

PRODUCING OIL-FREE CRISP DURIAN CHIP USING COMBINED MICROWAVE-HOT AIR DRYING WITH STEP-DOWN MICROWAVE POWER INPUT TECHNIQUE

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ABSTRACT

An application of a constant-continuous microwave power in combined microwave drying throughout the entire drying process to produce oil-free crisp durian chips is limited at high microwave power. This is because too high temperature of drying material leads to the charring in the dried product. Therefore, the objective of this work was to study the oil-free crisp durian chips undergoing combined microwave-hot air (MWA) drying with step-down microwave power input technique and compared with hot air (HA) drying. Drying kinetics and qualities of dried durian chips in terms of color, shrinkage and microstructure were evaluated. Mon Thong durian with initial moisture content of durian flesh was about 197.7-236.6% (d.b.) and total soluble solids of 14-15 °Brix was sliced to thickness of 1.5 mm and dried by the step-down MWA technique and HA methods to the final moisture content of 3.5% (d.b.). The durian chips were dried at microwave power of 600-800 W for 1 min followed by 400 W for 3 min and followed by 250 W to the final moisture content of 3.5% dry basis (d.b.) in the MWA drying and at hot air temperature of 65°C, air velocity of 0.3 m/s and recycled air of 80% in the HA drying. Experimental results showed that all cases of the step-down MWA technique provided higher drying rate than HA drying. The drying rate of this technique increased with an increase in the microwave power at first stage of drying. Dried durian chips obtained from the step-down MWA technique had higher lightness but lower in shrinkage, and more porous structure than HA-dried sample. Moreover, the step-down MWA technique provided dried durian chips with higher lightness but lower values of greenness and yellowness than the commercial fried durian chips.

Keywords: Color; Combined microwave drying; Durian chip; Microstructure; Step-down microwave technique

INTRODUCTION

Durian is one of the most popular and famous fruits, and is commonly grown in several countries of Southeast Asia. In addition, it is also the commercial fruit in the North, South and East of Thailand. Moreover, Thailand is regarded as the leading exporter of the high quality durian [1] with an export value of both fresh and processed product about US\$ 267.4 million in 2013 [2]. However, durian is often low price in the market during harvesting season due to its oversupply and short shelf-life [3]. The production of crispy durian chips from deep-frying method is one of alternative method to add value and extent shelf-life of durian. Currently, fried durian chip is one of product that is highly appreciated by

consumers. However, its high-oil product leads to short shelf-life from rancidity which is caused by the reaction between oil and oxygen during storage [4]. In addition, consuming high-oil product can lead to the risk of high blood pressure and heart disease. Thus, this product has not been interested in some health-concerned consumers.

To avoid this problem, oilfree durian chips obtained by hot air drying is an interesting method. However, this method takes a long drying time which leads to low energy efficiency of drying process and poor quality of product [5]. Improving the energy efficiency and dried product's quality can be done by a microwave heating. The microwave drying provides high drying rate because of an

electromagnetic wave can directly penetrate into the material and absorbed by water molecules. This phenomenon generates the volumetric heating inside the material and results in rapid moisture evaporation [6]. However, the distribution of electromagnetic wave is non-uniform inside the microwave drying chamber. As a result, the uneven heating of the product is occurred [7]. Overcoming this problem may be done by the combination of microwave drying with other common drying methods to the three periods of drying process i.e. initial, constant and falling drying rate periods in order to improve the product quality [8]. However, the unsuitable microwave drying conditions can cause poor product quality [9]. Perira et al. (2007) [10] reported that applying a high-microwave power in the final drying period of osmotic dried banana by combining the microwave-hot air drying resulted in temperature-thermal runaway phenomenon, causes charring in the dried product. Microwave heating is commonly applied by a constant and continuous microwave power in combined microwave drying throughout the entire drying process [11]. However, this technique cannot perform at the condition of highest microwave power because too high temperature of material causes charring in the dried product [12].

A stepwise microwave power technique is one of alternative technique used in the combined microwave drying to save the energy consumption of drying process and improve quality of product. A maximum-microwave power is applied to initial drying period since the material has high moisture content which can absorb more microwave energy leads to high temperature and high drying rate [13]. Then, the microwave power is stepped down to the suitable level in order to avoid overheat damage problem of material [14]. Advantages of this drying technique are safe the energy consumption and improve quality of product when compared with hot air drying. Chua et al. (2001) [15] reported that using a step-down air temperature technique for banana drying process provided more lightness of dried banana and shorter drying time when compared with a step-up air temperature technique. Varith et al. (2007) [16] reported that applying the two stepwise technique in drying of longan using combined microwave-hot air drying at microwave power of 450 W and hot air

temperature of 40 °C for 1.7 h followed by 300 W combined with hot air temperature of 8th TSAE International Conference (TSAE2015) March 17-19, 2015; Bangkok, Thailand 60°C for 3.3 h provided high energy efficiency when compared with constant drying temperature hot air drying.

Thus, the objective of this work was to study the effects of combined microwave-hot air drying with stepdown microwave power input technique and compares with hot air (HA) drying method on the drying kinetics and the quality attributes of dried durian chips in terms of color, shrinkage and microstructure.

MATERIAL AND METHODS

Material

Mon Thong durian, which obtained from the Talaad Thai market, Pathumthani province, Thailand, was peeled and sliced by a slice machine into 1.5 mm thickness. The total soluble solid of fresh durian was about 14-15°Brix, measured by a handheld refractometer. Its initial moisture content was about 197.7-236.6% dry basis (d.b.) which was determined by the vacuum method (934.06: AOAC, 1995) [17]. Sixty-one grams of the samples were carried out in each experiment.

Experimental set-up

A schematic diagram of a two-function type dryer was shown in Fig. 1. This dryer can be used as combined microwave-hot air drying or hot air drying. The main components of dryer comprised a modified micro-wave oven (LG model MS2427BM, Thailand) with a maximum power output of 800 W at 2450 MHz, a drying chamber with capacity of 24 liters, a blower (LDL Model RT 2005, Taiwan.) which connected to a 0.4-kW motor, a heater of 1 kW and a load cell connected to a weighing indicator (AD4329, Korea).

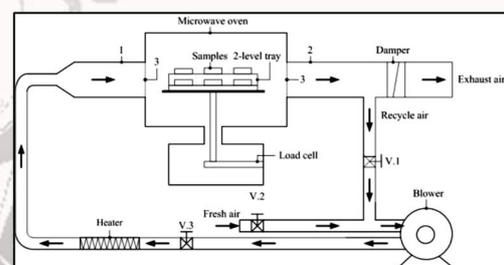


Fig. 1 A schematic diagram of a two-function type dryer: 1- Position of measuring air temperature at inlet of drying chamber ($T_{a,in}$) 2- Position of measuring of air temperature at outlet of

drying chamber ($T_{a,out}$) and 3-Protective grille for wave leakage to outside area.

Methods

Prior to the drying process, the air temperature inside the drying system was heated by a heater until the required drying temperature was obtained. Each chip of durian was placed on a 2-level tray to the required weight and put inside the drying chamber (microwave oven). In this work, the durian chips were dried by combined microwave-hot air (MWAHA) with step-down microwave power input technique to compared with hot air (HA) drying in terms of drying kinetics, qualities of dried durian chips and energy consumption of drying process. The step-down MWAHA drying was carried out at the microwave power of 600, 700 and 800 W for 1 min, followed by 400 W for 3 min and then by 250 W to the final moisture content of 3.5% dry basis. The microwave powers and the step-down microwave power inputs were controlled by an on-off time system in operating magnetron. The temperature of drying air was set at 65 °C by a PID controller with the accuracy of ± 1 °C and at air velocity of 0.3 m/s. The 80% of exit air from the drying chamber was recycled into the system by adjusting the damper as shown in Fig. 1. The air temperature both inlet and outlet of drying chamber were measured by k-type thermocouples and recorded by a data logger (Supcon, Model R3000, China). The sample temperature was measured by a fiber optic sensor and recorded by a fiber optic thermometer (Omega, model FOB104, Omega Engineering, Canada). While the HA drying was carried out at the same conditions of hot air in the step-down MWAHA drying. The energy consumption of drying processes both step-down MWAHA and HA methods were measured by Watt-hour meter (Mitsubishi, MF-33E, Thailand). The sample weight was continuously measured by a load cell and recorded by a weighing indicator (AD-4329, Korea) with an accuracy of ± 1 g.

Color measurement

Both top and bottom surface color of dried durian chips were measured by a Spectrophotometer (HunterLab Reston, model ColorFlex, VA, USA) with a D65 light source and a 10 view angle. The color value was expressed as L^* (lightness/darkness), a^* (redness/greenness) and b^* (yellowness/blueness) value. Ten

chips of dried durian were measured and the average values were reported.

Shrinkage measurement

The shrinkage of durian chip after drying was the ratio of different volume between the fresh and dried sample to the fresh volume. The percentage of shrinkage of dried durian chips was calculated by Eq. (1)

$$\% \text{Shrinkage} = \frac{V_o - V}{V_o} \times 100 \quad \dots(1)$$

Where V_o is the volume of the fresh sample before drying (cm^3) and is the volume of the sample after drying (cm^3). V

The volume of the fresh and dried samples was determined by a replacement method with solid, which in this work using glass beads with a diameter in the range of 0.106-0.012 mm [4]. The measurement method was performed following the method of Yan et al. (2008) [18]. The volume of the samples before and after drying (V) was calculated from Eq. (2) and averaged from ten measurements.

$$V = \frac{M_b - [M_{S+b} - M_v - M_s]}{\rho_b} \quad \dots(2)$$

Where M_b is the weight of the can filled with glass beads (g), M_v is the weight of the empty can (g), M_{S+b} is the weight of the can, samples and glass beads (g), M_s is the weight of the sample (g), and ρ_b is the bulk density of glass beads (g/cm^3).

Microstructure and images analysis

The microstructure photographs of cross-section durian chips after drying were characterized by using a scanning electron microscope (JEOL, model JSM-5410 LV, Tokyo, Japan) with an accelerating voltage of 15 kV. The microstructure in each dried sample was evaluated at 200x magnification.

The porous characteristics of dried durian chips such as pore area and pore diameter were evaluated by an image J program (available at <http://rsb.info.nih.gov/ij/index.html>). The pore and solid phase inside the microstructure images were segmented using Otsu's method. The solid phase was defined with white color while the black color is a pore. The threshold value was set in the range of 204-212. The pore diameter of binary image was determined with a known pore area.

Statistical analysis

All of the experimental data in terms of color, shrinkage, hardness, crispness and water activity were analyzed by statistical one-way analysis of variance (ANOVA) and Duncan's multiple range test using SPSS 13.0 software (IBM SPSS, Chicago, IL, USA). Mean values of data were considered at 95% significance level ($p < 0.05$).

RESULTS AND DISCUSSION

Drying kinetics of durian chips

Fig. 2 shows the drying kinetics of durian chips which were dried by using combined microwave-hot air (MWhA) with step-down microwave power input technique and hot air (HA) method. Results from Fig. 2 showed that moisture ratio (MR) of durian chips dried by the step-down MWhA method in all levels of microwave power were higher than those dried by the HA method. This is because the interaction between electromagnetic wave and moisture inside materials generates the volumetric heating and creates vapor pressure inside the material and results in rapid moisture evaporation [19]. Considering the effects of microwave power levels at first stage in the step-down MWhA drying on the drying kinetics, as shown in Fig. 2, it was found that the MR of durian chips undergoing the step-down MWhA drying increased with the microwave power at first stage of drying. This is because higher microwave power created higher temperature inside durian chips which resulted in higher boiling rate of water inside [13] and higher mass transfer rate due to higher vapor pressure difference as a result [5].

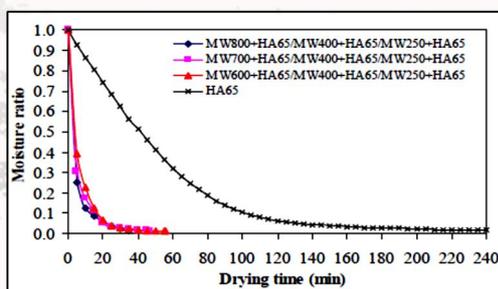


Fig. 2 Drying rates of durian chips dried by different experiment [MW: Microwave drying, 250, 400, 600, 700, 800: Microwave power (W), HA: Hot air drying, 65: Hot air temperature (°C), +: Combined, /: Followed by].

The variations of moisture content and temperature of durian chips undergoing step-

down MWhA and HA methods are shown in Fig. 3 to 6. The results showed that all conditions in the step-down MWhA drying had high temperature of durian chips than the HA drying. During the first stage of the step-down MWhA drying, the samples temperature rapidly increased because high moisture content in samples absorbed more microwave energy. The sample temperature then slightly decreased when the microwave power was stepped down and less moisture to absorb the microwave power [20] during the final stage of drying. The fluctuation of durian temperatures may be due to a cooling effect caused by evaporation of moisture accumulated on the surface of drying durian chips.

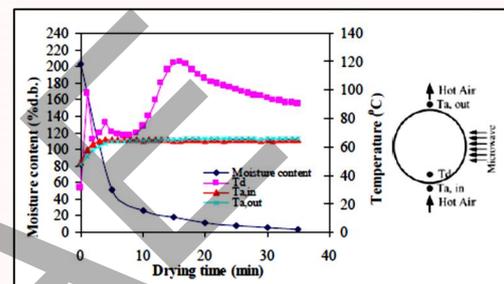


Fig. 3 Variations in moisture content and temperature of durian chips during MWhA drying at 800 W for 1 min followed by 400 W for 3 min and followed by 250 W and 65°C [$T_{a,in}$: Temperature of hot air at inlet of the drying chamber, $T_{a,out}$: Temperature of hot air at outlet of the drying chamber, T_d : Temperature of durian chips].

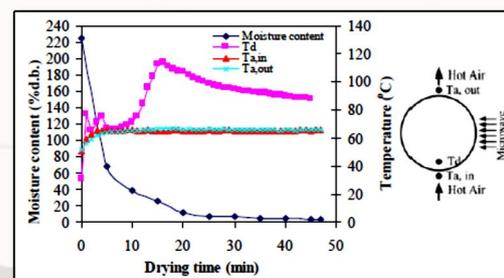


Fig. 4 Variations in moisture content and temperature of durian chip during MWhA drying at 700 W for 1 min followed by 400 W for 3 min and followed by 250 W and 65°C [$T_{a,in}$: Temperature of hot air at inlet of the drying chamber, $T_{a,out}$: Temperature of hot air at outlet of the drying chamber, T_d : Temperature of durian chips].

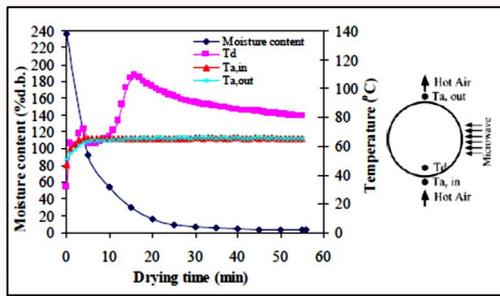


Fig. 5 Variations in moisture content and temperature of durian chip during MWA drying at 600 W for 1 min followed by 400 W for 3 min and followed by 250 W and 65°C [T_{a,in}: Temperature of hot air at inlet of the drying chamber, T_{a,out}: Temperature of hot air at outlet of the drying chamber, T_d: Temperature of durian chips].

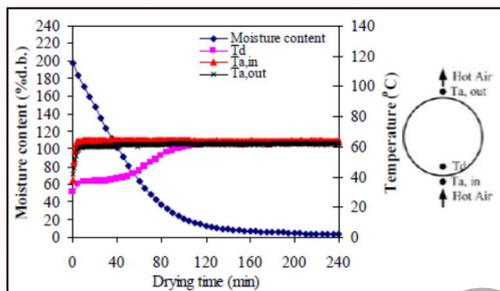


Fig. 6 Variations in moisture content and temperature of durian chips during HA drying at 65°C [T_{a,in}: Temperature of hot air at inlet of the drying chamber, T_{a,out}: Temperature of hot air at outlet of the drying chamber, T_d: Temperature of durian chips].

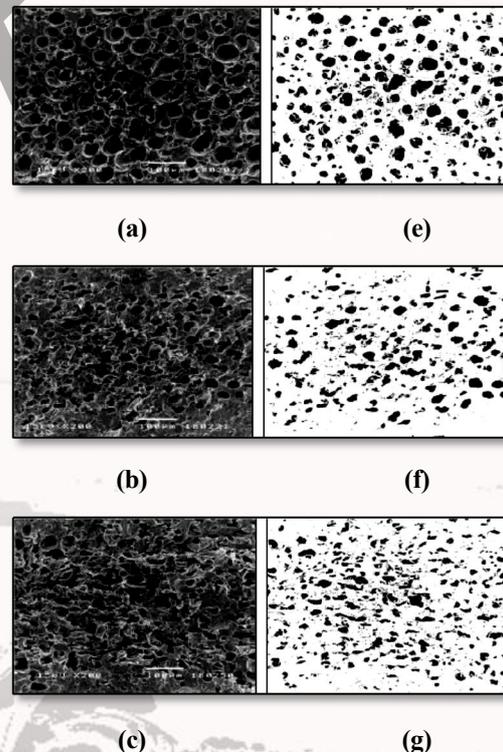
Color

The surface color of dried durian chips from the stepdown MWA and HA methods are shown in Table 1. It was found that the color of dried durian chips was in the range of lightness values (L*) of 74.46 to 80.36, greenness values (-a*) of -2.19 to -3.55 and yellowness values (+b*) of 23.63 to 28.25. All cases of dried durian chips from the step-down MWA method show more lightness (L*) and greenness (-a*) but less yellowness (+b*) when compared with the HA-dried sample. This is because of shorter drying time of the step-down MWA drying had less impact to the color of the sample while HA drying needed longer drying time and promoted non-enzymatic browning reaction. Meanwhile, changes in microwave power levels at early stage of the combined micro-wave technique were not affect the color (L*, a* and b*) of dried product because of the temperature of durian chips and the drying time were not

much different [10]. Moreover, it was also found that all cases of dried durian chips had high lightness but less greenness (-a*) and yellowness when compared to the commercial fried durian chips.

Microstructure and binary images

Fig. 7 shows the relationship between microstructure photographs of cross-section and binary images of durian chips undergoing step-down MWA and HA methods. The pore shapes of dried durian chips were assumed to be circle to quantify the porous characteristics of dried durian chips such as pore area and diameter. The porous structure of dried samples was created during drying which depended on the drying methods. It can be seen that the dried durian chips obtained by the step-down MWA method had larger porous structure than those dried by the HA method. This is because of high temperature of material obtained by the step-down MWA drying leads to rapid evaporation of moisture from interior to surface of the layer which developed high vapor pressure inside the chips to create porous structure as a result [21].



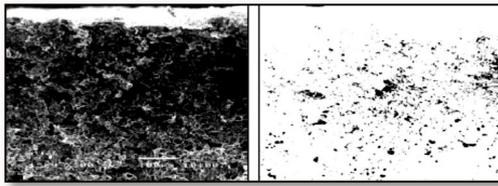
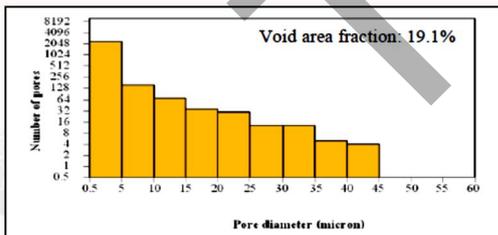
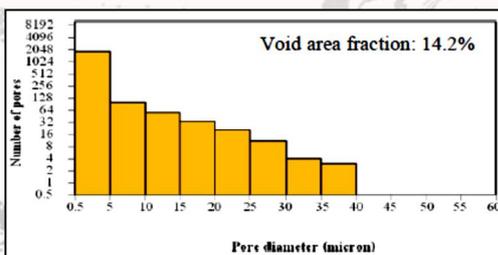


Fig. 7 Microstructure images of cross section (a-d) and binary images (e-h) of dried durian chip at different experiment: (a) and (e) W800+HA65/ MW400+HA65/MW250+HA65, (b) and (f) MW700+HA65/MW400+ HA65/MW250+HA65, (c) and (g) MW600+HA65/MW400+HA65/ MW250+ HA65, (d) and (h) HA65.

Fig. 8 shows the pore size distribution of durian chips dried by step-down MWA and HA methods. Dried durian chips obtained by the step-down MWA drying had a larger number of the pore diameter in the range of 20-45 μm . While those from the HA drying had pore size less than 20 μm . This is due to the porous structure developed under the step-down MWA drying as mentioned. The pore size and the void area fraction of dried samples depended on the microwave power level at the first stage of drying. Dried durian chips under 800 W microwave power at the first stage had a larger number of pore diameter more than 40-45 μm while the samples under 700 W and 600 W had pore size less than this range.

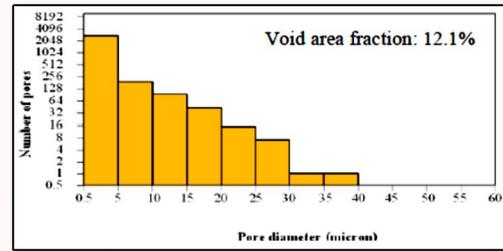


(a) MW800+HA65/MW400+HA65/MW250+HA65

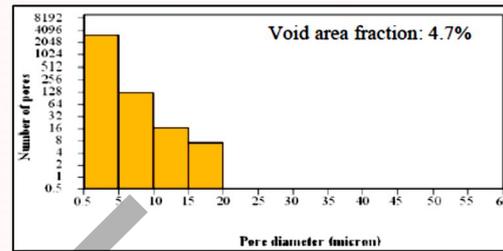


(b) MW700+HA65/MW400+HA65/MW250+HA65

Table 1 Color of dried durian chip



(c) MW600+HA65/MW400+HA65/MW250+HA65



(d) HA65
 Fig. 8 Pore size distribution of durian chips undergoing step-down MWA and HA methods.

The effects of step-down MWA and HA drying methods on the percentages of shrinkage of dried durian chips are shown in Table 2. It was observed that the percentages of shrinkage of dried durian chips from the step-down MWA method were significantly lower than HA-dried durian chips. This is because of the step-down MWA drying provided larger porous structure inside the material as shown in Fig. 7 and Fig. 8 which is led to low percentages of shrinkage of the dried samples. However, an increase in the microwave power input from 600 to 800 W at the first stage of the step-down MWA drying were not affect the shrinkage of dried samples as shown in Table 2.

Table 2 Percentages of shrinkage of dried durian chips

Drying method	Shrinkage (%)
MW800+HA65/MW400+HA65/MW250+HA65	55.86 \pm 2.61a
MW700+HA65/MW400+HA65/MW250+HA65	58.37 \pm 2.65ab
MW600+HA65/MW400+HA65/MW250+HA65	60.79 \pm 1.75b
HA65	77.80 \pm 1.94c

Superscripts at different in the same column of this table are significantly different at $p < 0.05$

Drying method	L*	a*	b*	Drying time (min)
MW800+HA65/MW400+HA65/MW250+HA65	80.14±1.45c	-3.04±0.44c	24.20±2.00a	35
MW700+HA65/MW400+HA65/MW250+HA65	80.28±1.20c	-3.38±0.54bc	24.12±3.09a	47
MW600+HA65/MW400+HA65/MW250+HA65	80.36±1.19c	-3.55±0.24b	23.63±1.61a	56
HA65	74.46±1.94b	-2.19±0.15d	28.25±1.99b	240
Commercial fried durian chip	62.74±1.52a	-6.42±0.97a	40.25±1.83c	-

Superscripts at different in same column of this table are significantly different at $p < 0.05$.

CONCLUSION

Drying of durian chips using combined microwave-hot air (MWA) drying with step-down microwave power input technique and hot air (HA) drying were investigated. The results showed that all cases of the step-down MWA drying had higher drying rates than in the HA drying. The drying rate also depended on the microwave power at the first stage of drying. The step-down MWA drying provided dried durian chips with higher lightness and more porous structure, but lower percentages of shrinkage than the HA method. However, an increase in the microwave power in the step-down MWA drying was not significant difference on qualities of dried durian chips. In addition, dried durian chips from the step-down MWA drying provided more lightness but lower values of greenness and yellowness when compare to the commercial fried durian chips.

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REFERENCES

- [1] Timkhum, P. and Terdwongworakul, A. Non-destructive classification of durian maturity of 'Monthong' cultivar by means of visible spectroscopy of the spine. *Journal of Food Engineering*. 112: 263-267 (2012)
- [2] Office of Agricultural Economics, Thailand. Import-export statistic, <http://www.oae.go.th> (accessed on 29/08/2014).
- [3] Jamradloedluk, J. Nathakaranakule, A. Soponronnarit, S. and Prachayawarakorn, S. Influences of drying medium and temperature on drying kinetics and quality attributes of durian chip. *Journal of Food Engineering*. 78: 198-205 (2007)
- [4] Bai-Ngew, S., Therdtthai, N. and Dhamvithee, P. Characterization of microwave vacuum-dried durian chips. *Journal of Food Engineering*. 104: 114-122 (2011)
- [5] Raikham, C., Prachayawarakorn, S., Nathakaranakule, A. and Soponronnarit, S. Optimum conditions of fluidized bed puffing for producing crispy banana. *Drying Technology*. 31: 726-739 (2013)
- [6] Bai-Ngew, S., Therdtthai, N. and Dhamvithee, P. Characterization of microwave vacuum-dried durian chips. *Journal of Food Engineering*. 104: 114-122 (2011)
- [7] Drouzas, A.E., Tsami, E. and Saravacos, G.D. Microwave/vacuum drying of model fruit gels. *Journal of Food Engineering*. 39: 117-122 (1999)
- [8] Zhang, M., Tang, J., Mujumdar, A.S. and Wang, S., A. Trends in microwave-related drying of fruits and vegetables. *Trends in Food Science & Technology*. 17: 524-534 (2006)
- [9] Soysal, Y., Ayhan, Z., Esturk, O. and Arikan, M.F. Intermittent microwave-convective drying of red pepper: drying kinetics, physical (colour and texture) and sensory quality. *Biosystems Engineering*. 103: 455-463 (2009)
- [10] Pereira, N.R., Jr, M.A. and Ahrne, L.M. Effect of microwave power, air velocity and temperature on the final drying of osmotically dehydrated bananas. *Journal of Food Engineering*. 81: 79-87 (2007)
- [11] Lin, Z., Raghavan, G.S.V. and Orsat, V. Temperature and power control in microwave drying. *Journal of Food Engineering*. 97: 478-483 (2010)
- [12] Díaz, G.R., Martínez-Monzó, J., Fito, P. and Chiralt, A. Modeling of dehydration-rehydration of orange slices in combined microwave/air drying. *Innovative Food Science and Emerging Technologies*. 4: 203-209 (2003)
- [13] Giri, S.K. and Prasad, S. Drying kinetics and rehydration characteristics of microwave-vacuum and convective hot-air dried mushrooms. *Journal of Food Engineering*. 78: 512-521 (2007)
- [14] Mousa, N. and Farid, M. Microwave vacuum drying of banana slices. *Drying Technology*. 20: 2055-2066 (2002)
- [15] Chua, K.J., Mujumdar, A.S., Hawlader, M.N.A., Chou, S.K. and Ho, J.C. Convective drying of agriculture products. Effect of continuous and stepwise change in drying air temperature. *Drying Technology*. 19: 1949-1960 (2001)

- [16] Varith, J., Dijkanarukkul, P., Achariyaviriya, A. and Achariyaviriya, S. Combined microwave-hot air drying of peeled longan. *Journal of Food Engineering*. 81: 459-468 (2007)
- [17] Association of Official Analytical Chemists Official Methods of Analysis of the AOAC International, 16th ed.; AOAC: Gaithersburg, MD (1995)
- [18] Yan, Z., Sousa-Gallagher, M.J. and Oliveira, F.A.R. Shrinkage and porosity of banana, pineapple and mango slices during air-drying. *Journal of Food Engineering*. 84: 430-440 (2008)
- [19] Clary, C.D., Mejia-Meza, E., Wang, S. and Petrucci, V.E. Improving grape quality using microwave vacuum drying associated with temperature control. *Journal of Food Science*. 72: E23-E28 (2007)
- [20] 20. Vongpradubchai, S. and Rattanadecho, P. Microwave and hot air drying of wood using a rectangular waveguide. *Drying Technology*. 29: 451-460 (2011)
- [21] Askari, G.R., Emam-Djomeh, Z. and Mousavi, M. An investigation of the effects of drying methods and conditions on drying characteristics and quality attributes of agricultural products during hot air and hot air/microwave-assisted dehydration. *Drying Technology*. 27: 831-841 (2009)

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