Effect of osmotic dehydration time on hot air drying and microwave vacuum drying of papaya

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Abstract

This study was subjected to hot air drying (70 °C) and microwave vacuum drying (1200 W and 13.3 kPa) of osmotically dehydrated papaya. Osmotic dehydration was carried out in sucrose solution (65 % (w/w)) at 40±2 °C for 1 – 4 h. The ratio of papaya to the solution was 1:5. In the hot air drying, an increase in osmotic dehydration time from 1 to 4 h decreased hardness, lightness (L* value) and chroma (C* value) of papaya significantly ($P \le 0.05$).In the microwave vacuum drying, a similar trend of hardness reduction was observed when the osmotic dehydration time was increased. However, the microwave vacuum dried papaya had lower hardness and chroma than the hot air dried samples. Hue angle ($\mathring{h}$) of the microwave vacuum dried papaya was in the range of 48.55 – 50.32 whereas that of the hot air dried samples was in the range of 0.83 – 0.91. Regarding the scanning electronic micrograph, increasing osmotic dehydration time could reduce the shrinkage of the hot air dried papaya and reduce the degree of damage in the microwave vacuum dried papaya. Comparing between both drying conditions, the microwave vacuum drying yielded the fine and porous structure, whereas, the hot air drying yielded the dense structure. Therefore, rehydration rate constant of the microwave vacuum dried papaya was significantly higher than that of the hot air dried samples ($P \le 0.05$).

Keywords: papaya, osmotic dehydration, drying, microwave

1. Introduction

Papaya (*Carica papaya* L.) is a nutritious fruit which widely consumed. Drying is one of common processes to preserve papaya for longer shelf-life. Hot air drying (HA) is widely used in agro-industry to dry fruits and vegetables due to a simple and flexible process. However, drying with hot air flow is time-consuming and has low energy efficiency, especially during the falling drying rate periods. The long drying time resulted in substantial degradation of product quality attributes, such as color, nutrient and flavor (Zhang et al., 2006).

Recently, microwave heating has been proposed as an alternative way to increase drying rate of material containing ionic liquids. The ionic liquids are claimed as very good media for absorbing microwaves, resulting in a very high heating rate (Lin et al., 2011). In addition to rapid heating, the microwave heating has the advantage of uniform heating due to the deep

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penetration of microwave into the product (Alibas, 2007). Microwave vacuum drying (MWVD) is the combined application of microwave heating and vacuum condition. It has been applied in drying of mint (Therdthai and Zhou, 2009) and durian (Bai-Ngew et al., 2011) to improve rehydration ability and texture of dried products, respectively.

Another way to reduce drying time is reduction of water content in materials prior to drying. Osmotic dehydration (OD) is sometimes applied as pretreatment to partially remove some water from materials prior to HA. The reduction of drying time when using HA resulted in product quality improvement in terms of color, flavor and texture (El-Aouar et al., 2006). OD removes some water by immersing foodstuffs, such as fruits and vegetables, into concentrated osmotic solutions having higher osmotic pressure and low water activity (Kaymark-Ertekin and Sultanoglu, 2000).

The objective of this research was to determine the effect of OD time on quality of dried papaya. Characteristics of osmotically dehydrated papaya before and after HA, and after MWVD were investigated.

2. Materials and Methods

2.1 Material

Papaya harvested at 90 days after blooming was peeled, cut into a cubic shape (1 x 1 x 1 cm^3) and soaked in 0.5 % w/w calcium chloride solution for 15 min.

2.2 Osmotic dehydration of papaya

The papaya cubes were immersed in the sucrose solution (65 % (w/w)) at 40 °C for 1, 2, 3 and 4 h with 40 rpm agitation. The osmotic solution to fruit ratio was 5:1. During OD, moisture content and total soluble solid of papaya cube were monitored to calculate water loss (WL) and solid gain (SG) using Eqns 1 and 2, respectively.

$$WL = \frac{M_0 X_0^w - M_t X_t^w}{M_0} \times 100 \qquad (1)$$

$$SG = \frac{M_0 X_0^{ts} - M_t X_t^{ts}}{M_0} \times 100 \qquad (2)$$

where M_0 and M_t were sample weight at time 0 and t, respectively. X_0^{ts} and X_t^{ts} were total solid concentration at time 0 and t, respectively. X_0^{w} and X_t^{w} were moisture fraction at time 0 and t, respectively. After OD, samples were frozen and keep at -18 °C until use.

2.3 Drying of osmotically dehydrated papaya cube

Frozen dehydrated papaya (200 g) was dried in a tray dryer (BWS-model, Frecon, Bangkok, Thailand) at 70 °C with air velocity of 2 m/s and a microwave vacuum dryer (MarchCool, Thailand) until moisture content was reduced to less than 0.1 kg water/ kg dry matter. In MWVD, power and pressure were set at 1200 W and 13.33 kPa, respectively.

2.4 Quality determination of dried papaya

Moisture content and sugar content were determined by AOAC methods (AOAC, 2000). Color in CIE system (L*, a*, b*, C* and ^{0}h) was measured by a colorimeter (Minolta Model CM-3500d, Japan). Hardness of dried samples was investigated by a texture analyzer (Lloyd, TA500, UK). A ball probe (P/0.5) was used with 20 mm/min test speed. The deformation ratio was 50%. Structure of dried samples was investigated by a scanning electron microscope (Hitachi TM-1000, Japan) with an accelerating voltage of 15kV. Magnification was adjusted to 50X. Rehydration kinetics was tested by soaking dried samples (5 g) in 100 g water (85 °C) for 30 min. Rehydration rate constant was estimated using Eqn 3.

$$\frac{W_t - W_e}{W_0 - W_e} = \exp(-kt) \qquad (3)$$

where W_0 is the initial weight (g), W_e is the equilibrium weight (g), W_t is weight (g) after rehydration for t min, k is rehydration rate constant (min^{-1}) and t is rehydration time (min).

2.5 Statistical analysis

All experiments were conducted with two independent replications. Means of all treatments were analyzed using ANOVA (SPSS version 15.0, SPSS (Thailand) Co., Ltd., Bangkok, Thailand). Duncan's multiple range test was used to identify differences at the 95 % significance level.

3. Results and Discussion

3.1 Effect of osmotic dehydration time on mass transfer, color and texture of papaya cubes

Initially moisture content of papaya cubes was 7.58 kg water/kg solid. After OD for 4 h, the moisture content of papaya cube was reduced to 1.22 kg water/kg solid (Table 1). The driving force for water removal was generated from the difference in osmotic pressure between food and its surrounding solution (Togrul and Ispir, 2007). Therefore, at the beginning of OD when the difference of osmotic pressure was high, a decrease in water loss was much more than that of the last 2 h. Meanwhile, the soluble solid in the osmotic agent actively migrated into cells and penetrated into intracellular spaces. As a result, solid gain was increased from 4.84 to 6.49 %. Thus total soluble solid in papaya cubes was increased from 9.8 °Brix to 42.2 °Brix. Permeability and selectivity of the tissue structures could be enhanced by heating during OD (Contreras et al., 2005).

Table 1. Moisture content (%), WL (%) and SG (%) of papaya cubes before and after OD.

OD (h)	Moisture content (kg water/kg dry solid)	Water loss (%)	Solid gain (%)	Total soluble solid (°Brix)
0	7.58±0.75a	-	-	9.8±1.35e
1	4.50±0.12b	35.84±0.59c	4.84±1.15c	22.3±0.84d
2	2.35±0.82c	51.54±0.64b	5.52±0.98b	29.6±0.75c
3	1.50±0.65d	62.97±1.75a	6.11±1.32a	35.5±0.52b
4	1.22±0.24d	67.15±0.93a	6.49±0.54a	42.2±1.45a

[a-e] Means within the same column followed by different letters were significantly different ($p \leq 0.05$).

After OD for 4 h, the water loss during OD was increased to 67.15%. Color pigment in papaya could be concentrated. As a result, lightness (L* value) of papaya cubes was decreased when OD was increased (Fig. 1). Also, a*, b* and C* values were significantly ($P \leq 0.05$) decreased as immersing time increased. This was possibly due to change of carotene. Heating frees-up carotenoids especially beta-carotene and lycopene. Related with the research of (Nunes and Moreira, 2009) which shows the decrease of b* of osmotically dehydrated mango when increased OD time without vacuum condition. However, no significant change ($P>0.05$) was observed in hue angle value (49.03 - 48.75). This may be due to gained sugar during OD (Osorio et al., 2007). It is reported that OD is effective to protect color of sample from heat (Singh and Gupta, 2007).

Regarding texture of the osmotically dehydrated papaya cubes, Hardness was decreased from 32.03 N to 7.32 N (Table 2) during OD for 4 h. possibly because of water migration from the cell. The water loss caused a decrease in the tension that the liquid exerted against the cell wall. Moreover, in this study, OD was carried out at 40 °C. The change of cell structure may also from thermal degradation.

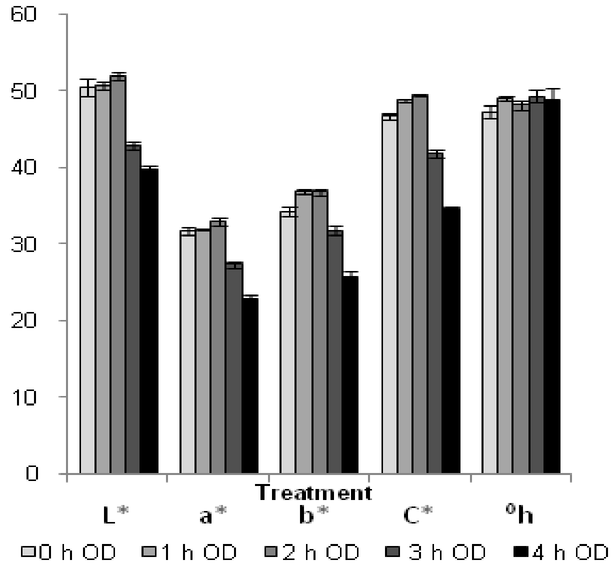


Figure 1. Color of papaya cubes before and after OD at 1, 2, 3 and 4 h.

3.2 Effect of osmotic dehydration on drying

3.2.1 Color of osmotically dehydrated papaya after drying

After HA, lightness of osmotically dehydrated papaya cubes was decreased. An increase in OD time tended to increase lightness (Fig. 2). Therefore, the change of lightness after HA was reduced. This was explained by degradation of carotenoid by heat. Redness (positive a* value) was increased as OD time increased. It was possibly due to non-enzymatic browning reaction. Therefore, the hot air dried papaya had a reddish tone. This was coincided with (Hiranvarachat et al., 2008) that observed reddish tone in the hot air dried carrot. This was related to OD prior to drying. It was also reported that OD could reduce trans-cis isomerization of beta-carotene during the subsequent drying stage (Heredia et al., 2010).

Due to vacuum condition during microwave drying, the decreased pressure enabled products to be dried faster than that under atmospheric pressure. Moreover non enzymatic browning reaction could be decreased. Therefore, color of the microwave vacuum dried papaya cubes was lighter than those of hot air dried samples. An increase in dehydration time did not change lightness of the microwave vacuum dried samples, unless 4 h OD was applied. This was due to observation of burning spot. Chroma was decreased related to the decrease in both a* value and b* value. Hue angle of all microwave vacuum dried samples were in the yellowish and orange tone. This possibly indicated the formation of cis-isomer during microwave heating. Similar result was reported in microwave drying of tomato (Heredia et al., 2010). The isomerization from trans-isomer to cis-isomer could have a health benefit for human due to better access. However, stability of cis-isomer was less than trans-isomer. Thus, additional treatment might be required to maintain the cis-isomer.

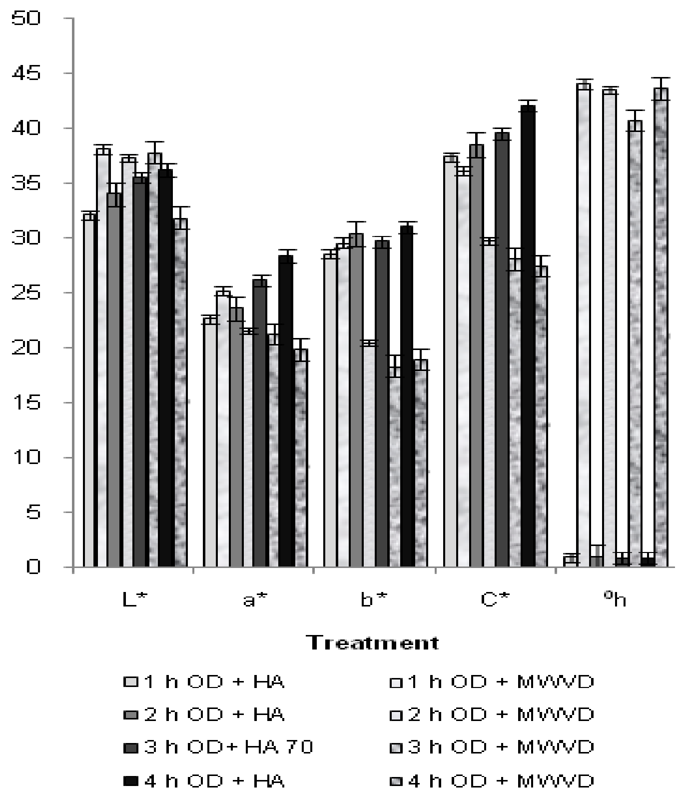


Figure 2. Color parameters of osmotically dehydrated papaya cubes after drying.

3.2.2 Hardness of osmotically dehydrated papaya cube after drying

After HA, hardness of osmotically dehydrated papaya cube was increased. An increase in immersing time during OD decreased the change of hardness of the hot air dried samples (Table 2). As a result, hardness of samples with 4 h OD was slightly increased from 7.32±0.69 N to 8.20±1.24 N after HA. In contrast, hardness of samples with 1 h OD was dramatically increased from 32.03±0.27 to 81.23±3.23 N after HA. This indicated advantage of OD on the textural improvement of the hot air dried papaya. However, hardness of hot air dried papaya cubes was still greater than that of microwave vacuum dried samples (0.30 - 0.36 N, regardless of OD time. This was mainly because of initially rapid reduction of surface moisture and consequent shrinkage, which often results in reduced moisture transfer and, sometimes, reduced heat transfer during the HA (Maskan, 2001).

In MWVD, low chamber pressure and rapid heat transfer in the samples could generate uniform heating and drying within the samples. As a result, shrinkage was reduced, drying time was shorten, and then surface hardening was eliminated. The increased immersing time from 1 to 4 h during OD did not significantly affect hardness of the microwave vacuum dried papaya cubes (P>0.05).

3.2.3 Structure and rehydration rate of osmotically dehydrated papaya cube after

From Fig. 3 (B, D, F, H and J) the microwave vacuum dried papaya appeared more and larger porous structure than the hot air dried samples. The hot air dried samples in Fig. 3 (A, C, E, G and I) had the packed structure. Similar result was observed in the microwave freeze drying of sea cucumber (Duan et al., 2010). This could be related to rapid heating and a decrease in pressure chamber that enhanced pressure gradient and mass transfer rate. However, too rapid heating may damage cell structure and then rehydration ability might be reduced. In this study, rehydration rate constant was improved from 0.104 - 0.124 min^{-1} to 0.363 – 0.437 min^{-1} when the MWVD was applied. This was coincided with (Maskan, 2001) that reported rehydration characteristic of microwave dried kiwifruit was better than that of hot air dried sample. The degree of improvement of rehydration rate also depended on OD time prior to drying. That meant OD could protect tissue from too rapid heat and mass transfer during MWVD. However, the advantage of OD on rehydration improvement was not noticeable in the hot air dried samples.

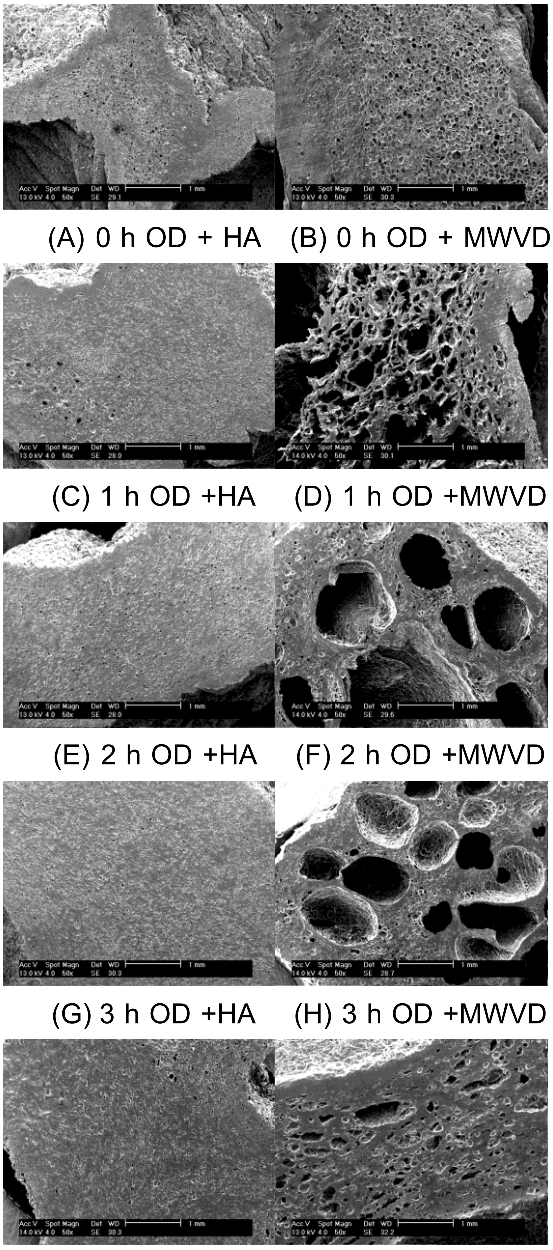
Table 2. Hardness of osmotically dehydrated papaya cubes drying.

Treatment	Hardness (N) Before drying	Hardness (N) After drying
1 h OD + HA	32.03±0.27a	81.2b3±3.23a
1 h OD + MWVD		0.36±0.02e
2 h OD+ HA	21.06±2.23b	49.37±1.32b
2 h OD + MWVD		0.24±0.02e
3 h OD + HA	15.93±0.30c	25.49±3.33c
3 h OD + MWVD		0.25 ±0.03e
4 h OD + HA	7.32±0.69d	8.20±1.24d
4 h OD + MWVD		0.30±0.01e

[a-e] Means within the same column followed by different letters were significantly different ($p \leq 0.05$).

4. Conclusion

Papaya cubes was OD in sucrose solution resulting in moisture loss, solid gain, color and textural change. After hot drying, hue angle was in a reddish tone due to non-enzymatic browning reaction. An increase in OD time maintained lightness and hardness of samples during drying stage. In MWVD, hue angle of the dried papaya was in yellowish and orange tone possibly due to formation of cis-isomer of carotene. From SEM, the microwave vacuum dried papaya had highly porous microstructure whereas the hot air dried papaya had packed microstructure. The increase in OD time could improve rehydration rate constant of microwave vacuum dried papaya, not hot air dried papaya. Although OD could improve color, texture, structure and rehydration of the microwave vacuum dried products, but process time could be dramatically increased. Therefore OD should be applied prior to MWVD, when the optimum microwave power, vacuum pressure, and time were unable to improve the product quality.



(A) 0 h OD + HA (B) 0 h OD + MWVD

(C) 1 h OD +HA (D) 1 h OD +MWVD

(E) 2 h OD +HA (F) 2 h OD +MWVD

(G) 3 h OD +HA (H) 3 h OD +MWVD

(I) 4 h OD +HA (J) 4 h OD +MWVD

Figure 3. Scanning electron micrograph of osmotically dehydrated papaya cubes (0-4 h OD).

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