International Food Research Journal 19(2): 743-750 (2012)

Physicochemical properties, glass transition state diagram and colour stability of pulp and peel of two dragon fruit varieties (*Hylocereus* spp.) as affected by freeze-drying

*Liaotrakoon, W., De Clercq, N., Lewille, B. and Dewettinck, K.

Laboratory of Food Technology and Engineering, Department of Food Safety and Food Quality, Faculty of Bioscience Engineering, Ghent University, Ghent, 9000 Belgium

Abstract: The aim of the current study was to investigate the freeze-dried characteristics: physicochemical properties, colour parameters, total colour change, total betacyanins content and glass transition state diagram, of pulp and peel of white-flesh (*Hylocereus undatus*) and red-flesh (*Hylocereus polyrhizus*) dragon fruits. The results show that all dragon fruits can be successfully freeze-dried. For nutritional point of view, the retention of vitamin C counts up to 71.13% after freeze-drying. The water solubility of freeze-dried pulp was significantly different compared to the peel ($p<0.05$), that was about 7 times higher than that of the peel. Freeze-dried pulp and peel of red-flesh dragon fruit were a potential source of betacyanins content that found up to 360.14 mg/100 g. All freeze-dried dragon fruits obtained low glass transition temperature, varied between -6.70 and 4.83°C. The visual colour of freeze-dried dragon fruits after rehydration was similar to their original colour. Thus freeze-drying seems to preserve the nutritional and colour properties of dragon fruits after processing. Furthermore, the impact of pH on the colour was also monitored due to the pH sensitivity of the red pigment, betacyanins present in the dragon fruit. The total colour change of all reconstituted freeze-dried gave very small value between pH 3 and pH 7 particularly the peel while the colour seriously changed at out of this pH range. Regarding to the finding results, it can be considered that the freeze-dried pulp of red-flesh dragon fruit can probably be used as a natural colorant due to relatively high in betacyanins, water solubility, vitamin C, and colour stability at low acid condition.

Keywords: Dragon fruit, freeze-drying, vitamin C, colour, betacyanins, glass transition temperature

Introduction

The aim of drying process is to remove moisture from raw material which generally refers to heating. The mechanism of drying consists of heat and mass transfer which affects on inferior product quality such as degradation of colour, nutritional values (vitamins and minerals), and antioxidant activities (Que *et al.*, 2008). Freeze-drying has been used to eliminate water from a frozen material at low temperature under vacuum condition. It is a dehydration process of frozen solvent, which normally refers to water in foodstuff, at very low temperature which sublimed directly from a solid phase into a vapour phase. The targets of freeze-drying are to produce a highly dried product where the main constituents are preserved compared to other methods of food drying due to a low temperature processing (Khalloufi and Ratti, 2003; Marques *et al.*, 2007). However, freeze-drying is an expensive method because of its equipment and operation cost compared to the other drying methods (Ratti, 2001).

The colour of food products is an important attribute resulting in sensorial characteristic and decision of consumer. To date, natural pigments from plants are on the increase of interesting instead of synthetic dyes to use in food industry and more pronounce that they enhance their added value due to the positive health effects (Stintzing and Carle, 2004). Betalains are water soluble pigments which comprise of the yellow betaxanthins and the red-purple betacyanins, that have been found in some plants and approved as food colorant by the European Union for foodstuff (Moreno *et al.*, 2008). In case of natural colorants, they are easily degraded during processing and storage due to instability to temperature, light, oxygen and so on. Thus the enhance stability of betacyanins in food should be taken into account. The effect of pigment content, antioxidants, and pH range on betacyanins stability has been studied particularly the influence of pH on the colour of betacyanins-containing material due to the deformation of betacyanins (Herbach *et al.*, 2006). In food industry, only red beet root has been used for edible betalains source as a natural colorant for foodstuff. However, the food scientists have recently found another source of betalains such as in amaranth, cactus fruits, Swiss chard, and yellow beet (Stintzing and Carle, 2007).

Dragon fruit (*Hylocereus* spp.) is a cactus fruit which has been widely cultivated in tropical climate regions such as Central and South America and also Southeast Asia i.e. Thailand, Vietnam and Malaysia.

*Corresponding author.
Email: *Wijitra.Liaotrakoon@UGent.be*
Tel: +32 9264 6162; Fax: +32 9264 6218

The fruit is also a potential source of betalains especially the red-flesh dragon fruit (*Hylocereus polyrhizus*) which contains a host of betacyanins (Wybraniec *et al.*, 2001; Stintzing *et al.*, 2002; Phebe *et al.*, 2009) thus the dragon fruit probably is used as a betacyanins source.

State diagram is unique for each material and can be determined using differential scanning calorimetry (DSC) that monitors heat effects associated with phase transitions and chemical reactions as a function of temperature, including glass transition temperature (T_g) which affects on chemical and physical changes during food processing and storage. The solids in food are an amorphous state that is very sensitive to change with temperature and moisture content. The T_g takes place when a glassy state changes to a rubbery state which probably is used to indicate properties, quality, stability and safety of food systems (Marques *et al*., 2007).

The research on quality attributes of freeze-dried tropical fruit is still lacking in literature particularly the dragon fruit. The aim of this research was to experimentally determine the freeze-dried characteristics (dry matter, water solubility, water absorption, and bulk density), the physicochemical properties (pH, vitamin C, total betacyanins content, colour) and state diagram of the peel, which is a by-product from dragon fruit processing, and the pulp of two dragon fruit varieties, white-flesh *(Hylocereus undatus)* and red-flesh *(Hylocereus polyrhizus)* dragon fruits. The effect of pH on colour of freeze-dried dragon fruits after rehydration was also investigated due to the pH sensitive of betacyanins, red pigment in the red-flesh dragon fruit. Hence, the outcome of this research can be used for the application of commercial food processing.

Materials and Methods

Dragon fruit preparation

Dragon fruit was purchased from a Thai shop in Belgium and investigated in 2 varieties, white-flesh (*Hylocereus undatus*) and red-flesh (*Hylocereus polyrhizus*) dragon fruits. Both peel and pulp were investigated separately. The dragon fruit was washed under tap water running and peeled by hand. The peel and pulp were homogenised by a juice extractor (JF 2750 Fritel, Belgium) to obtain the homogeneous juice without seeds. The juice was poured into a laboratory round bottom flask and frozen at -40°C for further study.

Freeze-drying process

The completely frozen dragon fruit juice was freeze-dried by using a freeze dryer (Heto Powerdry PL 3000 Thermo, Denmark) with total pressure and temperature inside a vacuum chamber equal to 4.6 Pa and -54°C, respectively. Average freeze-drying time was approximately 72 h and after stage of drying, a final product reached a final temperature of about 25°C. The freeze-dried was ground by coffee grinder and sieved through 60-mesh sieve to obtain homogeneous powder. The freeze-dried powder was storage at -40°C until further analysis.

Determinations of physicochemical properties

The dry matter, pH, and vitamin C content (titrimetric method) of the dragon fruits were conducted (AOAC., 1995). Bulk density determination was followed by 2 g of powder into a graduated cylinder and computed by dividing mass to volume (Goula and Adamopoulos, 2005). In case of water solubility and water absorption determinations, 1 g of the freeze-dried dragon fruit was weighted in a centrifuge tube, added 10 ml of distilled water, and homogeneously mixed. Afterwards, the mixture was then incubated in a water bath at 37°C for 30 min, and followed by centrifugation at 3000 g for 10 min. The residue was dried at 105°C for 3 h. The water solubility was computed by dividing weight of residue to weight of original sample while the water absorption was estimated by dividing weight of centrifuged precipitate to weight of original sample (Que *et al.*, 2008). All of these properties were performed in triplicate.

Determination of total betacyanins content

Total betacyanins content was evaluated by using a spectrophotometer at wavelength of 538 nm. The sample was diluted with distilled water and filtrated using a Whatmann No.1 filter paper to obtain an absorbance value between 0.8 and 1.0. The total betacyanins content was calculated following Eq. 1 and expressed as mg/100g (Rebecca *et al*., 2008; Stintzing *et al*., 2003).

$$\text{Total betacyanins content (mg/100 g)} = \frac{A \times DF \times MW \times 100}{\varepsilon \times L} \quad (1)$$

Where A is the absorption value at wavelength of 538 nm, DF is a dilution factor, MW is molecule weight (550 g/mol), ε is molar extinction coefficient (60,000 l/mol.cm) and L is path length of cuvette (1 cm).

Determinations of colour parameters and total colour change

Colour parameters (Hunter L^*, a^* and b^* values) were carried out and repeated 5 times for each sample by a spectrophotometer-colorimeter (CM-2500D

Minolta, Japan). L^* value means as lightness which varies from 100 for perfect white to zero for black, a^* value measures redness when positive, gray when zero, and greenness when negative, and b^* value refers to yellowness when positive, gray when zero, and blueness when negative. Total colour change was computed using Eq. 2 (Maskan, 2006).

$$\text{Total colour change} = \sqrt{(L^*_0 - L^*)^2 + (a^*_0 - a)^2 + (b^*_0 - b^*)^2} \quad (2)$$

Where L^*_0, a^*_0 and b^*_0 denote as the colour parameters of the original dragon fruit juice and L^*, a^* and b^* mean the colour parameters of the freeze-dried dragon fruit after rehydration which refers to a reconstituted sample. Respect to the reconstituted sample, the freeze-dried was rehydrated with distilled water until it reached to the same moisture content as its original juice.

Determination of glass transition state diagram

State diagram of freeze-dried dragon fruits was monitored by a differential scanning calorimetry (DSC model Q1000 V9.8 Build 296, USA). An average of 4 mg of the pulp and 2 mg of the peel freeze-dried dragon fruits were put on an aluminium pan and perfectly sealed. The heat profile of the pulp was equilibrium to -60°C, heated up to 100°C, cooled down to -60°C, and reheated up to 100°C with constant heating and cooling rates at 20°C/min. In case of the peel, they were heated up to 200°C instead of 100°C. DSC produced heat flow (watt/g) versus temperature thermogram. The glass transition temperature (T_g) was identified as a vertical shift in the heat flow curve of thermogram. Phase properties: the onset (T_{go}), midpoint (T_{gm}), and endpoint (T_{ge}) of T_g and specific heat changes ($\triangle H$), were analyzed by DSC thermogram using a software universal analysis V4.5A (TA Instruments, USA) and all measurements were performed in triplicate.

Influence of pH on colour changes

The effect of pH on the colour changes of the reconstituted freeze-dried dragon fruit was investigated because dragon fruit contains betacyanins that are susceptible to pH and resulting in colour changes. The reconstituted sample was subjected to the desired pH at pH 1, 3, 5, 7, 9 and 11, adjusting by concentrated HCl and 5 M NaOH solution. Eventually, the colour parameters (L^*, a^* and b^* values) were performed five times for each sample and total colour change (Eq. 2) were evaluated.

Statistical analysis

At least three replicate analyses were carried out and the results were reported as means $\pm$ standard deviation. The significance of differences among treatment means was determined by analysis of variance (ANOVA) with a significant level of 0.05.

Results and Discussion

Original dragon fruit characteristics

Physicochemical characteristics of the original dragon fruit juice: white-flesh pulp juice (WPUJ), white-flesh peel juice (WPEJ), red-flesh pulp juice (RPUJ) and red-flesh peel juice (RPEJ), were studied. The results showed that the pH of all dragon fruits slightly varied between 4.40 and 4.68 and it was similar to pH value of mango (Ahmed *et al.*, 2002). The dry matter of pulp juice was slightly higher than that of the peel that all dry matter varied between 6.55 and 10.93%, which the dry matter of RPEJ represented the lowest percentage. The vitamin C of the red-flesh dragon fruit was significantly different compared to the white-flesh ($p<0.05$), that was about 2 times higher than that of the white-flesh. It is also reported that vitamin C of pulp and peel in the same dragon fruit variety was not significantly different ($p>0.05$).

In case of dragon fruit's pigment, total betacyanins content of RPEJ was the highest (20.0 mg/100 g) followed by RPUJ and WPEJ (16.5 and 10.2 mg/100 g, respectively) while total betacyanins content of WPUJ could not be determined by the spectrophotometric method due to its very low amount. However, the betacyanins in the dragon fruits were lower than that of an extracted acidic red beet root (28.8 mg/100 g) (Azeredo *et al.*, 2007). Obviously, the visual colour of WPUJ was completely different compared to the others, it showed white colour while the rest represented red-purple colour suggesting a remarkable different in colour between RPUJ and WPUJ. In addition, the lightness (L^*) and redness (a^*) of peel of both dragon fruit varieties are not significantly different ($p>0.05$) while the yellowness (b^*) of RPEJ was significantly higher than that of WPEJ ($p<0.05$).

Freeze-dried characteristics

Physicochemical properties of freeze-dried dragon fruits

Yield is an important factor for manufacturer in term of operation cost. In this work, the yield of dragon fruit was monitored during processing. According to the finding results, yield of the red-flesh dragon fruit juice was slightly lower than that of the white-flesh variety. It may be explained by the fact that the red-flesh dragon fruit contains more gel-like materials such as pectin (Mahattanatawee *et al.*, 2006) and also some oligosaccharide (Wichienchot *et al.*, 2010) than that of the white-flesh. Moreover, it was also found that the juice yield of the peel was lower than that of the pulp. The yield of WPEJ and RPEJ was 26.67% and 20.26% whereas yield of WPUJ and RPUJ was 71.49% and 67.74%, respectively based on the original raw dragon fruits. After freeze-drying, the yield of freeze-dried dragon fruit was found up to 8.77% compared to the raw fruit and moreover, yield of the pulp freeze-dried was 3 times higher than that of the peel.

All dragon fruits were successfully freeze-dried and the freeze-dried characteristics results of the freeze-dried white-flesh pulp (DWPU), freeze-dried white-flesh peel (DWPE), freeze-dried red-flesh pulp (DRPU) and freeze-dried red-flesh peel (DRPE) show in Table 1. The pH value of all freeze-dried was similar with pH of their natural juices. The dry matter of all dragon fruit increased from about 10% to 95% after freeze-drying. It is clearly indicated that freeze-drying is an efficiency drying process to eliminate moisture from the dragon fruit.

Vitamin C is generally used as a nutrition loss index during food processing. In the present work, vitamin C content of original, frozen and freeze-dried dragon fruits was monitored. It was found that vitamin C of all cases was on the decrease during processing. The percentage of vitamin C retention of dragon fruit juice, frozen and freeze-dried was found up to 77.99%, 53.94% and 37.67%, respectively based on their raw dragon fruits as 100% vitamin C content. Vitamin C loses could be explained by the instability of ascorbic acid (vitamin C) to processing, moisture content, light and oxygen. As shown in Table 1, vitamin C of DRPE is the highest due to its initial value, following by DRPU, DWPE and DWPU, respectively. After freeze-drying, the vitamin C retention was found up to 71.13%, showed only a small decreasing. It could be suggested that the small loss of vitamin C during freeze-drying are attributed to low temperatures and to use of vacuum in the process. The similar result has been reported in papaya and guava (Hawlader *et al.*, 2006), acerola (Marques *et al.*, 2007), and carrots (Lin *et al.*, 1998). Hence, the freeze-drying could preserve nutritional value, colour, flavour, and taste for freeze-dried pineapple, cherry, guava, papaya and mango (Marques *et al.*, 2006).

Moreover, the water solubility of freeze-dried red-flesh dragon fruit was slightly lower than that of the white-flesh variety. It may be suggested that the red-flesh had more pectin and oligosaccharide, as previously discussed, than that of the white-flesh which probably play a role as water solubility obstacles. Table 1, the water solubility of the freeze-dried dragon fruit peel is much lower than that of the pulp whereas the water absorption of the peel is on the other hand much higher than that of the pulp. Furthermore, the bulk density of freeze-dried dragon fruit pulp is about 4 times higher than that of the peel.

Total betacyanins content of DRPE is the highest follows by DRPU and DWPE, respectively (Table 1) due to the initial values. The betacyanins content of DRPE was approximately 2 times lower than that of a dried red beet (Castellanos-Santiago and Yahia, 2008). It may be recommended that betacyanins in dragon fruit could be extracted and concentrated (Harivaindaran *et al.*, 2008) before freeze drying. Regarding to the results, the dragon fruit peel, which is a by-product from dragon fruit processing, was a potential source of betacyanins (up to 360.14 mg/100 g after freeze-drying) this indicates that it probably is used as a betacyanins colorant from the natural source like found in beet root. Unfortunately, the dragon fruit peel was very difficult to dissolve in water that showed very low percentage of water solubility (less than 15%, Table 1). Interestingly, DRPU was also rich in betacyanins (224.98 mg/100 g) and much easier dissolved in water (75%, Table 1) compared to the peel. For that reason, it could be recommended that DRPU probably is a suitable natural colorant. In case of the freeze-dried dragon fruit pulp, it also could be served as a juice instant powder or an intermediate product for beverage and confectionary manufactures because it remained a host of vitamin C, provided similar colour as original colour and dissolved very well in water which was in easy-to-use form.

After freeze-drying, the colour parameters of the freeze-dried dragon fruit were determined and the results show in Table 1. By comparison with the original dragon fruit juice, L^* value of the freeze-dried dragon fruit peel slightly decreased while L^* value of the freeze-dried dragon fruit pulp on the other hand increased. It was also found that a^* value of all cases increased whereas b^* value decreased, excluding DWPU, based on the original dragon fruit juice. Moreover, the visual colour of DWPE, DRPE and DRPU showed the same colour, red-purple while DWPU was white powder.

Glass transition state diagram of freeze-dried dragon fruits

A heat flow of the freeze-dried dragon fruit was analyzed by DSC. The DSC measurement is based on the changes in heat capacity of the powder. The state diagram of the freeze-dried dragon fruit was

Table 1. Characteristics and quality attributes of the freeze-dried dragon fruits

Properties	DWPU	DWPE	DRPU	DRPE
pH	4.51 ± 0.00^{c}	4.67 ± 0.00^{b}	4.39 ± 0.00^{d}	4.69 ± 0.01^{a}
Dry matter (%)	93.15 ± 0.64^{b}	94.63 ± 0.18^{a}	93.41 ± 0.10^{b}	95.37 ± 0.18^{a}
Vitamin C (mg/100g)	9.52 ± 0.27^{d}	15.68 ± 0.74^{c}	24.57 ± 0.50^{b}	34.50 ± 0.72^{a}
Water solubility (%)	81.29 ± 0.66^{a}	15.15 ± 0.56^{c}	75.00 ± 0.68^{b}	10.19 ± 0.77^{d}
Water absorption (g gel/100g)	0.91 ± 0.13^{c}	8.92 ± 0.32^{b}	1.39 ± 0.04^{c}	10.51 ± 0.70^{a}
Bulk density (g/ml)	0.507 ± 0.011^{a}	0.123 ± 0.009^{c}	0.450 ± 0.006^{b}	0.104 ± 0.008^{d}
Betacyanins (mg/100g)	No detected	185.52 ± 0.15^{c}	224.98 ± 0.07^{b}	360.14 ± 0.54^{a}
Colour parameters				
L^* value	84.65 ± 0.14^{a}	28.69 ± 0.50^{c}	40.14 ± 0.37^{b}	21.65 ± 0.42^{d}
a^* value	1.41 ± 0.06^{c}	35.88 ± 0.72^{a}	19.46 ± 0.43^{b}	34.64 ± 0.43^{a}
b^* value	10.83 ± 0.80^{a}	-5.24 ± 0.37^{b}	-8.23 ± 0.21^{c}	-8.52 ± 0.36^{c}

Superscripts with the different letters in a same row are significantly different at a probability, $p<0.05$.

drawn according to DSC data which referred to DSC thermogram. For each DSC thermogram, the onset (T_{go}), midpoint (T_{gm}), and endpoint (T_{ge}) of T_g, and specific heat changes or enthalpy ($\triangle$H) were computed as showing in Figure 1. The heat change from the glassy state to the rubbery state is referred to $\triangle$H of glass transition state. The $\triangle$H occurs at T_g that specific for each material and could be used to indicate the quality of material.

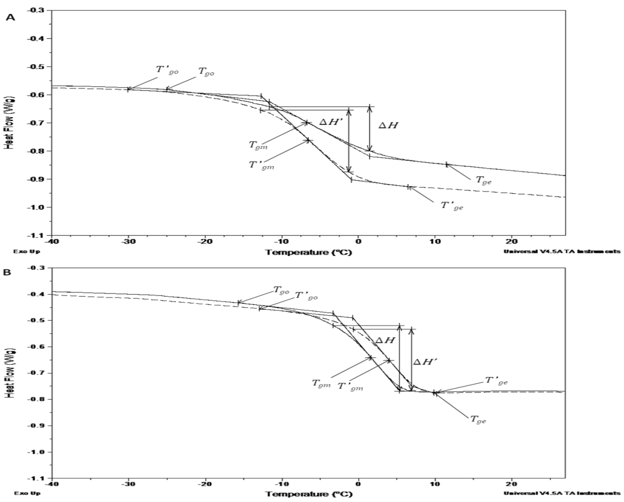

Figure 1. Glass transition state diagram as a function of temperature of the freeze-dried dragon fruits: A) the peel and B) the pulp. The dashed line corresponds to the white-flesh dragon fruit and the smoothed line represents the red-flesh dragon fruit

The average value of T_{go}, T_{gm}, T_{ge} and $\triangle$H of triplicate analyzed of the freeze-dried dragon fruit shows in Table 2. The T_{gm} of the freeze-dried pulp is approximately 3 times higher than that of the peel, varies between 2.60 and 4.83°C and between -6.70 and -2.41°C, respectively. The T_{gm} of the freeze-dried white-flesh dragon fruit is slightly higher than that of the red-flesh variety. Furthermore, the $\triangle$H of all cases is not significantly different ($p>0.05$), varies between 0.2209 and 0.2420 watt/g (Table 2). Regarding to the finding results, it could be concluded that all freeze-dried dragon fruits are the low T_g powders, it may be explained by the fact that dragon fruit is rich in sugar which contains glucose, fructose and some oligosaccharide such as sorbitol (To *et al.*, 1999; Wichienchot *et al.*, 2010) and T_g values of some sugars, like glucose and fructose, showed very low (Bhandari and Howes, 1999; Cruz *et al.*, 2001). However, it was also reported that the T_g of freeze-dried dragon fruit was higher than that of freeze-dried acerola (Marques *et al.*, 2007), Chinese gooseberry (Wang *et al.*, 2008), persimmon (Sobral *et al.*, 2001), and guava (Marques *et al.*, 2009). In contrast, the T_g of freeze-dried dragon fruit was lower than that of some freeze-dried tropical fruits such as mango, papaya and pineapple (Marques *et al.*, 2009).

Currently, the low T_g value has been associated with the stickiness and agglomeration problems in food powders especially the sugar-acid rich product in addition to fruit juices (Bhandari and Howes, 1999). Stickiness is a characteristic that probably causes the over-heating of thermal-sensitive substances resulting in product degradation during processing and storage, and undesirable sensorial characteristics of low T_g product (Bhandari *et al.*, 1997). The low T_g product could probably be enhanced the T_g value by simply decreasing moisture content of the product and more pronounced by adding a high molecular drying aids such as maltodextrin due to the plasticizing effect (Khalloufi *et al.*, 2000; Silva *et al.*, 2006; Sobral *et al.*, 2001; 2009) whereas lower molecular weight solutes, such as fructose and glucose, resulting in a decrease of T_g value (Silva *et al.*, 2006). Eventually, the state diagram obtained in the present study may be helpful in developing better product made of the freeze-dried dragon fruit powders.

Colour changes of freeze-dried dragon fruits after rehydration

To study the colour of the reconstituted freeze-dried, the colour parameters of the freeze-dried dragon fruits after rehydration with water were compared with their original dragon fruit juice and the results are given in Figure 2. The colour parameters of juice and reconstituted sample of all dragon fruits are similar particularly the peel of white-flesh dragon fruit, showed not significantly different for all colour parameters ($p>0.05$). In addition, the total colour change values of all reconstituted samples gave only a small change, varied between 1.00 and 1.72 compared

Table 2. Heat flow properties at glass transition state of the freeze-dried dragon fruits

Heat flow properties	DWPU	DWPE	DRPU	DRPE
T_{go} (°C)	-0.15±1.92^{a}	-9.96±3.81^{b}	-2.82±1.10^{a}	-12.94±1.20^{b}
T_{gm} (°C)	4.83±2.11^{a}	-2.41±5.79^{bc}	2.60±1.69^{ab}	-6.70±0.22^{c}
T_{ge} (°C)	8.15±1.94^{a}	1.39±3.22^{b}	5.91±1.23^{a}	0.70±0.93^{b}
$\triangle H \times 10^{-2}$ (watt/g)^{ns}	22.09±0.85	22.14±0.35	24.20±0.97	23.39±0.52

Superscripts with the different letters in a same row are significantly different at a probability, p<0.05, and ns is meant not significantly different (p>0.05) within the row.

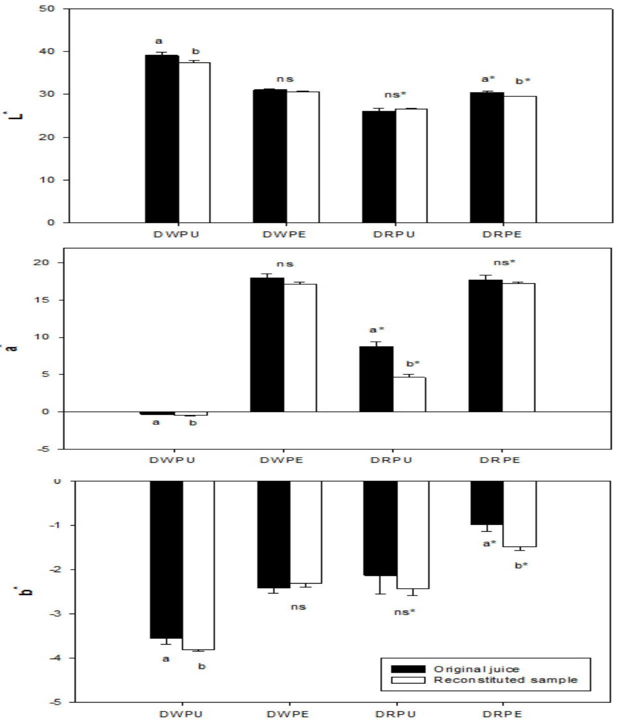

Figure 2. Comparison of colour parameters between the original juices and the reconstituted freeze-dried dragon fruits

to the natural juice. This result is similar with the result was found in guava (Hawlader *et al*., 2006). Nevertheless, it was also noticed that the visual colour of reconstituted DWPU became slightly brighter while the visual colour of reconstituted DWPE, DRPE and DRPU became slightly darker and redder compared to the natural juice. However, it could be recommended that freeze-drying seems to prevent colour changes after processing and rehydration, which is referred to reconstituted sample. According to Krokida *et al.* (2001), freeze-drying was the best method to improve colour compared to convectional, vacuum, microwave, and osmotic drying methods.

Influence of pH on colour after rehydration

Betacyanins are pH sensitive pigments which normally exhibit a pH stability ranging from pH 3 to 7. They are resulting in colour changes of betacyanins foodstuff respect to pigment degradation (Herbach *et al.*, 2006). Regarding to the finding results, freeze-dried dragon fruits, DWPE, DRPE and DRPU, are a potential source of betacyanins (Table 1) therefore, the investigation of the colour changes of the reconstituted freeze-dried dragon fruits at varying pH conditions was also essential to study. An effect of pH on colour changes of the freeze-dried after rehydration was expected. The total colour change value of the reconstituted could be used to represent as an index of colour stability at varying pH and the results show in Figure 3.

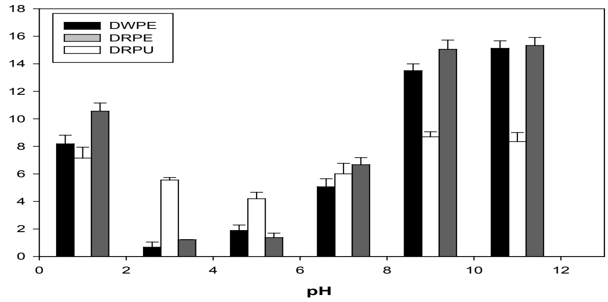

Figure 3. Influence of varying pH on total colour change of the freeze-dried dragon fruits after rehydration

As expected, the total colour change values of the reconstituted freeze-dried dragon fruit between pH 3 and pH 7 gave only small values and they dramatically increased at extremely acid and basis conditions, found up to 15.33 due to colour instability of betacyanins. This results are in agreement with the result found by Herbach *et al.* (2006). Observably, the reconstituted freeze-dried dragon fruits became pink at strong acid condition (pH 1), became brown at strong basis condition (pH 9), and became yellow at extremely basis condition (pH 11). Figure 3, the total colour change value of the peel is similar for both dragon fruit varieties and the colour changes of DRPU is the most stable compares to the others at whole varying pH range. It may be concluded that all reconstituted freeze-dried dragon fruits, excluding DWPU, may show the highest red-purple colour at their pH natural (pH 4.40 and 4.68) and the colour of these reconstituted was relatively stable at pH range between 3 and 7. Thus it is probably suitable for application in a low-acid and neutral foods which mostly seen in manufactured food products.

Conclusion

Overall, the freeze-drying was an efficiency drying method for the dragon fruits due to good quality attributes of the final product after freeze-drying. Freeze-dried pulps of both dragon fruit varieties were an excellent of nutritional value (vitamin C), colour stability and water solubility. Thus it is recommended to explore their potential uses for applications as an instant juice powder or an intermediate product in food industry. Hence, DRPU was a potential source of betacyanins and also relatively high in colour stability after rehydration at low-acid condition which might be served as a suitable natural colorant and in this case, it is also suggested that dragon fruit should be concentrated to improve betacyanins content prior to freeze-drying. By-product of dragon fruit, which referred to the peel, was also a host of vitamin C and betacyanins contents unfortunately, it obtained the difficulty of water solubility. All freeze-dried dragon fruit powders provided low T_g which might enhance a stickiness problem during processing and storage. It is suggested to add drying agent such as maltodextrin to eliminate the stickiness problem during processing and storage.

References

Ahmed, J., Shivhare, U.S. and Kaur, M. 2002. Thermal colour degradation kinetics of mango puree. International Journal of Food Properties 5: 359-366.

AOAC. 1995. Association of Official Analytical Chemists, Official methods of analysis of the association of the official analysis chemists. 16 ed. Arlington.

Azeredo, H.M.C., Santos, A.N., Souza, A.C.R., Mendes, K.C.B. and Andrade, M.I.R. 2007. Betacyanin stability during processing and storage of a microencapsulated red beetroot extract. American Journal of Food Technology 2: 307-312.

Bhandari, B.R. and Howes, T. 1999. Implication of glass transition for the drying and stability of dried foods. Journal of Food Engineering 40: 71-79.

Bhandari, B.R., Datta, N. and Howes, T. 1997. Problems associated with spray drying of sugar-rice foods. Drying Technology 15: 671-684.

Castellanos-Santiago, E. and Yahia, E.A. 2008. Identification and quantification of betalains from the fruits of 10 Mexican prickly pear cultivars by high-performance liquid chromatography and electrospray ionization mass spectrometry. Journal of Agricultural and Food Chemistry 56: 5758-5764.

Cruz, I.B., Oliveira, J.C. and MacInnes, W.M. 2001. Dynamic mechanical thermal analysis of aqueous sugar solutions containing fructose, glucose, sucrose, maltose and lactose. International Journal of Food Science and Technology 36: 539-550.

Goula, A.M. and Adamopoulos, K.G. 2005. Spray drying of tomato pulp in dehumidified air: II. the effect on powder properties. Journal of Food Engineering 66: 35-42.

Harivaindaran, K.V., Rebecca, O.P.S. and Chandran, S. 2008. Study of optimal temperature, pH and stability of dragon fruit (*Hylocereus polyrhizus*) peel for use as potential natural colorants. Pakistan Journal of Biological Sciences 11: 2259-2263.

Hawlader, M.N.A., Perera, C.O., Tian, M. and Yeo, K.L. 2006. Drying of guava and papaya: impact of different drying methods. Drying Technology 24: 77-87.

Herbach, K.M., Stintzing, F.C. and Carle, R. 2006. Betalain stability and degradation-structural and chromatic aspects. Journal of Food Science 71: 41-50.

Khalloufi, S. and Ratti, C. 2003. Quality deterioration of freeze-dried foods as explained by their glass transition temperature and internal structure. Journal of Food Science 68: 892-903.

Khalloufi, S., El-Maslouhi, Y. and Ratti, C. 2000. Mathematical model for prediction of glass transition temperature of fruit powders. Journal of Food Science 65: 842-848.

Lin, T.M., Durance, T.D. and Scaman, C.H. 1998. Characterization of vacuum microwave, air and freeze dried carrot slices. Food Research International 31: 111-117.

Mahattanatawee, K., Manthey, J.A., Luzio, G., Talcott, S.T., Goodner, K. and Baldwin, E.A. 2006. Total antioxidant activity and fiber content of select florida-grown tropical fruits. Journal of Agricultural and Food Chemistry 54: 7355-7363.

Marques, L.G., Silveira, A.M. and Freire, J.T. 2006. Freeze-drying characteristics of tropical fruits. Drying Technology 24: 457-463.

Marques, L.G., Ferreira, M.C. and Freire, J.T. 2007. Freeze-drying of acerola (*Malpighia glabra* L.). Chemical Engineering and Processing 46: 451-457.

Marques, L.G., Prado, M.M. and Freire, J.T. 2009. Rehydration characteristics of freeze-dried tropical fruits. LWT - Food Science and Technology 42: 1232-1237.

Maskan, M. 2006. Production of pomegranate (*Punica granatum* L.) juice concentrate by various heating methods: colour degradation and kinetics. Journal of Food Engineering 72: 218-224.

Moreno, D.A., Garcia-Viguera, C., Gil, J. and Gil-Izquierdo, A. 2008. Betalains in the era of global agri-food science, technology and nutritional health. Phytochemistry Reviews 7: 261-280.

Phebe, D., Chew, M.K., Suraini, A.A., Lai, O.M. and Janna, O.A. 2009. Red-fleshed pitaya (*Hylocereus polyrhizus*) fruit colour and betacyanin content depend on maturity. International Food Research Journal 16: 233-242.

Que, F., Mao, L., Fang, X. and Wu, T. 2008. Comparison of hot air-drying and freeze-drying on the physicochemical properties and antioxidant activities of pumpkin (*Cucurbita moschata* Duch.) flours. International Journal of Food Science and Technology 43: 1195-1201.

Ratti, C. 2001. Hot air and freeze-drying of high-value foods: a review. Journal of Food Engineering 49: 311-319.

Rebecca, O.P.S., Zuliana, R., Boyce, A.N. and Chandran, S. 2008. Determining pigment extraction efficiency and pigment stability of dragon fruit (*Hylocereus polyrhizus*). Journal of Biological Sciences 8: 1174-1180.

Silva, M.A., Sobral, P.J.A. and Kieckbusch, T.G. 2006. State diagrams of freeze-dried camu-camu (*Myrciaria dubia* (HBK) Mc Vaugh) pulp with and without maltodextrin addition. Journal of Food Engineering 77: 426-432.

Sobral, P.J.A., Telis, V.R.N., Habitante, A.M.Q.B. and Sereno, A. 2001. Phase diagram for freeze-dried persimmon. Thermochimica Acta 376: 83-89.

Stintzing, F.C. and Carle, R. 2004. Functional properties of anthocyanins and betalains in plants, food, and in human nutrition. Trends in Food Science & Technology 15: 19-38.

Stintzing, F.C. and Carle, R. 2007. Betalains-emerging prospects for food scientists. Trends in Food Science & Technology 18: 514-525.

Stintzing, F.C., Schieber, A. and Carle, R. 2002. Betacyanins in fruits from red-purple pitaya, *Hylocereus polyrhizus* (Weber) Britton & Rose. Food Chemistry 77: 101–106.

Stintzing, F.C., Schieber, A. and Carle, R. 2003. Evaluation of colour properties and chemical quality parameters of cactus juices. European Food Research Technology 216: 303-311.

Syamaladevi, R.M., Sablani, S.S., Tang, J., Powers, J. and Swanson, B.G. 2009. State diagram and water adsorption isotherm of raspberry (*Rubus idaeus*). Journal of Food Engineering 91: 460-467.

To, L.V., Ngu, N., Duc, N.D., Trinh, D.T.K., Thanh, N.C., Mien, D.V.H., Hai, C.N. and Long, T.N. 1999. Quality assurance system for dragon fruit The Australian Centre for International Agricultural Research Proceedings 100, Ho Chi Minh City, Vietnam.

Wang, H., Zhang, S. and Chen, G. 2008. Glass transition and state diagram for fresh and freeze-dried Chinese gooseberry. Journal of Food Engineering 84: 307-312.

Wichienchot, S., Jatupornpipat, M. and Rastall, R.A. 2010. Oligosaccharides of pitaya (dragon fruit) flesh and their prebiotic properties. Food Chemistry 120: 850-857.

Wybraniec, S., Platzner, I., Geresh, S., Gottlieb, H.E., Haimberg, M., Mogilnitzki, M. and Mizrahi, Y. 2001. Betacyanins from vine cactus *Hylocereus polyrhizus*. Phytochemistry 58: 1209-1212.