



Effect of Microwave-Vacuum Drying on Drying Characteristics and Quality of Mulberry

Yossaphat Thanthanasupawat¹, Ampawan Tansakul^{1*}

¹Department of Food Engineering, King Mongkut's University of Technology Thonburi, Tungkrui, Bangkok 10140, Thailand

* Corresponding author: Tel: +66-2470-9252, Fax: +66-2470-9240, E-mail: ampawan.tan@kmutt.ac.th

บทคัดย่อ

ลูกหม่อนอุดมไปด้วยสารต้านอนุมูลอิสระและสารออกฤทธิ์ทางชีวภาพ ที่ร่างกายมนุษย์ไม่สามารถผลิตขึ้นเองได้ ลูกหม่อนมีสรรพคุณเป็นยาพื้นบ้าน ใช้ในการรักษาโรคต่างๆ เช่น รักษาไข้ บำรุงตับและไต และใช้แก้โรคความดันโลหิตสูง เป็นต้น อย่างไรก็ตาม ลูกหม่อนเป็นผลไม้ที่มีความชื้นสูง และเสียหายง่ายหากไม่มีการเก็บรักษาที่ดี นอกจากนั้นแล้ว ยังมีฤดูการเก็บเกี่ยวผลผลิตที่สั้นมาก การอบแห้งเป็นการลดปริมาณความชื้นเพื่อยืดอายุการเก็บรักษาของลูกหม่อน และยังสามารถนำไปประยุกต์ใช้กับอาหารประเภทอื่นๆ ได้อีกด้วย การประยุกต์ใช้ไมโครเวฟร่วมกับการอบแห้งแบบสุญญากาศสามารถทำให้อัตราการอบแห้งสูงขึ้น และได้ผลิตภัณฑ์ที่มีคุณภาพดีขึ้น

ในงานวิจัยนี้ ทำการศึกษาการอบแห้งลูกหม่อน ด้วยไมโครเวฟร่วมกับการอบแห้งแบบสุญญากาศ ลูกหม่อนที่มีความชื้น 810 %ฐานแห้ง มีค่าแอกติวิตีของน้ำ (Aw) เท่ากับ 0.98 ถูกอบแห้งที่พลังงานไมโครเวฟ (65 120 และ 170 วัตต์) และความดันสัมบูรณ์ (41.33 31.33 และ 21.33 กิโลปาสกาล) ต่างๆ จนกระทั่งได้ความชื้นสุดท้าย 12 %มาตรฐานแห้ง มีค่าแอกติวิตีของน้ำ (Aw) เท่ากับ 0.55 ผลการศึกษาพบว่าระดับพลังงานไมโครเวฟและความดันสัมบูรณ์ มีผลต่อจลนพลศาสตร์ของการอบแห้ง และคุณภาพของลูกหม่อนอบแห้ง ทางด้าน สี และความแข็ง อย่างมีนัยสำคัญ ผลจากการศึกษาสรุปได้ว่า จุดที่เหมาะสมสำหรับไมโครเวฟร่วมกับการอบแห้งแบบสุญญากาศ คือ ที่พลังงานไมโครเวฟ 120 วัตต์ และความดันสัมบูรณ์ 21.33 กิโลปาสกาล

คำสำคัญ: ลูกหม่อน, ไมโครเวฟร่วมกับการอบแห้งแบบสุญญากาศ, คุณภาพ

Abstract

Mulberries (*Morus nigra*) are rich in antioxidants and essential bioactive substances that human body is not able to produce them. Mulberries are used effectively in folk medicines, e.g., treat fever, protect liver and kidney from damage, and lower blood pressure. However, mulberries are high moisture content fruits and extremely sensitive to storage. In addition, their harvesting seasons are very short. Drying to lower moisture content for prolonging shelf life and for further usage in other food applications is needed. The application of microwave-vacuum drying (MVD) is promising since MVD leads to higher drying rate and yields the dried product of better quality. In this study, MVD of mulberries was investigated. Fresh mulberries with initial moisture content of 810 % (db), water activity of 0.98, were dried at various microwave powers (65, 120 and 170 W) and absolute pressures (41.33, 31.33 and 21.33 kPa) until the final moisture content of 12 % (db), water activity of 0.55, were reached. The results revealed that the microwave power and absolute pressure levels significantly influence on drying characteristics and qualities of the MVD mulberries, viz., color and hardness. Thus, the optimum condition for microwave-vacuum drying is at microwave power of 120 W and absolute pressure of 21.33 kPa.

Keywords: Mulberry, Microwave-Vacuum Drying, Quality

1 Introduction

Sun drying is traditionally used for mulberry drying. Since exposure to direct sun radiation results in undesirable color changes and contamination with dust, soil, and insects may occur. Currently most of the dried fruits are produced by the technique of hot

air drying, which is alternatively used in obtaining a good quality in shorter time compared to sun drying. Since conventional drying has several limitations, e.g., non-uniform product quality; long drying times; harder texture; significant color change (Chien et al., 2014).

Microwave drying has some advantages over the conventional drying, e.g., shorter drying time, improved quality, higher efficiency of energy, etc. (Duygu et al., 2011). Vacuum drying prevents oxidation due to absence of air and thereby maintains color, texture and flavor of the dried products. Especially, vacuum-assisted drying gives an enormous important in order to dry material with low thermal conductivity (Yongsawatdigul et al., 1995). In recent years, MVD has been investigated as a potential method for obtaining high quality dried food products. MVD combines the advantages of rapid volumetric heating by microwaves and the low temperature evaporation of moisture with faster moisture removal by vacuum and thus it has the potential to improve energy efficiency and product quality (Chien et al., 2014; Yongsawatdigul et al., 1995; Zhang et al., 2016).

Therefore, the effects of operating parameters (microwave power and absolute pressure) on the drying characteristics and qualities (color and hardness) of MVD mulberries undergoing MVD process were investigated.

2 Materials and Methods

2.1 Material

Mulberries (*Morus nigra*) were procured from a mulberry farm at Samut-Sakhon province, Thailand. Mulberries were considered as cylindrical shape, with length of 30.57 ± 1.27 mm, diameter of 12.29 ± 0.76 mm, presenting soluble solid content of 8.80 ± 0.14 °Brix with water activity of 0.981 ± 0.01 at 25 °C. Initial moisture content of mulberries was 811.03 ± 36.38 % dry basis (db) using AOAC method (AOAC, 2000).

2.2 Drying experiment

A sketch of microwave-vacuum dryer with turntable is shown in Figure 1. A domestic microwave

oven (Samsung, Model MW71B, Thailand) (800 W, 2,450 MHz) was developed as experimental equipment. The power of microwave oven was calibrated using the standard procedure (IMPI 2-L test) (Buffler, 1993). Core temperatures of samples were observed with a fluoroptic probe (accuracy of 0.01 °C) connected to a control unit (Luxtron; Model M600, Santa Clara, California, U.S.A.). Weights of samples were measured using a load cell (Tedeia-Huntleigh; Model 1022, Singapore) that connected to a weighing indicator (accuracy of 0.01 g) (AND; Model 4329, Tokyo, Japan). The vacuum condition inside the chamber was generated and controlled by a vacuum pump (Busch, R5, Germany) with a pressure regulator. A turntable motor (5-6 rpm) was equipped on a load cell connecting to a sample holder. Approximately 30 g of the mulberries were placed on the rotating plate in a single layer. A microwave dryer was operated to generate three microwave power outputs (65, 120 and 170 W) as continuous wave. A vacuum pump was switched on to evacuate the drying chamber to desired absolute pressures (41.33, 31.33, and 21.33 kPa). The experiments were conducted until the final moisture content of 12 % (db), water activity of 0.55.

2.3 Drying characteristics

The effect of drying conditions on drying characteristics was studied. The moisture ratio (MR) was calculated using Eq. (1):

$$MR = \frac{M - M_e}{M_0 - M_e} \quad (1)$$

where M is moisture content of MVD mulberries (%db), M_e is the equilibrium moisture content which is assumed to be zero due to the vacuum condition (Maskan, 2000) and M_0 is the initial moisture content (%db) of fresh mulberries.

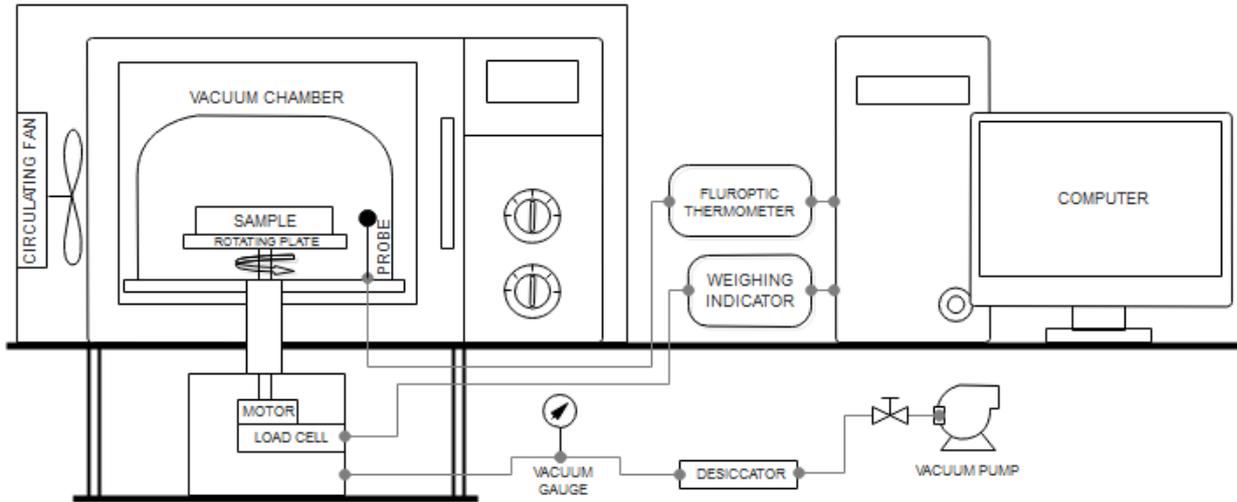


Figure 1 Schematic diagram of combination the microwave-vacuum dryer.

2.4 Color measurement

Surface colors of MVD mulberries were measured using a colorimeter (HunterLab, ColorQuest XE Plus, Reston, VA, USA). The colors values were expressed in CIELAB, i.e., L^* (whiteness/darkness), a^* (redness/greenness) and b^* (yellowness/blueness) coordinates, standard illuminant D65 and observe 10° . A colorimeter was calibrated against a standard white plate ($L^*=91.7$, $a^*=-1.16$ and $b^*=1.06$). The color changes were calculated by:

$$\frac{\Delta L^*}{L_0^*} = \frac{L^* - L_0^*}{L_0^*} \quad (2)$$

$$\frac{\Delta a^*}{a_0^*} = \frac{a^* - a_0^*}{a_0^*} \quad (3)$$

$$\frac{\Delta b^*}{b_0^*} = \frac{b^* - b_0^*}{b_0^*} \quad (4)$$

where L_0^* , a_0^* and b_0^* are initial color parameters of the fresh mulberries, respectively. In addition, total color differences (ΔE^*) were calculated by:

$$\Delta E^* = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \quad (5)$$

2.5 Texture measurement

Textural property of MVD mulberries were measured as puncture force, which was a measure of the hardness by a texture analyzer (TA-XT Plus; Stable Micro Systems, Surry, England) using 6 mm cylindrical probe with speeds of 0.5 mm/s and penetration

distance of 70% strain. The maximum force required to break the surface of MVD mulberries were recorded.

2.6 Statistical analysis

All experiments were performed in duplicate. The analysis of variance (ANOVA) and Turkey's range test were used to determine statistically significant differences of mean values using the Minitab® 16 (Student version, Minitab Inc., PA, USA) with the level of significance at 95 % ($P=0.05$).

3 Results and Discussion

3.1 Temperature profiles of MVD mulberries

The variation in core temperature of MVD mulberry during drying is presented in Figure 2. The temperature profile varied up and down as the microwave power was turned on and off, respectively. The drying curve was simultaneously observed, is also showed in the same figure. At first stage of drying period, the peaks provided higher in magnitude levels than the later stage of drying period. It might be due to the ability of mulberry in absorbing microwave energy by remaining its moisture content. The higher moisture content of mulberry at first stage of drying period had more ability in absorbing microwave energy as compared with the later stage of drying period. The temperature profiles were observed during experiment of each drying condition. An increasing in microwave power tended to increase the temperatures of MVD mulberries due to an increase in energy absorbed by themselves as shown in Figure 3. Apart from

microwave power levels, the absolute pressure levels influenced the temperatures of MVD mulberries as shown in Figure 4. At first stage of drying period, the temperatures of MVD mulberries at higher absolute pressure were higher than the temperatures obtained from the lower absolute pressure. In contrast, at later stage of drying period, the temperature profiles of different absolute pressure levels were overlapped because a limited amount of water was available in the MVD mulberries. The sensible heat turned into an outstanding factor affecting the temperatures of MVD mulberries (Yongsawatdigul et al., 1995).

In fact, the boiling point of water at lower absolute pressure is lower than at higher absolute pressure. As expected, the operating at lower absolute pressure allowed water to evaporate at a lower temperature. However, the temperatures of MVD mulberries were relatively greater than the boiling point of water at corresponding absolute pressure levels. It could be explain that the greater temperature of these profiles is the elevation of the boiling point of water due to soluble substances in the MVD mulberries (Drouzaf et al., 1996).

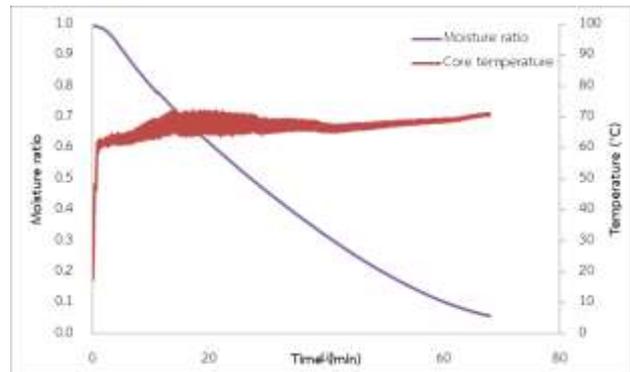
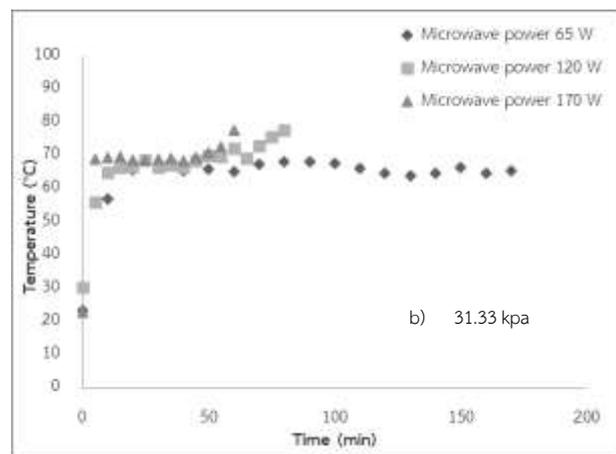
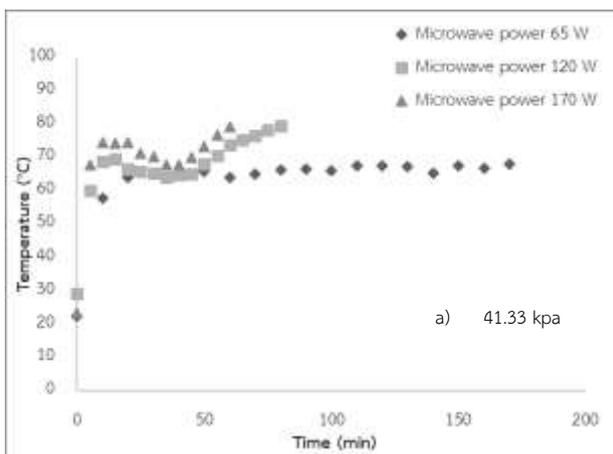


Figure 2 Temperature profile and drying curve of MVD mulberry at microwave power of 120 W and absolute pressure of 21.33 kPa.

3.2 Drying characteristics of MVD mulberries

The results were shown by the drying curves of MVD mulberries at various microwave power and absolute pressure levels. On the drying curves, two drying rate period were revealed. The moisture content of MVD mulberries was very high during the initial period of drying which resulting in a higher absorption of microwave energy and higher drying rates due to the higher moisture diffusion. As drying continued, the loss of moisture content in the MVD mulberries caused a decrease in the absorption of microwave energy which of microwave energy which resulting in falling drying rates.



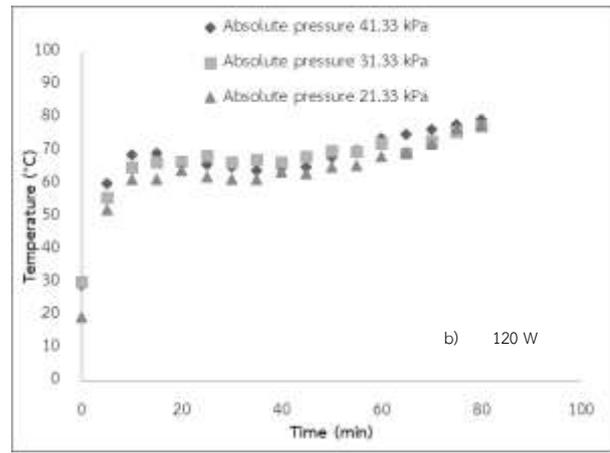
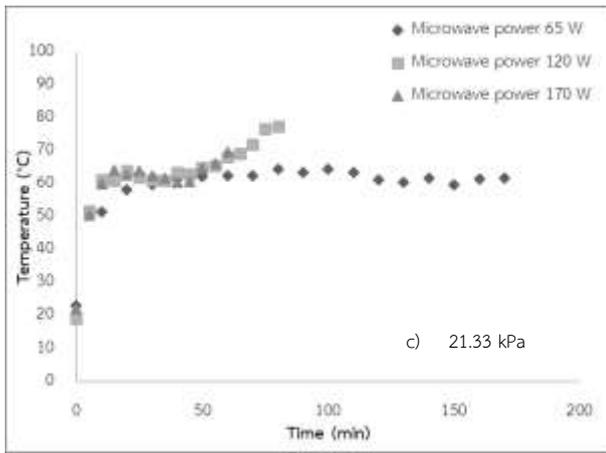


Figure 3 Temperature profiles of MVD mulberries at different absolute pressures: (a) 41.33, (b) 31.33 and (c) 21.33 kPa.

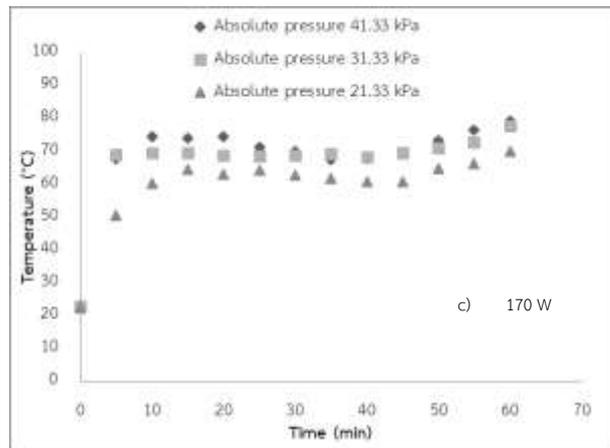
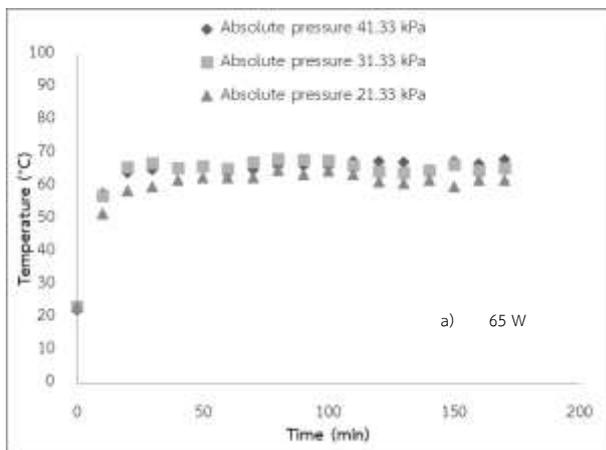


Figure 4 Temperature profiles of MVD mulberries at different microwave powers: (a) 65, (b) 120 and (c) 170 W.

The effect of microwave powers significantly influenced the drying time of MVD mulberries. The drying time of MVD mulberries undergoing microwave power of 170 W were shorter than those dried with lower microwave power of 120 W and 65 W to any absolute pressures levels (Figure 5). On the other hand, the effect of absolute pressures did not significantly influence the drying time of MVD mulberries to any microwave power levels (Figure 6). The drying time of each drying condition was reported in Table 1.

Table 1 Drying time of MVD mulberries at various microwave power and absolute pressure levels.*

Microwave power (W)	Absolute pressure (kPa)	Drying Time (min)
65	41.33	176 ± 2 ^a
	31.33	174 ± 1 ^a
	21.33	173 ± 2 ^a
120	41.33	89 ± 1 ^b
	31.33	86 ± 1 ^b
	21.33	85 ± 1 ^b
170	41.33	66 ± 1 ^c
	31.33	64 ± 1 ^c
	21.33	62 ± 1 ^c

*Means in the same column with different superscript is significantly different ($P < 0.05$).

As expected, at the same absolute pressure level, rate of moisture reduction increased with an increase in microwave power. The results indicated that mass

transfer within the MVD mulberries was more rapid during the higher microwave power heating. This is because more heat was generated within the MVD mulberries creating a large vapor pressure difference between the center and the surface of the MVD mulberries due to the characteristic microwave volumetric heating (Duygu et al., 2011; Lin et al., 1998). This result was consistent with many reports (Drouzas and Schubert, 1996; Mongpraneet et al., 2002; Vankatesh et al., 2008; Kantrong et al., 2012; Saengrayap et al., 2014; Sunjka et al., 2008).

3.3 Qualities of MVD mulberries

3.3.1 Color

Figure 7 shows that both of microwave powers and absolute pressures significantly provided a decrease ($P < 0.05$) in lightness. All drying conditions became darker because non-enzymatic browning, namely Maillard reaction took place during drying. Saengrayap (2014) reported that the higher microwave power that caused higher temperature of products accelerated the Maillard reaction, especially at higher drying temperatures.

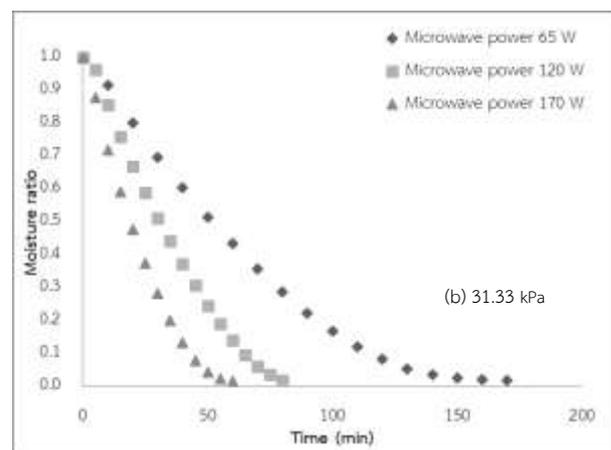
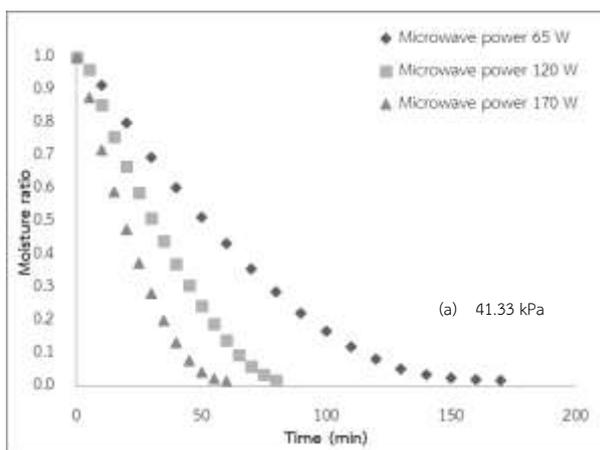
The changes of redness and yellowness are shown in Figure 8 and 9, respectively. Drying at higher microwave power and absolute pressure provided a

significant decrease ($P < 0.05$) in redness and yellowness because MVD mulberries were exposed to higher drying temperature as observed. The MVD mulberries had lower redness and yellowness value than the fresh one because color pigments destruction was developed. Anthocyanin pigments primarily generated the color of mulberry. The degradation of anthocyanin pigments depended on temperature. An increase in temperature accelerated degradation and being faster at high temperature (Kara et al., 2012).

Furthermore, the variation of total color differences (ΔE^*) of MVD mulberries depended on the microwave power and absolute pressure factors. The MVD mulberries at higher microwave power and absolute pressure significantly provided higher ($P < 0.05$) in ΔE^* as shown in Figure 10. This could be due to the drying condition as exposed to high temperature caused the color formation based upon Maillard reaction and the color destruction based upon pigment destruction (Kara et al., 2012).

3.3.2 Texture measurement

The hardness of MVD mulberries were illustrated in Figure 11. It was found that the effect of microwave power and absolute pressure levels did not significant



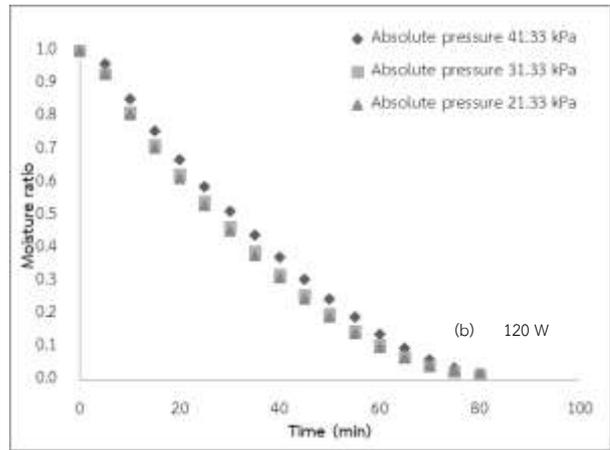
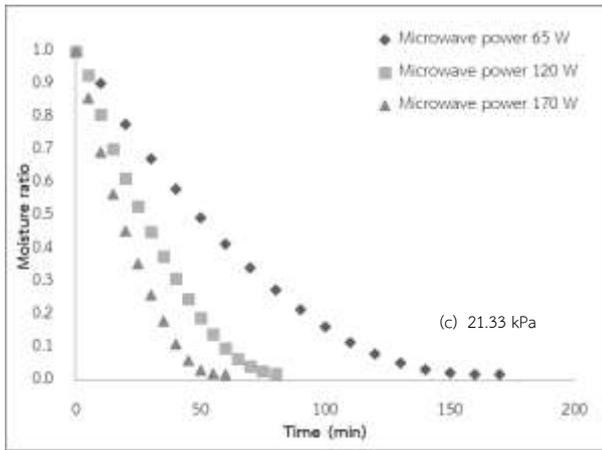


Figure 5 Drying curves of MVD mulberries at different absolute pressures: (a) 41.33, (b) 31.33 and (c) 21.33 kPa.

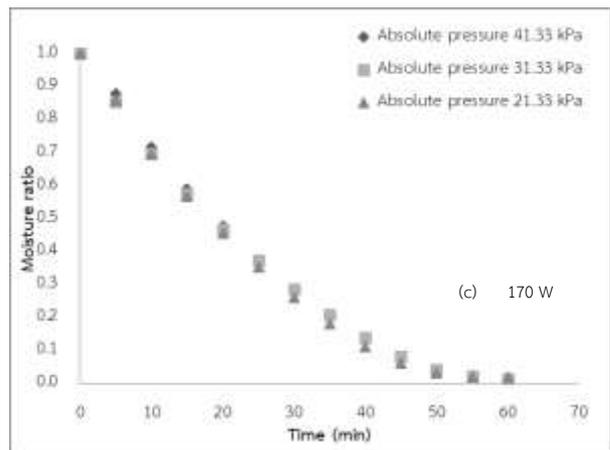
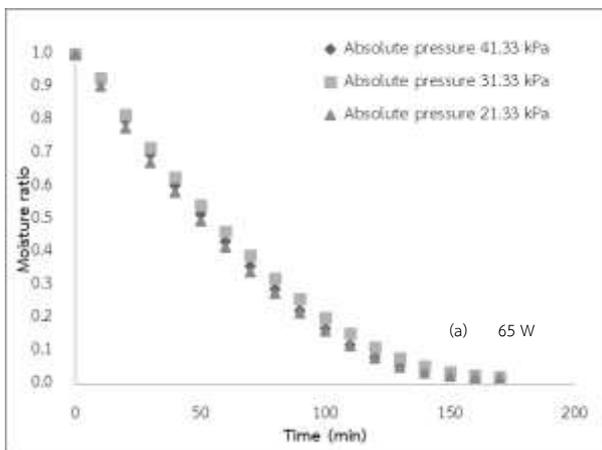


Figure 6 Drying curves of MVD mulberries at different microwave powers: (a) 65, (b) 120 and (c) 170 W.

influence to the hardness of MVD mulberries. This result was consistent with reported on dried fruits, as banana slices (Swasdisevi et al., 2007) and cranberries (Sunjka et al., 2008). As mention above, MVD process could be enhanced the color of MVD mulberries. The optimum criteria for drying mulberry are drying time and qualities of MVD mulberries. Drying at microwave power of 65 W and 120 W at absolute pressure of 21.33 kPa were not significant different in terms of qualities.

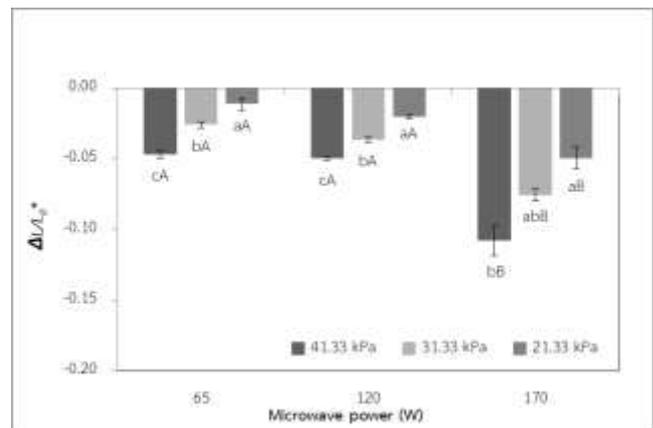


Figure 7 Lightness changes of MVD mulberries.

** (a-c had significant difference in the level of absolute pressure. A-C had significant difference in the level of microwave power.)

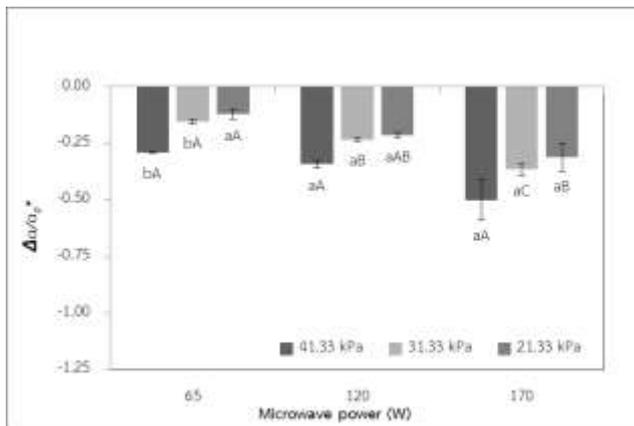


Figure 8 Redness changes of MVD mulberries.

** (a-c had significant difference in the level of absolute pressure. A-C had significant difference in the level of microwave power.)

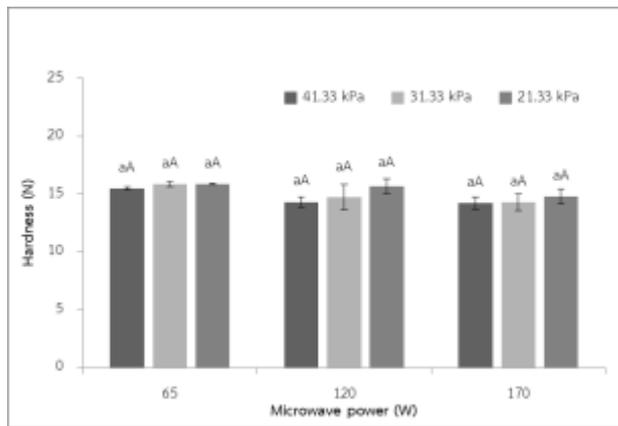


Figure 11 Hardness of MVD mulberries.

** (a-c had significant difference in the level of absolute pressure. A-C had significant difference in the level of microwave power.)

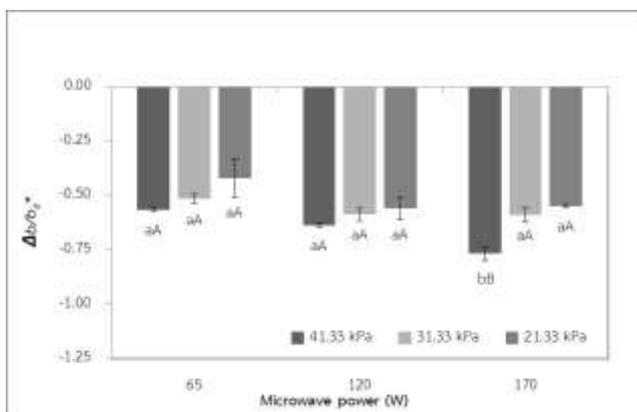


Figure 9 Yellowness changes of MVD mulberries.

** (a-c had significant difference in the level of absolute pressure. A-C had significant difference in the level of microwave power.)

Drying condition at microwave power of 120 W at 21.33 kPa gave best qualities i.e., lower changes of lightness, redness, yellowness and total color differences while the drying time was significantly lower than 65 W at 21.33 kPa. Therefore, this point was proposed as the optimum condition for drying of MVD mulberries.

4 Conclusions

The drying characteristics of MVD mulberries showed that microwave powers significantly affected on the drying time, while absolute pressures did not significantly influence on the drying time. Moreover, lightness, redness, yellowness and total color differences of MVD mulberries significantly decreased with increasing microwave powers and absolute pressures. In term of hardness, microwave powers and absolute pressures did not significantly influence to the hardness of MVD mulberries. Consequently, the optimum conditions of MVD mulberries are at microwave power of 120 W and absolute pressure of 21.33 kPa with respect to drying time, color and hardness criteria.

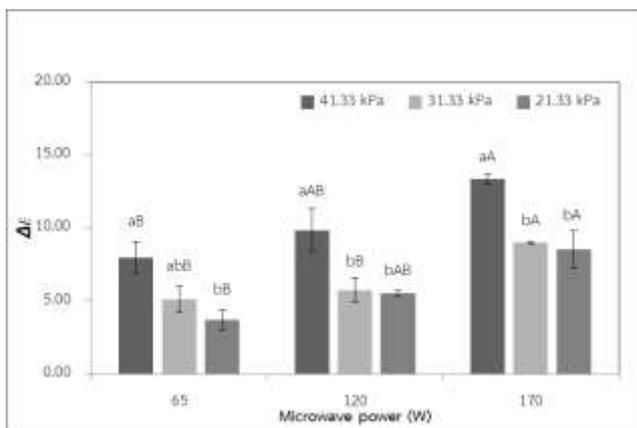


Figure 10 Total color differences of MVD mulberries.

** (a-c had significant difference in the level of absolute pressure. A-C had significant difference in the level of microwave power.)

5 Acknowledgements

This work was supported by the Higher Education Research Promotion and National Research University (NRU) Project of Thailand, office of the higher Education Commission.

6 References

- AOAC. 2000. Official Methods of Analysis 17th ed., Association of Official Analytical Chemists, Gaithersburg, Maryland, USA.
- Buffer, C.R. 1993. Microwave cooking and processing: Engineering fundamentals for the food scientists. Van Nostrand Reinhold.
- Chien, H., Figiel, A., Chung, L. 2014. Combined drying of apple cubes by using of heat pump, vacuum-microwave, and intermittent techniques. Food Bioprocess Technol 7, 975-989
- Duygu, E. 2011. Microwave drying and moisture diffusivity of white mulberry: experimental and mathematical modeling. Mechanical Science and Technology 10, 2711-2718.
- Drouzaf, A., Schuber, H. 1996. Microwave Application in Vacuum Drying of Fruits. Food Engineering 28, 203-209.
- Kantrong, H., Tansakul, A. 2012. Drying characteristics and quality of shiitake mushroom undergoing microwave-vacuum drying and microwave-vacuum combined with infrared drying. Journal of Food Science and Technology. doi: 10.1007/s13197-012-0888-4.
- Kara, S., Alben, E. 2012. Thermal degradation kinetics of anthocyanins and visual colour of Urmu mulberry. Food Engineering 116, 541-547.
- Lin, T., Durance, T., Scaman, C. 1998. Characterization of vacuum microwave, air and freeze dried carrot slices. Food Research International 31, 111-117.
- Maskan, M. 2000. Microwave/air and microwave finish drying of banana. Journal of Food Engineering 44(2), 71-78.
- Mongpraneet, S., Abe, T., Tsurusaki, T. 2002. Accelerated drying of welsh onion by far infrared radiation under vacuum conditions. Food Engineering 55, 147-156.
- Sengrayap, R., Tansakul, A. 2015. Effect of far-infrared radiation assisted microwave-vacuum drying on drying characteristics and quality of red chilli. Food Science and Technology 52, 2610-2621.
- Sunjka, S., Orsat, V., Raghavan, G. 2008. Microwave/vacuum drying of cranberries (*Vaccinium macrocarpon*). Food Technology 2, 100-108.
- Swasdisevi, T., Devahastin, N., Soponronnarit, S. 2007. Optimization of drying process using infrared-vacuum drying of Cavendish banana slices. Journal of Science and Technology 29(3), 809-816.
- Vankatesh, M., Mohit, G., Anthony, O. 2008. Drying Kinetics and Quality Characteristics of Microwave-vacuum Dried Saskatoon Berries. Microwave Power & Electromagnetic Energy 42, 4-4 - 4-12.
- Yongsawatdigul, J., Gunasekaran, S. 1995. Microwave-vacuum drying of cranberries: part 1 Energy use and efficiency: part 2 Quality evaluation of Cavendish banana slices. Sci Technol 29(3), 809-816.
- Zhang, M., Tang, J., Mujumdar, A., Wang, S. 2006. Trends in microwave related drying of fruits and vegetables. Trends in Food Science & Technology 17, 524-534.