from microbiological damages, if the temperature fluctuation is not wide. Although the number of microbes usually decreases during processing and frozen storage (except spores), it does not mean that the frozen food is sterile, as evidenced by the process of decay in the frozen products.

Broto *et al.* (2002) has studied rapid freezing of ripe mangoes of Gedong variety in various forms and storing period. Rapid freezing of intact or whole mango by the direct immersion method gave no good results. The treatment could not freeze the fruit evenly in a short time. When the immersion time was too long, however, it caused destruction of the fruit, hence the fruit was not consumable and the nutrient losses were very high. Based on the results, the rapid freezing of mango was done in the form of cube cuts with an appropriate attention on the immersion time, thus the mangoes can be frozen evenly and the fruit tissue was not decayed. The study aimed to determine the effect of immersion period and frozen storage period on the characteristics of frozen sliced Arumanis mango.

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MATERIALS AND METHODS

Research was conducted from July to October 2007 in the laboratory of the Indonesian Center for Postharvest Research and Development, Bogor, West Java. Raw materials used in this study were ripe Arumanis mangoes obtained from a farmer's orchard in Cirebon and liquid nitrogen obtained from the PT Aneka Gas, Jakarta. The chemicals used were potassium iodide, starch, sodium hydroxide, oxalic acid, ethanol, indicator papers, PCA medium, and other chemicals for analysis. The tools used were cryocane, freezers, knives, basin, chromometer, hand refractometer, burette, incubators, and glasswares.

Rapid freezing experiments using the mango slices of cv. Arumanis were performed on a laboratory scale by using the factorial in a completely randomized design. The treatment factors were four periods of immersion in liquid nitrogen, i.e. 0, 30, 40 and 50 seconds and three periods of storage, i.e. 1, 2, and 3 months.

Selected ripe mangoes were washed, peeled, and sliced into 2 cm x 2 cm x 2 cm cubes (Broto *et al.* 2002) with a weight of 250 g for each sample. Prior to rapid freezing in liquid nitrogen, the mango samples were soaked in a 1000 ppm $CaCl_2$ solution for 15 minutes. The samples were then rapid frozen by immersing in liquid nitrogen for 30, 40, and 50 seconds, respectively, and packed in PE plastics and kept in a freezer at -30°C for 3 months. Diagram of rapid freezing of mango slices applied in this study is presented in Figure 1. Before testing the frozen mango slices, samples were taken from the freezer and thawed by defrosting in a microwave oven for 10 minutes.

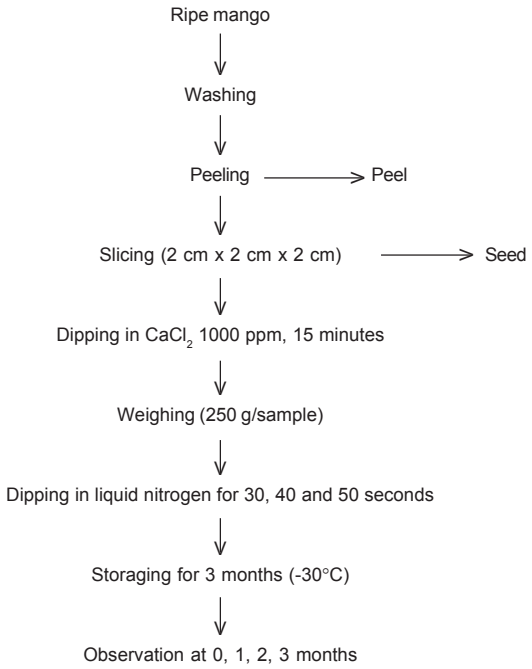


Figure 1. Frozen sliced mango production process.

Observation were done on the chemical characteristics of the samples, including pH using a pH meter, total soluble solids (TSS) using a hand refractometer, vitamin C content using the titration method of AOAC (1995), total acid content using the titration method of AOAC (1995), physical quality of the color using a chromometer, total number of microbial contaminants using the plate count method of Fardiaz (1992), and organoleptic or hedonic test of the flavor, taste, color and overall performances of the product based on five scales, i.e. 1 = very dislike; 2 = dislike; 3 = slightly prefer, 4 = like, 5 = very like.

RESULTS AND DISCUSSION

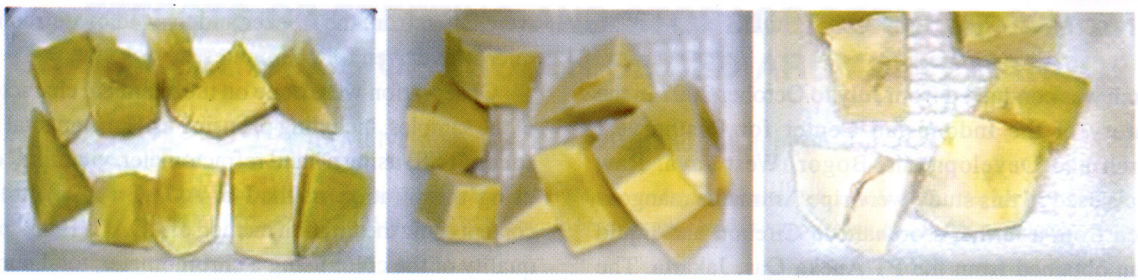
Result of the rapid freezing of the sliced Arumanis mango in liquid nitrogen at different immersion periods is shown in Figure 2. Immersion of sliced mango fruits for 40 seconds in the liquid nitrogen gave an optimum result with a complete freezing of the fruit tissues evenly. Immersion for 30 seconds resulted in incomplete freezing, particularly in the inner part of the fruit tissues, wherein immersion for 50 seconds resulted in cracking of the mango tissues. The freezing process affected characteristics of the frozen sliced mango as described below.

Chemical Quality

Vitamin C content

One of the most important indicators in frozen fruit quality is the vitamin C content. Changes in the vitamin C content in the frozen sliced mango higher than in other treatments was found after 3 months of storage, i.e. 27.66 mg/100 g. Immersion of the sliced mango for 40 seconds gave the best results with the smallest decrease in vitamin C content during storage (Table 1).

Ice crystal formation plays a very important role during the freezing. Number and size of the ice crystals greatly affect quality of the products, and the process of crystal core or crystal nucleus formation is directly affected by size of the ice crystals. In the slow freezing, the heat evaporation rate is slow so that the number of crystal nucleus formed was very small and will develop into bigger shapes. On the contrary, when the formation of crystal nucleus was fast, the rate of heat evaporation was also fast, hence the number of crystal nucleus was large and the crystal size was small. In food freezing, the formation of small and evenly distributed ice crystals is highly expected (Khadatkar *et al.* 2004).



Dipping for 30 seconds Dipping for 40 seconds Dipping for 50 seconds

Figure 2. Performance of frozen sliced Arumanis mango treated with different periods of dipping in liquid nitrogen.

Table 1. Vitamin C content of frozen sliced Arumanis mango treated with different dipping times in liquid nitrogen and storage periods.

Dipping period (second)	Vitamin C content (mg/100 g) at storage month			
	0	1	2	3
0	58.59c	57.99c	35.83b	24.01a
30	59.80c	51.50c	36.17ab	22.66a
40	57.27c	53.13c	31.11ab	27.66ab
50	58.88c	61.46c	32.69ab	27.66ab

Numbers with the same letters in the same columns and rows are not significantly different at 5% DMRT.

The high vitamin C damage in sliced mangoes frozen for 30 seconds may be due to the unoptimally freezing time so that the formation of ice crystals was not evenly distributed. This has led to the oxidation of the vitamin C. The presence of mango flesh that has not been frozen caused difference in temperatures in the respective mango flesh that triggers the occurrence of oxidation reaction and enzyme activity. Visually, part of the mango flesh that has not been frozen had a darker color than that of the frozen flesh due to the browning process as an indication of the oxidation reaction and enzyme activity.

The thawing process can also cause damage to vitamin C. Differences in storage temperatures and thawing caused destruction of vitamin C because of the oxidation process. Vitamin C is in the form of L-ascorbic acid and oxidized into L-dehydroascorbate, and both still have the activity of a vitamin C (Lee and Kader 2000). However, L-dehydroascorbate is chemically more labile in nature, so that it could change further into L-diketogluconate that does not have the vitamin C activity anymore. Change in water phase from solid to liquid during thawing also causes vitamin C which is very easily soluble in water will go missing. It is also found in a study conducted by Sahari *et al.* (2004) that store frozen strawberry fruits for 3 months. Ziena (2000) also reported the same thing on the storage of frozen orange juice for a month.

Total acid content and pH

Total acid content and pH illustrate changes in fruit acidity and fruit quality. High total acid content is followed with high fruit acidity, which is indicated by low pH. The changes in total acid content and pH in the stored product is presented in Figure 3. Statistical analysis showed that the interaction between time of immersions in liquid nitrogen and time of storages were not significantly different. The interaction between immersion period in liquid nitrogen and storages after 0 month (control) on the total acid contents was not significantly different. After 1-3 month storage, however, the decreases in total acid content of the different products were significantly different from those stored for 0 month (control). In treatment of immersion for 40 seconds, the changes in total acid contents during storage were relatively stable, and followed also with the most stable pH conditions (initial pH 4.3 and final pH 4.9), when compared with other treatments. The highest pH value (5.33) was found in the

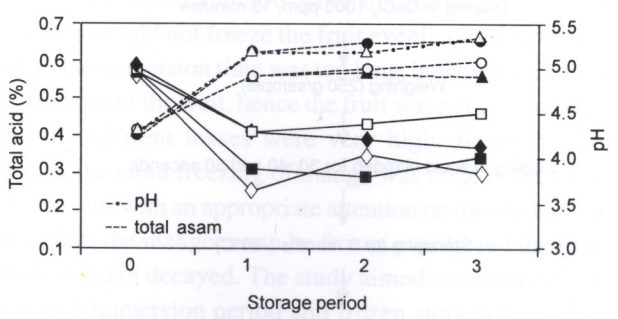


Figure 3. Change in total acids and pH of frozen sliced Arumanis mango.

combination between 0 second immersion and 3 month storage. Result of this treatment was not significantly different from the frozen mango slices immersed in liquid nitrogen for 30 and 50 seconds.

Changes in the total acid contents and pH were due to the changes in organic acid contents in the products. According Sahari *et al.* (2004), these changes could be influenced by storage period, enzymatic reaction, and microbiological changes. Urbany and Horti (1992) reported that the freezing method affected the pH value. A similar statement was made by Sahari *et al.* (2004) that have done slow freezing of strawberries at -12°C; pH of the products was increased upon storage with the highest value of >3.4, thus induced the anthocyanin damage in the fruits.

Total soluble solids

The interaction between time of fruit immersion in liquid nitrogen and storage period gave a significant effect on the TSS of the frozen mango slices (Table 2). During the freezing and storage processes, physical and chemical changes occurred in the fruit including loss of water and soluble solids (Chiralt *et al.* 2001). During storage, TSS of the sliced mango decreased after storing for 3 months. Broto *et al.* (2002) reported a similar result that there was a decrease of TSS in the sliced mango of cv. Gedong Gincu after storing for a month. The losses of nutrient component in the frozen mango slices of cv. Arumanis during the freezing and storage can be caused by the decrease in the TSS.

Table 2. Total soluble solid (TSS) of frozen sliced Arumanis mango treated with different dipping times in liquid nitrogen and storage periods.

Dipping time (second)	TSS (°Brix) at different storage periods (month)			
	0	1	2	3
0	16.00ab	15.40ab	15.67ab	14.80ab
30	16.00ab	14.03b	14.63ab	14.2ab
40	16.20b	14.60ab	14.40ab	14.07ab
50	15.99b	15.40ab	14.60ab	14.13ab

Numbers with the same letters in the same columns and rows are not significantly different at 5% DMRT.

Interaction between the time of immersion and storage period gave a significant effect on the hue (H°) and chroma (C*) values of the frozen mango slices of cv. Arumanis. The interaction between immersion for 40 seconds and storage for 3 months showed that the hue value was significantly different than the other treatments. In the Cartesian diagram (Anonymous 2003), the range of angle H° between 0° and 90° are shown red, orange and yellow colors; the angle between 90° and 180° are shown in yellow, yellow-green, and green colors; the angle between 180°-270° are shown in green, cyan, and blue colors; the angle between 270°-360° are shown in blue, purple and magenta colors, and then return to red color at the 360° angle. Whereas the chroma values are the composition of color indices of red ($a > 0$), green ($a < 0$), yellow ($b > 0$), and blue ($b < 0$).

The hue and chroma values of the frozen sliced mango of cv. Arumanis continued to decline during storage, with its respective range of index values between 92.86-83.27° and 77.62-37.66°. After 3 months of storage, chroma values of the products were between 37.66-42.53 and the hue angle were between 83.27° and 85.09° (Table 3), indicating the biggest hue angle of 85.09º and the smallest changes in the hue value during the storage. In this composition (H° = 85.09° and C* = 39.57), the product performance appeared in bright yellow color, which is brighter than the other products (L* C* H° color system in the Minolta Chroma Meter CR 300/301).

This color change was probably occurred due to the browning reaction that proceed oxidative and enzymatically. Research results of Calligaris *et al.* (2002) showed that during frozen storage of the tomato puree at -7°C and -18°C,

Table 3. Hue and chroma values of frozen sliced Arumanis mango treated with different dipping times in liquid nitrogen and storage periods.

Dipping time (seconds)	Storage period (month)							
	0		1		2		3	
	Hue (H°)	Chroma	Hue (H°)	Chroma	Hue (H°)	Chroma	Hue (H°)	Chroma
0	92.54fghi	77.62d	90.73d	67.48bcd	89.43c	76.02cd	83.27a	42.53a
30	91.89defgh	65.53d	91.38def	55.48b	93.91i	58.71b	83.60a	39.99a
40	92.65ghi	64.70bc	92.12efghi	55.71b	92.86hi	64.52bc	85.09b	39.57a
50	91.62defg	63.89bc	91.00de	66.58bcd	90.90de	66.63bcd	83.36a	37.66a

Numbers with the same letters in the same columns and rows are not significantly different at 5% DMRT.

the lipoxygenase enzyme activity is still ongoing, but it was declined drastically during 4 month storage. Lisiewka and Kmiecik (2000) also explained that the activities of peroxidase, catalase, and lipase enzymes were still present in the frozen slices of tomato fruit stored at -20°C and -30°C.

Brightness

Statistical analysis showed that the interaction between immersion time and storage period gave a significantly different effect on the brightness of the frozen sliced mango of cv. Arumanis (Table 4). The fruit brightness decreased during storage. Rapid freezing for 50 seconds resulted in the lowest brightness value after 3 month storage, i.e. 55.85. The decrease in brightness value of frozen sliced mango during storage was presumably due to enzymatic reactions that cause the color becomes darker.

Sensoric Quality

Sensory assessment was done by using a hedonic test on taste, color, flavor, and appearance parameters. Results of organoleptic test at 3 months after storage are presented in Table 5. In general, the panelists accepted the frozen sliced mango of cv. Arumanis that have been frozen in the liquid nitrogen. The acceptance levels were ranging from 3.3 to 3.7 (does not like to moderately like). Immersion time did not give a significant effect on the acceptance of taste, aroma, and appearance of the Arumanis mango slices. The highest acceptance value for the flavor (3.7) was found on treatment with 50 second immersion in liquid nitrogen.

In general, the panelists still liked the color of the frozen sliced mango of cv. Arumanis. Its acceptance values ranged from 3.2 to 3.7 (moderately like to like). The highest response was obtained from Arumanis mango slices frozen for 40 seconds, while the lowest response was from mango slices frozen slowly. The low acceptance value for the color of slow frozen sliced mango was associated with the slow freezing process, which promotes the activity of enzymes in the product that change the color becomes darker.

In frozen fruits and vegetables, the color changes are associated with biochemical or physicochemical mechanisms, i.e. (1) changes in content of natural pigments in the fruit and vegetable tissues (chlorophyll, anthocyanin and carotenoids); (2) changes due to enzymatic browning; (3) breaking off tissues of chloroplast and chromoplast cells; and (4) existence of oxidative reactions (Cano 1996). On frozen slices of mango fruits, the color changes can occur due to enzymatic and oxidative browning reactions that cause the product becomes darker in color. The panelist assessment on their favorite color of frozen mango slices of cv. Arumanis was in line with the changes in the brightness, as well as in the hue and chroma values.

The values of aroma acceptability of the frozen sliced mango by the panelists were in the range of 3.0-3.4 (moderately like). The highest aroma acceptability value was obtained from frozen sliced mango treated with 50 second dip freezing in the liquid nitrogen, whereas the lowest values were those frozen for 30 and 40 seconds. Freezing affected the flavor and aroma of the products due to the fast decomposition or the occurrence of ester diffusion processes. Dehydration that occurred during the kiwi fruit freezing has caused changes in formation of ester compounds and decreases in aldehyde and alcohol compounds, resulting in changes in profiles of the folatil components (Talens *et al.* 2003). According to Young and Paterson (1985), the folatil component changes in the dehydrated kiwi fruit have in common with changes in the process of fruit ripening, i.e. decrease in aldehyde compounds (trans-2-hexenal) and increase in ester compounds. Freezing strawberry fruits reduced their aroma and resulted in off flavor (Deng and Ueda 1993).

Performances of the frozen sliced mango of cv. Arumanis were still preferred by the panelists with a range of 3.2-3.6 preference values (medium preference). The

Table 4. Brightness of frozen sliced Arumanis mango treated with different dipping times in liquid nitrogen and storage periods.

Dipping time (second)	Brightness at storage month			
	0	1	2	3
0	78.02d	65.79c	64.01	56.35ab
30	64.88c	62.84bc	62.62abc	56.64ab
40	64.88c	63.06bc	62.51abc	56.62ab
50	64.24c	66.15c	64.24c	5585a

Numbers with the same letters in the same columns and rows are not significantly different at 5% DMRT.

Table 5. Sensory scoring of frozen sliced Arumanis mango after storage for 3 months.

Dipping time (second)	Scoring			
	Taste	Color	Aroma	Performance
0	3.3a	3.2a	3.3a	3.2a
30	3.5a	3.5a	3.0a	3.4a
40	3.5a	3.7a	3.0a	3.6a
50	3.7a	3.4a	3.4a	3.3a

Numbers with the same letters in the same columns and rows are not significantly different at 5% DMRT.

lowest panelist preference (3.2) was obtained in the treatment by freezing for 50 seconds and the highest (3.6) was in treatment by freezing for 40 seconds. In general, appearance of the product was still quite good and did not show considerable damages. Based on overall evaluation of the sensory quality parameters, the frozen slices of Arumanis mango with 40 and 50 seconds dipping in liquid nitrogen had the best acceptance response by the panelists.

Microbiological Analysis

Microbiological analysis of the frozen mango slices showed that the total microbial population was far below the standard requirement for frozen vegetables (Table 6). The standard frozen vegetables required a minimum total plate count (TPC) value of 10^5 colonies/ml. Some microorganisms that grow at low temperatures, such as fungi *Cladosporium* and *Sporotrichum* are able to grow at -6.7°C, while *Penicillium* and *Monilia* grow at -4°C. In addition, there are some yeast species that grow at -34°C (Kumalaningsih and Hidayat 1995). Contaminations by *Listeria monocytogenes* in chicken breast, bacon, spinach, cheese, and fish were decreased to 100 colonies/ml after storage at -18°C for 240-300 days. Beside *L. monocytogenes*, other microbes resistant to low storage temperatures are *Bifidobacterium bifidum* that is still survive at -25°C (Kebary 1996) and *Lactobacillus acidophilus* at temperature of -30°C (Foschino *et al.* 1992; Gianfranceschi and Aurelli 1996).

Defrosting also strongly affects the microbial life. Rapid warming will kill the microbes. Besides, rapid cooling of microbe cells from their optimal temperatures to low temperatures may also cause microbial death; this is known as cold shock. This condition is related to the lipid changes in cell membranes that damage the cell permeability or inhibit the enzyme activities, such as the ribonuclease inhibitors (Kumalaningsih and Hidayat 1995).

Table 6. Total plate count of frozen sliced Arumanis mango after storage for 3 months.

Dipping period (second)	Total plate count (colony/ml)
0	8200a
30	14000a
40	250a
50	1900a

Numbers with the same letters in columns and rows are not significantly different at 5% DMRT.

CONCLUSION

Dipping period in liquid nitrogen and storage period at -30°C affected quality of frozen sliced mango fruits of cv. Arumanis. Dipping for 40 seconds in the liquid nitrogen gave the best quality when the frozen sliced mango was stored for 3 months. It had a pH of 4.9, total soluble solid (TSS) 14,07 °Brix, vitamin C content 27.66 mg/100 g, total acid 0.46%, and yellow color with a 56.62 brightness, hue value 85.09, chroma value 39.57; and based on taste, aroma, and color, the product was preferred by the panelists. TPC of the product after 3 month storage was 50 colonies/ml, far below the standard requirement (100,000 colonies/ml).

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