Songklanakarin J. Sci. Technol.
34 (5), 517-523, Sep. - Oct. 2012

SJST SONGKLANAKARIN JOURNAL OF SCIENCE AND TECHNOLOGY
http://www.sjst.psu.ac.th

*Original Article*

# Freezing characteristics and texture variation after freezing and thawing of four fruit types

Arpassorn Sirijariyawat and Sanguansri Charoenrein*

*Department of Food Science and Technology, Faculty of Agro-Industry,*
*Kasetsart University, Chatuchak, Bangkok, 10900 Thailand.*

Received 14 November 2011; Accepted 19 July 2012

## Abstract

One major problem with frozen fruits is a loss of texture. Therefore this study investigated the effects of the freezing process on the freezing profiles, texture, and drip loss of apple, mango, cantaloupe, and pineapple fruit samples. All frozen-thawed fruits varied in these three properties because of diversity in the fresh fruits. Mango had the highest total soluble solids content and the lowest freezing point, whereas pineapple showed the highest freezing rate. The highest firmness and crunchy texture were found in fresh apple, and these properties were absent in the other fresh fruits. The firmness of all frozen fruits significantly decreased by different percentages as compared to those of the fresh fruits. The drip loss of each fruit type was also significantly different with apple samples having the highest firmness decrease and drip loss. This study shows that freezing characteristics and frozen fruit properties depend on type of fruit.

**Keywords:** freezing, fruit, freezing rate, texture, drip loss

## 1. Introduction

The use of the freezing process to increase the length of fruit viability has gained widespread attention since the reduction of available water due to ice crystal formation and subzero temperatures provides an environment which favors reduced chemical reactions leading to increased storage stability (Zaritzky, 2006). However, freezing is not a perfect method of preservation since even at low temperatures food quality deterioration may still occur. The formation of ice can result in textural changes and disruption of cell compartments causing the release of chemically reactive components (Lim *et al.*, 2004).

Due to the high water content of many fruit types, fruits are one of the most difficult of all food products to freeze without causing changes in appearance, texture, flavor, and color of the freeze-thawed product. In particular, one major effect of fruit freezing is a loss of tissue firmness (Coggins and Chamul, 2004), but the related loss of water holding capacity can also be a problem for many types of frozen fruit. Fruit samples which exhibit excessive drip loss on thawing may lack the proper juiciness when chewed leading to a perceived reduction in fruit quality (Kerr, 2004).

The effects of the freezing process on many fruit types have already been reported. For example, Marin *et al.* (1992) examined the chemical and biochemical changes in mango after air blast freezing at -40°C and during storage at -18°C for a 4 month period. They found that freezing mango slices did not lead to changes in moisture content or soluble solids content, however, the titratable acidity of the slices decreased due to the freezing process. Bartolomé *et al.* (1996) studied the sugar content and composition of pineapple after being frozen and stored in a cold room at -18°C for a 12 month period. They reported that freezing the pineapple fruit slices led to minimal changes in soluble solids and sugar content (fructose, glucose and sucrose) after 1 year of frozen storage. Simandjuntak *et al.* (1996) studied changes in the composition, drip loss and color of cantaloupe and honey

---

* Corresponding author.
Email address: fagisscr@ku.ac.th

dew melon stored for 5 and 10 months at -23°C. They reported a negative correlation between drip loss and total neutral sugar content and a positive correlation between drip loss and the pectin fraction yield as storage time increased. Jie *et al.* (2003) measured the freezing points (during freezing at -30°C) and soluble solids of 11 types of fruit. They found a high negative correlation between soluble solids and freezing point. Chassagne-Berces *et al.* (2009) reported the effects of three different freezing protocols (at -20°C, -80°C and -196°C) on the mechanical properties of apple cylinders. They found that freezing at -20°C and being immersed in liquid nitrogen were the protocols which most affected the fruit texture. Studies on the effect of the freezing process on the quality of strawberry (Delgado and Rubiolo, 2005; Modise, 2008), muskmelon (Maestrelli *et al.*, 2001), raspberry (Antonio, 2003), and kiwi (Talens *et al.*, 2003) have also been reported. These diverse studies show that the freezing process has both chemical and physical effects on the properties of frozen fruits. However, most previous research studies examined only one type of fruit. Consequently, the comparison of results between the different research projects is complicated because of the variation in preparation and analytical methods of each research.

Therefore, the objective of the present work was to consistently investigate the freezing point and freezing rate of several fruits (apple, mango, cantaloupe, and pineapple) and the effect of the freezing process on the texture of these frozen fruits.

## 2. Materials and Methods

### 2.1 Raw materials

Apples (cv. Fuji), mangoes (cv. Nam Dok Mai), cantaloupes (cv. Sunlady), and pineapples (cv. Smooth Cayenne) were purchased from the Si Mum Muang central market in Bangkok, Thailand, during February to March 2010. The fruits were selected for uniformity in size, maturity based on the peel and flesh color, and total soluble solids content. The measured total soluble solids contents at 25°C were in the ranges of 11–14 °Brix for apples, 16–19 °Brix for mangoes, 9–11 °Brix for cantaloupes, and 13–15 °Brix for pineapples.

### 2.2 Sample preparation

Twenty percent of the total fruit length from the stem and blossom ends of each fruit was discarded since these segments are known to have highly diverse fruit properties, particularly the firmness and sweetness. Only the central segments of the fruit samples were used to help minimize variation within the samples. All of the fruit samples were washed, peeled, cut into 1.5 cm cubes and packed in plastic bags.

### 2.3 Freezing and thawing process

Thermocouples (K type, Omega engineering, USA.) were inserted into the center of the fruit cubes and adhesive tape was used to fix the thermocouples. All of the fruit cubes were frozen at -40°C in a cryogenic freezer (Minibatch 1000L, Bangkok Industrial Gas Co., Thailand), which allowed the flow rate of liquid nitrogen to be adjusted, until the central temperature of the samples reached -25°C. The frozen samples were then stored at -18°C in a chest freezer (Sanyo refrigerator, model SF-C1497, Japan) for 30 days before being thawed at 8°C in a low temperature incubator (Low Temperature Incubator, IPP400, Memmert, Germany) prior to the analysis of the frozen-thawed samples. The central temperature of the fruit cubes during the freezing and thawing process were recorded every 1 min using the thermocouples and a data logger (Presica 2002). The central temperatures, which were the sample's warmest point, were recorded for two sample cubes in each replication. The experiments were repeated twice.

The approximate initial freezing points for all of the fruit samples were estimated from the freezing profile, using the first obviously observed change in slope. The freezing rate of the samples was expressed as the rate of temperature decrease from the initial temperature (25°C) to -18°C per minute (°C/min) (adapted from Chassagne-Berces *et al.*, 2010).

### 2.4 Moisture content and total soluble solids content

The moisture contents of all of the fresh fruit samples were analyzed by drying the samples in a vacuum oven at 70°C until the samples reached a constant weight (AOAC., 1999). For the total soluble solids content, the fresh fruits were first blended and then crushed through cheesecloth. The total soluble solids were then measured from the resulting fruit juices using a hand refractometer (Digital Hand-held Pocket Refractometer, PAL-1, Atago, Japan). The measurements were done in triplicate for each treatment.

### 2.5 Texture

The texture of the fresh and frozen-thawed samples was determined using a Texture Analyzer (TA.XT2, Stable Micro Systems, UK) with a 36 mm cylindrical flat head probe (P36). The firmness was measured using a compression of 50% strain and a compression rate of 1 mm/s. The maximum peak force was expressed as a firmness value in Newton. Ten pieces of fruit were tested for each treatment. The firmness decrease was calculated using the following equation:

$$\text{Firmness decrease (\%)} = (F_i - F_f) \times 100 / F_i$$

where $F_i$ is the firmness of the fresh fruit cubes, and $F_f$ is the firmness of the frozen-thawed fruit cubes.

### 2.6 Drip loss

The drip loss of the frozen samples was measured using the method outlined by Lowithun and Charoenrein (2009). Four frozen sample cubes were laid over absorbent paper and placed into a double layered zip lock plastic bag to eliminate evaporation during thawing. Then the samples were thawed at 8°C. The drip loss was measured by periodically weighing the absorbent paper until a constant value was reached. The measurements were done in triplicate for each treatment and the results were calculated using the following equation:

$$\text{Drip loss (\%)} = (W_t - W_0) \times 100 / W_s$$

where $W_0$ is the weight of the absorbent paper prior to thawing, $W_t$ is the weight of the absorbent paper after thawing and $W_s$ is the weight of the sample.

### 2.7 Statistical analysis

The collected data were analyzed using a one-way analysis of variance with SPSS for Windows. Duncan's multiple range test was used to compare the means ($p<0.05$).

## 3. Result and Discussion

### 3.1 Freezing point and freezing profile

The temperature of each fruit sample was recorded during the freezing process at -40°C. The freezing profiles of the four types of fruit are shown in Figure 1. The approximate initial freezing points of all of the fruits were estimated from the freezing profile, where the first clear change in slope was observed. The initial freezing points of all of the fruit samples were in the range of -1.6 to -3.0°C (Table 1). Some previous reports on the initial freezing point of fruits found values between -2.20 to -2.32°C for apple (Jie *et al.*, 2003) and -1.4 to -2.0°C for pineapple (Hayes, 1987). These values were slightly different from our freezing point results (-1.6 and -2.1°C for apple and pineapple, respectively). These slight differences are most likely due to diversity in fruit varieties or environmental differences in fruit cultivation which could affect the chemical composition of fruits especially the total soluble solids content.

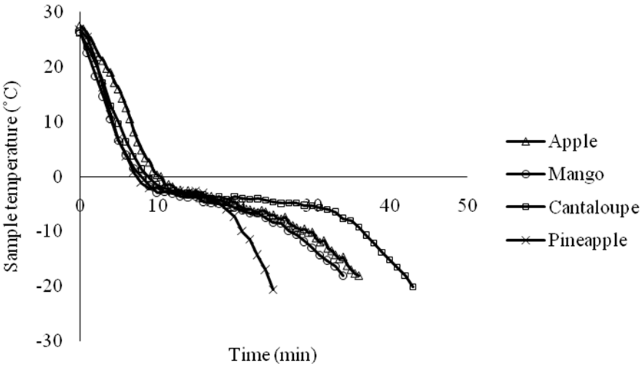


Figure 1. Freezing profile of fruit samples frozen at -40°C. The temperature of two sample cubes was recorded for each replication. The data were averaged from 2 replications.

For these four fruits, mango displayed the lowest initial freezing point (-3.0°C) followed by pineapple (-2.1°C), with the others showing a similar value (-1.6°C). The total soluble solids of these four fruits were also significantly different ($p<0.05$). The highest total soluble solids value was found in mango followed by pineapple, then apple, and cantaloupe. Higher total soluble solids contents imply higher sugar contents which result in a lower freezing point. From these results, the initial freezing points seem to have a negative relation to the total soluble solids content of the fruit samples. Similar findings were reported by Jie *et al.* (2003). They reported a high negative correlation between the total soluble solids of 11 fruits and the freezing point values. However, the differences in freezing points of the various fruits may also be due to factors other than the total soluble solids content including the type of sugar used, sugar content, and acid content.

A correlation between freezing points and total soluble solids content had previously been reported by Chen *et al.* (1990) and Auleda *et al.* (2011). Chen *et al.* (1990) studied the depression of the freezing points of mixed solutions of sugar and acid at various concentrations (0–60 °Brix). Their results showed that the freezing points of these solutions decreased as concentrations (°Brix) increased. Most notably, the freezing point values decreased for concentrations higher than 30 °Brix. Auleda *et al.* (2011) studied the freezing point of apple juice, pear juice and peach juice at various concentrations within the range of 10–40 °Brix. Their results confirmed that the freezing point values of the juices decreased with increasing concentrations. However, their studies were carried out in fruit juice systems with the addition of sugar and acid, while our study used four fresh fruits.

### 3.2 Freezing rate

The freezing rates of the tested fruits are shown in Table 1. These results show that pineapple had the highest freezing rate ($p<0.05$) and cantaloupe had the lowest. The compositions of the fruit initial moisture contents were found to have a significant effect on the freezing rate. Previously it had been found that food products with higher initial freezing points, lower initial water contents and higher unfreezable water contents had shorter freezing times (Hsieh *et al.*, 1977). For that reason, the higher moisture contents of the cantaloupe samples were most likely what caused the lower freezing rate (Table 1).

The apple and pineapple samples had similar moisture content values but pineapple was found to have a significantly higher freezing rate ($p<0.05$) than that of apple. Differ-

Table 1. Properties, freezing rate, and initial freezing point of the apple, mango, cantaloupe and pineapple samples.

| Fruit | Moisture content (g/100g sample) | TSS (°Brix) | Freezing rate (°C·min$^{-1}$) | Initial freezing point (°C) |
|---|---|---|---|---|
| Apple | $86.54^{b}\pm0.70$ | $12.9^{b}\pm0.03$ | $1.3^{a}\pm0.1$ | -1.6 |
| Mango | $82.43^{a}\pm0.60$ | $17.6^{d}\pm0.34$ | $1.3^{a}\pm0.2$ | -3.0 |
| Cantaloupe | $91.64^{c}\pm1.12$ | $10.0^{a}\pm0.00$ | $1.0^{a}\pm0.1$ | -1.6 |
| Pineapple | $85.61^{b}\pm0.87$ | $13.9^{c}\pm0.04$ | $1.9^{b}\pm0.2$ | -2.1 |

Data are recorded as the mean ± standard deviation as measured from 2 replications. In each column, values followed by different letters are significantly different ($p<0.05$).

ences in thermal conductivity are another explanation for the different freezing rate values. Pineapples have been reported to have higher thermal conductivity values than that of apples at 28°C with a moisture content of 84.9% (Sweat, 1974). These data could possibly explain the slower decrease in temperature of the apple cube samples as compared to the pineapple cubes during the cooling above the initial freezing point (Figure 1). Moreover, the lower density values of the apple samples probably also further reduced the thermal conductivity because of voids in the fruits (Sweat, 1974).

In comparison between mangoes and pineapples, the freezing rate of mango samples was significantly lower ($p<0.05$) than that of pineapples even though the mangoes had a slightly lower moisture content. Laohasongkram *et al.* (1995) reported that the thermal conductivity of mangoes (for moisture contents in the range of 79–81%) at -18°C was 0.925 W/m·°C whereas the thermal conductivity of pineapple (for moisture contents in the range of 80–85%) at -18°C was 1.11 W/m·°C (Chaiwanichsiri *et al.*, 1996). The high thermal conductivity of pineapples supports the difference in freezing rate between these two types of fruit.

## 3.3 Firmness

The firmness of both the fresh and frozen-thawed fruits was measured using a compression test (Table 2). This compression test is a general measurement of the deformability of the tissue taken as a whole (Bourne, 2002). In order to better understand the texture of all four fruit types, the texture profiles of both the fresh and frozen-thawed fruits are shown in Figure 2.

The firmness values of all the fresh fruit samples were significantly different ($p<0.05$) from each other. The fresh apple samples had the highest firmness values, follow by cantaloupe, pineapple, and the lowest firmness value was found for mango. With respect to texture profiles, the fresh apple and cantaloupe samples had the highest maximum peak force which indicates that these fruits have a firm texture, whereas the fresh mango profile showed a low maximum peak force which indicates a soft texture. The texture profile of the fresh apple samples also showed a large number of small fracture peaks which indicates the samples had a rigid and crunchy texture. These textural properties were not found in the other fruits (Figure 2).

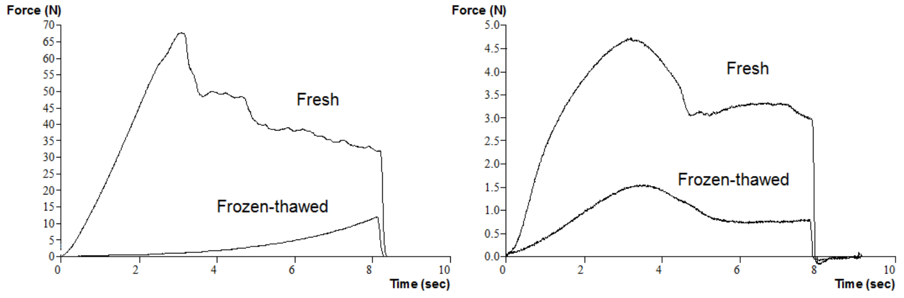
The firmness values of all of the frozen-thawed fruit samples decreased with respect to that of the fresh fruit samples (Table 2). During freezing, the water in the samples partially formed ice crystals which negatively damaged the cellular integrity of the cellular compartments reducing the turgor pressure and firmness values of the samples.

The type of fruit also exhibited an effect on %firmness decrease after the freezing and thawing process. For apple,

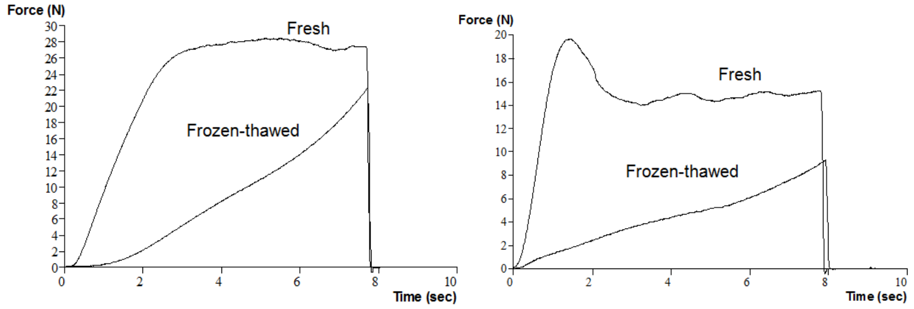
Table 2. Drip loss and firmness of both fresh and frozen-thawed apple, mango, cantaloupe and pineapple cubes.

| Fruit | Firmness (N) | | Firmness decrease (%) | Drip loss (%) |
|---|---|---|---|---|
| | Fresh | Frozen-thawed | | |
| Apple | $68.81^{d}\pm1.41$ | $11.10^{b}\pm0.69$ | $83.87^{d}\pm0.66$ | $44.04^{d}\pm1.48$ |
| Mango | $4.77^{a}\pm0.18$ | $1.61^{a}\pm0.24$ | $66.32^{c}\pm3.75$ | $18.70^{a}\pm2.16$ |
| Cantaloupe | $27.61^{c}\pm2.20$ | $21.66^{c}\pm1.90$ | $21.58^{a}\pm0.60$ | $26.71^{b}\pm1.33$ |
| Pineapple | $18.37^{b}\pm2.77$ | $9.10^{b}\pm0.27$ | $49.97^{b}\pm6.12$ | $38.00^{c}\pm1.51$ |

Data are recorded as the mean ± standard deviation from 2 replications. In each column, values followed by different letters are significantly different ($p<0.05$). Ten and four sample cubes were used for the firmness and drip loss measurement, respectively.



**(a) Apple** **(b) Mango**



**(c) Cantaloupe** **(d) Pineapple**

Figure 2. Texture profiles of both fresh and frozen-thawed (a) apple cubes, (b) mango cubes, (c) cantaloupe cubes, and (d) pineapple cubes, respectively. Ten sample cubes were used for each measurement. The experiments were done in 2 replications.

the frozen-thawed samples showed the highest level of %firmness decrease after freezing and thawing ($p<0.05$) in spite of fresh apple having the highest firmness level. This result is most likely due to the rigid structure, high firmness value, and crunchiness of fresh apple in comparison with the other fruits.

The freezing and thawing process affected both the maximum peak forces and the texture profiles of all of the fruit samples. For the frozen-thawed samples, the change in texture profiles of the apple, cantaloupe, and pineapple samples followed the same trend (Figure 2a, 2c, and 2d), while a dissimilar texture profile was found for frozen-thawed mangoes (Figure 2b). For the three similar texture profiles, the force was found to increase with increasing time or distance of compression and showed a maximum peak force at the end of the compression process. This phenomenon implies that there was no turgor force from tissue layers during the compression of the probe on the fruit cubes. The maximum force resulted from the compression of the damaged tissues caused by the freezing and thawing process. In the case of the frozen-thawed mango, the maximum peak force decreased in comparison with that of fresh mango; however, the texture profiles of both mango samples showed the same trend with the maximum peak force in the middle of the compression process. After that the force decreased and tended to be rather constant through to the end of the compression. Most likely some mango tissues were destroyed by the freezing and thawing process, but some of the tissues still had turgor pressure to resist the compression force from the probe. Our results show that fresh fruits with firm textures tend to have less resistance to deterioration by ice crystals during freezing and thawing than fresh fruits with a soft texture.

These types of effects of the freezing process on fruit texture have not been previously reported. However, reductions in firmness values subsequent to freezing and thawing of apple, mango, melon, and pineapple have been reported. The study of Maestrelli *et al.* (2001) also reported on the effect of freezing using an air blast freezer at -48°C on the texture of muskmelon spheres. Their results showed that the freezing process caused a 30% reduction of the maximum forces of cultivar Rony, while it did not influence those of cultivar Mirado. They confirmed that the effects of freezing on texture of these two melon cultivars were quite different. Ramallo and Mascheroni (2010) reported on the firmness and turgor loss of pineapple induced by ice crystal formation during freezing at -31.5°C. Chassagne-Berces *et al.* (2010) studied the effect of freezing on the texture of frozen apple and mango cylinders (1.2 cm in diameter and 2 cm in height). They found that the impact of the freezing protocol (-20°C vs -80°C, and immersion in liquid nitrogen) was much higher for apple than for mango. They suggested that their results could be related to differences in the textures of apple and mango in the fresh state. This finding is similar to the texture results for frozen apple and mango found in our study.

### 3.4 Drip loss

The ice crystals which form during the freezing process are known to damage fruit cells. Then during the thawing process, liquid can leak from the interior to the exterior of the cells resulting in drip loss. Different types of fruit have different levels of drip loss with our results showing that the drip loss after being frozen-thawed was not related to the % firmness decrease after being frozen-thawed (Table 2). Also the drip losses of all four fruit types were significantly different ($p<0.05$) from each other. Subsequent to freezing and thawing, apple showed the highest drip loss and mango had the lowest value. The reason for this is most likely due to the severe damage in the apple tissues after freeze-thawing. The drip loss of the frozen-thawed mango also showed a significantly lower value ($p<0.05$) than that of cantaloupe and pineapple. These differences in drip loss were most likely due to the high moisture content of cantaloupe and the juicy texture of pineapple in comparison with mango.

Drip loss is typically attributed to three main factors: high internal pressure in the product, formation of ice crystals in the product and the irreversibility of water removal from cells (Jul, 1984). However, Jul (1984) claimed that none of these factors completely explained the phenomenon of drip loss. Simandjuntak *et al.* (1996) proposed that an increase in drip loss indicated a greater loss of liquid cellular components and may be caused by either mechanical or enzyme-catalyzed disruption of cell walls and membranes during frozen storage. In addition, the ice crystal growth which may occur during frozen storage could lead to crystal formation which might also cause mechanical damage by physically rupturing cell walls.

Chassagne-Berces *et al.* (2010) reported a decrease in water content after freezing and thawing of apple cylinders whereas they found that no significant change in water content occurred after freezing and thawing of mango cylinders. These results are in agreement with the results of Marin *et al.* (1992) on other mango varieties. All of these reports correspond well to our finding that apple had the highest drip loss while mango had the lowest drip loss.

## 4. Conclusion

Among the four fruits studied in this research, mango showed the highest total soluble solids and the lowest freezing point, whereas, pineapple showed the highest freezing rate. In the case of apple, frozen apple had the highest value for both %firmness decrease and drip loss after thawing, in spite of the fact that fresh apple exhibits the highest firmness and crunchy texture which was not found in our mango, cantaloupe, and pineapple samples. Our results show that the properties of fresh fruit (moisture content, total soluble solids content, and texture) have a considerable effect on the freezing characteristics, drip loss and firmness values of frozen-thawed fruits.

## Acknowledgements

This research was supported by grant funds under the program of Strategic Scholarships for Frontier Research Network for the Joint Ph.D. Program Thai Doctoral degree from the Office of the Higher Education Commission Thailand, and the Thailand Research Fund under project RSA5480020.

## References

Antonio, D.M. 2003. Parameters affecting pre-cooling, freezing, storage and transport of red raspberry fruits, individually frozen in discontinuous tunnels. Comparison among five varieties of *Rubus* sp. International Journal of Refrigeration. 26, 586-592.

AOAC. 1999. Official methods of analysis of AOAC international. AOAC international, Gaithersburg, Maryland, U.S.A.

Auleda, J.M., Raventós, M., Sánchez, J. and Hernández, E. 2011. Estimation of the freezing point of concentrated fruit juices for application in freeze concentration. Journal of Food Engineering. 105, 289-294.

Bartolomé, A.P., Rupérez, P. and Fúster, C. 1996. Changes in soluble sugars of two pineapple fruit cultivars during frozen storage. Food Chemistry. 56, 163-166.

Bourne, M.C. 2002. Food texture and viscosity: Concept and measurement. 2 nd ed. Academic Press, London, U.K.

Chassagne-Berces, S., Fonseca, F., Citeau, M. and Marin, M. 2010. Freezing protocol effect on quality properties of fruit tissue according to the fruit, the variety and the stage of maturity. LWT-Food Science and Technology. 43, 1441-1449.

Chassagne-Berces, S., Poirier, C., Devaux, M.F., Fonseca, F., Lahaye, M., Pigorini, G., Girault, C., Marin, M. and Guillon, F. 2009. Changes in texture, cellular structure and cell wall composition in apple tissue as a result of freezing. Food Research International. 42, 788-797.

Chen, C.S., Nguyen, T.K. and Braddock, R.J. 1990. Relationship between freezing point depression and solute composition of fruit juice systems. Journal of Food Science. 55, 566-567.

Chiwanichsiri, S., Laohasongkram, K., Thunpithayakul, C. and Mekmanee, S. 1996. Thermophysical properties of fresh and frozen pineapples. Asean Food Journal. 11, 1-5.

Coggins, P.C. and Chamul, R.S. 2004. Food sensory attributes. In Handbook of frozen foods, Y.H. Hui, P. Cornillon, I.G. Legaretta, M.H. Lim, K.D. Murrell, W.K. Nip, editor. Marcel Dekker, New York, U.S.A., pp. 93-148.

Delgado, A.E. and Rubiolo, A.C. 2005. Microstructural changes in strawberry after freezing and thawing processes. LWT - Food Science and Technology. 38, 135-142.

Hayes, G.D. 1987. Food engineering data handbook. Longman Scientific & Technical, New York, U.S.A.

Hsieh, R.C., Lerew, L.E. and Heldman, D.R. 1977. Prediction of freezing times for foods as influenced by product properties. Journal of Food Process Engineering. 1, 183-197.

Jie, W., Lite, L. and Yang, D. 2003. The correlation between freezing point and soluble solids of fruits. Journal of Food Engineering. 60, 481-484.

Jul, M. 1984. The quality of frozen foods. Academic Press, London, U.K.

Kerr, W.L. 2004. Texture in frozen foods. In Handbook of frozen foods, Y.H. Hui, I.G. Legaretta, M.H. Lim, K.D. Murrell and W.K. Nip, editor. Marcel Dekker, New York, U.S.A., pp. 149-168.

Laohasongkram, K., Chaiwanichsiri, S., Thunpithayakul, C. and Ruedeesarnt, W. 1995. Thermal properties of mangoes. Journal of the Science Society of Thailand. 21, 63–74.

Lim, M.H., MeFetridge, J.E. and Liesebach, J. 2004. Frozen food components and chemical reactions. In Handbook of frozen foods, Y.H. Hui, P. Cornillon, I.G. Legaretta, M.H. Lim, K.D. Murrell and W.K. Nip, editor. Marcel Dekker, New York, U.S.A., pp. 67-81.

Lowithun, N. and Charoenrein, S. 2009. Influence of osmodehydrofreezing with different sugars on the quality of frozen rambutan. International Journal of Food Science and Technology. 44, 2183-2188.

Maestrelli, A., Scalzo, R.L., Lupi, D., Bertolo, G. and Torreggiani, D. 2001. Partial removal of water before freezing: cultivar and pre-treatments as quality factors of frozen muskmelon (*Cucumis melo*, cv reticulatus Naud.). Journal of Food Engineering. 49, 255-260.

Marin, M.A., Cano, P. and Fuster, C. 1992. Freezing preservation of 4 spanish mango cultivar (*Mangifera indica* L): chemical and biochemical aspects. Zeitschrift fur Lebensmittel-Untersuchung und-Forschung. 194, 566-569.

Modise, D.M. 2008. Does freezing and thawing affect the volatile profile of strawberry fruit (*Fragaria* x *ananassa* Duch.)?. Postharvest Biology and Technology. 50, 25-30.

Ramallo, L.A. and Mascheroni, R.H. 2010. Dehydrofreezing of pineapple. Journal of Food Engineering. 99, 269-275.

Simandjuntak, V., Barrett, D.M. and Wrolstad, R.E. 1996. Cultivar and frozen storage effects on muskmelon (*Cucumis melo*) colour, texture and cell wall polysaccharide composition. Journal of the Science of Food and Agriculture. 71, 291-296.

Sweat, V.E. 1974. Experimental values of thermal conductivity of selected fruits and vegetables. Journal of Food Science. 39, 1080-1083.

Talens, P., Escriche, I., Martýinez-Navarrete, N. and Chiralt, A. 2003. Influence of osmotic dehydration and freezing on the volatile profile of kiwi fruit. Food Research International. 36, 635-642.

Zaritzky, N. 2006. Physical-chemical principles in freezing. In Handbook of frozen food processing and packaging, D.W. Sun, editor. CRC Press, Boca Raton, Florida, U.S.A., pp. 3-31.