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Combined microwave and hot air convective dehydration on physical and biochemical qualities of dried longan flesh

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Abstract

The effect of microwave radiation densities (100 and 300 W) and hot air velocities (5 and 10 m/s) on the physical and biochemical properties as well as consumer acceptability of dried longan fleshes was investigated. It was found that the moisture in the longan dried by microwave-air convective oven was displaced faster than the traditional drying. The firmnesses of longan dried at 300 W were higher than those in longan dried at 100 W. The loss of lightness (*L* parameter) or the increase of redness (a^* parameter) in longan dried at 300 W could be associated with the increase of Maillard browning and caramelization reactions. Lowest microwave power density could be preserved total phenolic compounds, gallic acid and ellagic acid in the products greater than conventional- and high microwave power-drying techniques. Panelists were most satisfied with sensory qualities of the dried longan using microwave power 100 W with air velocity 5 and 10 m/s. It was concluded that drying at 100 W and air velocity 5 m/s was acceptable for the production of dried longan fleshes.

Introduction

Longan fruit (*Dimocarpus longan* Lour.) is an important export product in Thailand and mainly grown in the Northern region, in particular Chiang Mai, Chiang Rai and Lamphun provinces. The annual production of fresh longan is about 500,000 tons and the export volume is 80,000 tons of dried fruit (Chaikham *et al*., 2012). Longan flesh has been found to be rich in polyphenolic compounds including gallic and ellagic acids (Rangkadilok *et al.*, 2005, 2007; Chaikham and Apichartsrangkoon, 2012a, b), and many types of minerals (Wall, 2006). Gallic and ellagic acids have been proven for their pharmacological properties such as antityrosinase, antiglycated, antifungal and anticancer (Prasad *et al*., 2010; Yang *et al.*, 2011; Rangkadilok *et al*., 2012). Generally, longan has short shelf-life which affects its fresh market. Thus, it is necessary to study the post-harvest processing of longan.

Drying is an essential technique for handling longan flesh in order to prolong shelf-life, since this process inhibits enzymatic degradation and restrictions microbial growth (Ahrné *et al.*, 2007; Siriamornpun *et al*., 2012). Hot air convective dehydration is the most commonly employed commercial technique for drying vegetables and fruits. However this method is simple to accomplish, the low efficiency of heat transfer makes the qualities of dried products normally unacceptable, i.e. loss of flavor, color and nutrients (Nijhuis and Torringa, 1996; Ahrné *et al.*, 2007). Recently, microwave-combined hot air dehydration is an alternative technique for fruits and vegetables. In the air drying systems, hot air removes the water on the surface of the product, while microwave energy removes the water in the product (Alibas, 2007). Alibas (2007) noted that combination system of microwave and hot air drying can be increased the drying rate and improved the qualities of the dried products. Several studies were carried out with microwave–assisted hot air ovens and various fruits and vegetables were successfully dried such as potato (Khraisheh *et al.*, 2000), pumpkin (Alibas, 2007), banana (Ahrné *et al*., 2007) and pineapple (Botha *et al.*, 2012).

The objective of this work was to investigate the effect of microwave powers (100 and 300 W) and hot-air velocities (5 and 10 m/s) on the physical and biochemical properties as well as consumer acceptability of dried longan fleshes as compared to conventional dried sample.

Materials and Methods

Longan fruits and drying conditions

Fresh longans (cv. *Daw*) from an orchard in

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Chiang Mai, Thailand were peeled, removed the seeds and cleaned. The fleshes were kept at room temperature to drain for 15 min, subsequently divided into 5 groups. The first was dried using a hot air oven (Tray dryer, Navaloy, Thailand) at 60°C and air velocity of 0.5 m/s for 10 h (Rithmanee and Intipunya, 2012), which used as the control. Groups 2-5 were dried by combined microwave radiation power with hot air convection. The drying conditions are shown in Table 1.

The microwave-assisted hot air drying equipment was developed in the Research Unit of Food Product from Nature, Science and Technology Research Institute, Chiang Mai University, Chiang Mai, Thailand. The equipment consisted of Electrolux EMS26405X microwave oven (Bangkok, Thailand) and electric heater. The bottom of the microwave oven was connected to a hot air tube to provide the hot air up to 60°C using a heater with air velocity between 5-10 m/s. The rotation speed of the polypropylene tray with a diameter of 200 mm was around 10-15 rpm.

Determination of moisture content and water activity

Moisture content of samples was analyzed according to AOAC method (AOAC, 2000) by an oven method at 105°C. Water activity of the samples was analyzed using an AquaLab Water Activity Metre (Decagon, USA).

Firmness measurement

Firmness of the dried samples was analyzed using a TA-XT Plus Texture Analyser (Stable Micro Systems Ltd., Guildford, UK) with a Warner Bratzler blade set. The blade traveling speed was set at 1 mm/s, and distance traveled by the blade through the sample was 30 mm in order to make a complete cut of the samples. The maximum force used to cut the sample was recorded as the firmness value (N) (Rithmanee and Intipunya, 2012).

Color parameter assessments

A colorimeter (Minolta Chroma Meter, CR-300, Japan) was used to measure the color parameters of the samples. Analytical data were expressed as Hunter *L* (lightness), a^* (greenness/redness) and b^* (yellowness/blueness) parameters.

Determination of 5-hydroxymethylfurfural content

5-Hydroxymethylfurfural (HMF) was determined using a modified High-Performance Liquid Chromatography (HPLC) method described by Alcazar *et al.* (2006). Five grams of dried longan were blended with 50 ml deionized water for 20 min and filtered through a 0.20 µl nylon filter, then filtrate used for HPLC assay. The HPLC system (Shimadzu LC-10AD; Shimadzu, Kyoto, Japan) consisted of a low-pressure pump and a photodiode array detector (SPD-M20A; Shimadzu) adjusted to λ_{max} 280 nm. Chromatographic separation was performed with a C18 column (YMC-Pack ODS-AM, 5 µm, 4.6 mm ID x 250 mm; YMC, Kyoto Japan). The isocratic system used a mixture of 18% (v/v) acetonitrile (Merck, Munich, Germany) and 82% (v/v) mixed acid solution (the mixture of 2 ml acetic acid and 0.2 ml phosphoric acid in 997.8 ml deionized water), as a mobile phase with a flow rate of 1 ml/min at 35°C. A 20 µl sample was injected into the column. Standard HMF (Sigma–Aldrich, St. Louis, MO) was dissolved in acetonitrile to obtain the concentrations of 2-10 mg/L for the calibration curve. The peak area of each component was determined and converted to concentration.

Determination of reducing sugar

The dinitro salicylic acid (DNS) assay was used to determine the concentration of reducing sugar of dried longan extract (Chaplin and Kennedy, 1994; Charalampopoulos and Pandiella, 2010). A 1 g of dried longan was blended with 99 ml distill water for 10 min and filtered through a Whatman® paper No. 41 (Whatman International Inc., New Jersey, USA). The concentration of reducing sugar was measured by adding 0.1 ml of DNS reagent (Sigma–Aldrich) to 9.9 ml of filtered sample in a capped test tube. The mixture was mixed and heated up at 100°C for 10 min, then cooled down to room temperature in a water bath. The absorbance was measured using a spectrophotometer (Perkin Elmer UV WINLAB; Perkin Elmer, Waltham, MA) at λ_{max} 570 nm. A standard curve was constructed using L-glucose (Sigma–Aldrich) at various concentrations.

Determination of total phenolic compounds

Total phenolic contents were determined using the Folin–Ciocalteu reagent (Chaikham and Apichartsrangkoon, 2012a, b). Ten grams of dried longan were blended with 8 ml of 100% ethanol for 5 min using a blender (National, Thailand) with highest speed, and centrifuged (Hettich zentrifugen, Rotina 46R, Germany) at 4000 rpm for 15 min. A 0.5 ml aliquot of supernatant was added to 2.5 ml of 10% Folin–Ciocalteu reagent (Sigma–Aldrich) and allowed to react for 5 min. Subsequently, 2 ml of saturated sodium carbonate solution (Ajax, Sydney, Australia) were added to the mixture and held for 2 h at room temperature. The apparent blue complex

was determined using a Perkin Elmer UV WINLAB spectrophotometer at λ_{max} 765 nm (Perkin Elmer). Total phenolic contents were expressed as mg gallic acid equivalent per 100 g sample (mg GAE/100 g).

Determination of gallic and ellagic acids

Gallic and ellagic acids were determined using a HPLC method described by Rangkadilok *et al.* (2005) and Chaikham and Apichartsrangkoon (2012a, b) with some modifications. Five grams of dried longan were blended with 10 ml of 100% methanol for 5 min and stirred using a magnetic stirrer for 30 min, subsequently centrifuged at 4000 rpm at 25°C for 15 min. The supernatant was filtered through a 0.20 µm nylon membrane and the filtrate used for HPLC assay. The mobile phase was a mixture of 0.4% formic acid (solvent A) and 100% methanol (solvent B) with a flow rate of 1.0 ml/min. The gradient system of the mobile phase commenced from 0 min (100% A) to 4 min (95% A), 10 min (70% A), 16 min (66% A), 22 min (45% A), 28 min (55% A), and 34 min (100% A), and maintained at this state to 40 min. The temperature of the column was adjusted to 25°C and UV detection was at λ_{max} 270 nm with an injection volume of 20 µl. Standard gallic and ellagic acids (Sigma–Aldrich) were separately diluted in methanol to obtain the concentrations of 1-5 mg/L for the calibration curves. Peak areas were determined and converted to the content of each component.

Sensory evaluation

Sensory evaluation was carried out using 50 Thai panelists. The evaluation method applied a 9-point hedonic scale (9 = like extremely, 5 = neither like nor dislike, 1 = dislike extremely), testing scores of above 5.0 were considered to be acceptable. Sensory attributes considered were color, odor, taste, texture and overall acceptability. Samples consisted of 2 pieces (~ 10 g) of dried longan fleshes and were identified using a 3-digit random number. Samples were presented to the panelists on a plastic cup and served at room temperature. Panelists were advised to rinse their mouth with water between each test (Chattong and Apichartsrangkoon, 2009).

Statistical analysis

All data were the means of triplicate determinations with individual duplication (n = 6). Analysis of variance (ANOVA) was carried out by using the SPSS Version 14.0 (SPSS Inc., Chicago, USA), and the determination of significant differences among treatment means was done by Duncan's multiple range tests ($P \leq 0.05$).

Results and Discussion

Moisture content and water activity of dried longan flesh were fixed at not exceeding 18% and 0.6 respectively, according to Thailand Agricultural Standard for dried longan flesh (No. TAS 8-2006; Thai Agricultural Standard, 2006). This study showed that moisture content and water activity of all dried longan fleshes were between 13.72-16.42% and 0.46-0.59 respectively (Table 2), which were in accord with the limits of the standard above. The longan dried at 100 W and air flow rate of 5 m/s still remained higher moisture ($P \leq 0.05$) than the control and other microwave-dried samples. The increase of hot air velocity during microwave drying from 5 to 10 m/s could enhance the reduction of moisture content and water activity in the samples. Ahrné *et al.* (2007) stated that air velocity has an important role during microwave drying, not only as a carrier of evaporated moisture but also as it contributes to a more homogeneous and faster drying process. In overall, the total water in the longan was heated quickly causing the elimination of the slow rate drying step, thus the production time for high microwave power drying was shorter than that of low microwave power and traditional drying in that order (Table 1). The fast internal heat generation caused by microwave energy on the beginning of drying causes a fast increase in product temperature and a large vapor differential between the center and the surface of the product, leading to a high moisture loss (Pereira *et al*., 2007). Ahrné *et al.* (2007) dehydrated banana (10 mm thick) under various conditions of convective microwave power, and found that increase of microwave power from 400 to 800 W caused a reduction of the drying time at 40°C of 62% and at 60°C of 47%.

Firmness is one of the most desirable attributes of dried longan flesh. Analysis of the texture showed that firmnesses of highest microwave power-dried longans were higher than those in longan dried at 100 W. At high microwave power, the firmness significantly rose ($P \leq 0.05$) when hot-air velocity increased, while a non-significant difference ($P > 0.05$) of this quality in low microwave power-dried samples was observed (Table 2). This result indicated that high microwave power-drying of longan brought into the higher stress at maximum forces applied than hot air- and low microwave power-dried longans. The firmness increased due to loss of moisture during drying, which can be seen that the sample with the lowest moisture content had the highest firmness value.

Color is an appearance property of food products

Table 1. Drying conditions for dehydrating the longan flashes using hot air and microwave-hot air ovens at temperature 60°C

Drying conditions	Drying times
Conventional drying with hot-air flow rate 5 m/s (control)	10 h
Microwave power 100 W and hot-air flow rate 5 m/s	3 h
Microwave power 100 W and hot-air flow rate 10 m/s	3 h
Microwave power 300 W and hot-air flow rate 5 m/s	1 h 30 min
Microwave power 300 W and hot-air flow rate 10 m/s	1 h 30 min

Table 2. Moisture content, water activity and firmness of longan fleshes dried by hot air and microwave-hot air ovens at temperature 60°C

Treatment conditions	Moisture contents (g/100 g)	Water activity (a_w)	Firmness (N)
Control	15.36±0.23^{b}	0.53±0.02^{bc}	64.53±1.26^{c}
100 W:5 m/s	16.42±0.36^{a}	0.59±0.02^{a}	65.57±0.65^{c}
100 W:10 m/s	15.19±0.84^{b}	0.55±0.02^{b}	63.94±2.27^{c}
300 W:5 m/s	15.78±0.19^{b}	0.50±0.01^{c}	75.92±3.07^{b}
300 W:10 m/s	13.72±0.72^{c}	0.46±0.01^{d}	86.57±5.29^{a}

Means of the same letters within each column are not significantly different ($P > 0.05$). Means were the analysis of triplication.

Table 3. Color parameters of longan fleshes dried by hot air and microwave-hot air ovens at temperature 60°C

Treatment conditions	Color parameters		
	L	*a**	*b**
Control	43.25±1.45^{b}	7.63±0.21^{c}	12.49±0.24^{b}
100 W:5 m/s	46.65±0.67^{a}	5.12±0.09^{e}	14.30±0.28^{a}
100 W:10 m/s	46.66±1.36^{a}	6.07±0.23^{d}	14.55±0.27^{a}
300 W:5 m/s	38.87±1.43^{c}	8.17±0.08^{b}	12.48±0.43^{b}
300 W:10 m/s	37.65±1.14^{c}	9.56±0.12^{a}	10.41±0.43^{b}

Means of the same letters within each column are not significantly different ($P > 0.05$). Means were the analysis of triplication.

that affects the consumer acceptance. Table 3 shows that lightness value (L) significantly improved ($P \leq 0.05$) in dried longan at low microwave power, whereas this parameter of high microwave power-dried samples apparently depreciated ($P \leq 0.05$), as compared to the control. The redness parameters (a^*) of high microwave power-dried samples were significantly higher ($P \leq 0.05$) than those of low microwave power-dried and control batches. It was interesting to note that this parameter of both microwave power-dried samples remarkably increased ($P \leq 0.05$) with the increasing hot-air velocity (Table 3). Besides lightness and redness, the yellowish (b^*) of longan dried at 300 W was significantly lower ($P \leq 0.05$) than others, while the highest values were observed in both dried longans at 100 W (Table 3). In all over, amongst microwave-dried longans the loss of lightness or the increase of redness could be associated with the increase of Maillard browning and caramelization reactions, in particular high microwave power-dried products. The non-enzymatic or Maillard degradation usually takes place between alpha-amino groups and reducing sugars or ascorbic acid decomposition or destruction of pigments (Landl *et al*., 2010; Wang and Ho, 2008). The highest yellowish of low microwave power-dried batches presented the good quality for dried longan flesh which it became golden-yellow (Rithmanee and Intipunya, 2012).

HMF could be formed in sugar-rich foods during thermal processing. The results from Table 4 showed that HMF was not detected in the control and longans dried at 100 W, while dried samples at high microwave power (300 W) with high air velocity (10 m/s) showed the highest content of this brown compound ($P \leq 0.05$). This result corresponded to the decrease in L^* parameter and increase in a^* parameter (Table 3). Ameur *et al.* (2006) revealed that HMF is not present in fresh or untreated foods, but it rapidly accumulates in sugar-rich foods during heating. Longan flesh contains high sugar contents (total soluble solids ~ 15%), mainly sucrose, glucose and fructose (data not shown). Li *et al.* (2011) studied the influence of microwave irradiation power on dehydration of fructose in the ionic solution, and observed that HMF has been rapidly produced under various power densities (400-800 W). Tosi *et al.* (2002) found that thermal processing (100-160°C) could enhance the formation of HMF in honey. The accumulation of HMF is considered undesirable in thermally processed foods, and its presence in food is focused on some potential toxicological concern, such as genotoxicity and mutagenicity (Abraham *et al.*, 2011; Zhang *et al*., 2012). For food quality assurance, HMF legal limits were already issued for some foodstuffs sets up a limit of 25 ppm (Zhang *et al*., 2012). However, the amounts of HMF in high microwave power-dried longans were still within the limits of this standard.

The amounts of reducing sugar in high microwave power-dried longans (300 W) were significantly lower ($P \leq 0.05$) than those of dried samples at 100 W and control (Table 4). This result showed that non-enzymatic browning including Maillard and caramelization reactions occurred during the heating process under high microwave power density (300 W), which led to the reduction of reducing sugar in the samples. During the heating process, Maillard reaction occurs between reducing sugars and amino acids or proteins (Sapers, 1993). Sucrose can be hydrolyzed during heating to obtain two reducing sugars including glucose and fructose (Naknean *et al.*, 2009). Further degradation of these products is responsible for the formation of brown-pigment compounds, in particular HMF (Clarke *et al*., 1997; Quintas *et al*., 2007).

Phenolic compounds are highly found in various fruits and they have been reported to have strong antioxidant activities (Chaikham and

Table 4. 5-Hydroxymethylfurfural, reducing sugar and phenolic acid contents of longan fleshes dried by hot air and microwave-hot air ovens at temperature 60°C

Treatment conditions	HMF (ppm)	Reducing sugar (g/100 g)	Total phenolic compounds (mg GAE/100 g)	Phenolic compounds (mg/100 g)	
				Gallic acid	Ellagic acid
Control	nf^{c}	14.32±0.53^{a}	320.18±3.56^{b}	0.95±0.25^{b}	7.85±0.62^{b}
100 W:5 m/s	nf^{c}	15.30±0.90^{a}	369.15±5.18^{a}	1.38±0.34^{a}	9.10±0.51^{a}
100 W:10 m/s	nf^{c}	15.67±0.57^{a}	375.45±4.17^{a}	1.46±0.12^{a}	8.96±0.45^{a}
300 W:5 m/s	4.29±0.35^{b}	10.87±0.41^{b}	319.18±6.01^{b}	0.85±0.13^{b}	7.49±0.41^{b}
300 W:10 m/s	7.26±1.72^{a}	10.26±0.28^{b}	324.16±3.49^{b}	0.98±0.15^{b}	7.56±0.33^{b}

Means of the same letters within each column are not significantly different (P > 0.05). Means were the analysis of triplication.

Table 5. Sensory attribute scores of longan fleshes dried by hot air and microwave-hot air ovens at temperature 60°C

Treatment conditions	Preference scores				
	Color	Odor^{ns}	Taste	Texture	Overall acceptability
Control	5.40±0.64^{b}	6.45±0.44	6.59±0.53^{a}	6.50±0.49^{a}	6.03±0.36^{b}
100 W:5 m/s	6.68±0.52^{a}	6.50±0.50	6.85±0.37^{a}	6.43±0.55^{a}	6.82±0.50^{a}
100 W:10 m/s	6.74±0.39^{a}	6.18±0.42	6.54±0.45^{a}	6.54±0.36^{a}	6.55±0.43^{a}
300 W:5 m/s	4.60±0.33^{b}	6.13±0.46	4.09±0.28^{b}	4.28±0.31^{b}	4.41±0.39^{b}
300 W:10 m/s	4.52±0.35^{b}	5.90±0.59	4.18±0.42^{b}	3.95±0.38^{b}	4.05±0.40^{b}

Means of the same letters within each column are not significantly different (P > 0.05). ns is non significantly different. Means were the analysis of 50 replications.

Apichartsrangkoon, 2012a, b). The antioxidant potential of phenolic compounds is dependent on the number and arrangement of the hydroxyl groups as well as the presence of the electron-donating substitute in the ring structure (Elzaawely *et al*., 2007; Siriamornpun *et al*., 2012). As shown in Table 4, total phenol, gallic acid and ellagic acid contents of longans dried at high microwave power (300 W) and control were 319.18-324.16 mg GAE/100 g, 0.85-0.98 mg/100 g and 7.49-7.85 mg/100 g respectively, which were significantly lower ($P \leq 0.05$) than those of low microwave power-dried batches. Hayat *et al.* (2010) dried citrus mandarin pomace under different microwave power densities (125-500 W), and found that the total phenolic contents were decreased with increasing microwave power. This indicated that some phenolic compounds possibly were degraded by microwave treatment. In addition, the reduction of these components in conventional drying (control sample) might be due to the oxidation degradation by polyphenol oxidase and peroxidase during drying, which further produces brown pigments in the products (Rithmanee and Intipunya, 2012). Tanongkankit *et al.* (2010) found that total phenolic compounds of white cabbage outer leaves (*Brassica oleracea* L. var. capitata) dried by hot air were extremely diminished. Reyes *et al.* (2010) stated that various disadvantages of hot air-drying are described as a longer drying time, damage to sensory characteristics and to the nutritional properties of foods, oxidation of pigments and destruction of vitamins, and solute migration from the interior of the food to the surface. Conventional drying with milder temperatures (~50-60°C) may release oxidative and hydrolytic enzymes due to the disruption of cell walls which can destroy the antioxidants and phenolic acids in fruits and vegetables (Chism and Haard, 1996; Dewanto *et al.*, 2002). Wojdylo *et al.* (2009) revealed that the exposure to high temperature level for a short time such as microwave drying can inactivate these enzymes and protect the phenols from further decomposition. Yousif *et al.* (2000) illustrated that a greater susceptibility of oxidation was observed in hot air dried oregano as compared to the sample dehydrated by freeze and vacuum microwave drying, since the presence of heat and oxygen, enzymatic activity of polyphenol oxidase is favored. Overall, low microwave power density (100 W) could be preserved nutrients in the products greater than conventional and high microwave power drying.

Table 5 displays preference scores for the dried longans. The product specific color, taste and texture scores of both low microwave power-dried samples were significantly higher ($P \leq 0.05$) than those of high power-dried batches; while the odor scores of these products were not significant difference ($P \leq 0.05$). The highest color scores in low microwave power-dried samples might be due to the color of dried longan became golden-yellow which is the good quality for dried longan, this result was in accord with the color parameters (L, a^* and b^*) as presented in Table 3. Longan dried at 300 W showed the lowest

taste scores ($P \leq 0.05$) which might be due to the formation of bitter components such as HMF (Table 4). The texture scores of high microwave power-dried samples were apparently lesser ($P \leq 0.05$) than that of samples dried at 100 W, since the textures (firmness) of the former samples were considerably harder (Table 2). Therefore, drying at microwave power 100 W was acceptable for the production of dried longan fresh.

Conclusion

Overall, this study indicated that the moisture in the longan flesh dried by microwave-air convective oven was promptly heated causing the elimination of the slow rate drying step, thus the production time for this method was shorter than the traditional drying. The firmnesses of longan dried at 300 W were higher than those in longan dried at 100 W, and significantly rose when hot air velocity increased. Amongst microwave-dried longans the loss of lightness or the increase of redness could be associated with the increase of Maillard browning and caramelization reactions, particularly longan dried at 300 W. Low microwave power density (100 W) could be preserved nutrients (total phenolic compounds, gallic acid and ellagic acid) in the products greater than conventional and high microwave power drying. Panelists were most satisfied with sensory qualities of longan flesh dried at microwave power 100 W with air velocity 5 and 10 m/s.

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