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Foam-mat drying of passion fruit aril

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Abstract

This study was aimed to determine the effect of methylcellulose concentration and whipping time on the properties of passion fruit aril foam. The effect of foam-mat drying conditions on moisture diffusivity, physicochemical, microbiological and antioxidant properties of the dried product was also investigated. Passion fruit aril incorporated with methylcellulose at a mass concentration of 0.75%, 1.5%, 2.25% and 3.0% was whipped for 0 min, 10 min, 20 min and 25 min. The passion fruit aril foam mats (1-mm, 2-mm and 3-mm thick) were dried at 60°C, 70°C and 80°C with a constant air velocity of 0.5 m/s. The optimum condition for forming foam was 2.25% methylcellulose after 25 min whipping as it provided the highest foam expansion (187.25%) and stability as well as the lowest foam density (0.41 g/ml). Drying the passion fruit aril foam chiefly occurred in the falling rate period. Effective moisture diffusivity increased with increasing temperature and foam thickness. This value ranged from 1.06×10^{-7} m^2/s to 1.01×10^{-6} m^2/s. Passion fruit aril foam (1-mm thick) dried at 70°C for 90 min showed the highest amount of ascorbic acid and β-carotene as well as antioxidant activity (assayed by DPPH and ABTS methods) ($p\leq0.05$). Based on microbial counts, freshly prepared foam-mat dried passion fruit aril samples were considered safe.

Introduction

Passion fruit *(Passiflora edulis)* is one of the most common tropical plants grown in Thailand. The aril part of this fruit is a good source of ascorbic acid (vitamin C) and carotenoids, which are strong antioxidants. It has a rich flavor and is pleasantly aromatic (Lopez-Vargas *et al.*, 2013; Seixas *et al.*, 2014). Passion fruit aril presents high water content, which makes it perishable and has a relatively short shelf-life. Therefore, the conversion of passion fruit aril into a dried form makes it available year round and extends its shelf-life. Passion fruit powder produced from the passion fruit aril can be used as a flavoring ingredient in many products such as ice cream and yogurt. Passion fruit powder can be prepared by spray drying, freeze drying and vacuum drying (Angel *et al.*, 2009; Borrmann *et al.*, 2013). The good choice for drying passion fruit, especially the aril part would be simple, low-cost, rapid, lower energy and include the foam-mat technique.

Foam-mat drying is a process by which liquid or semi-solid foods are whipped to form foam in the presence of foaming and/or stabilizing agents. The foam is then spread in a thin layer and dried in a hot air stream (Rajkumar *et al.*, 2007; Thuwapanichayanan *et al.*, 2008). The dried foam obtained is conditioned and powderized (Rzepecka *et al.*, 1975; Sangamithra *et al.*, 2014). The open structure of the foam accelerates internal moisture removal and the drying rate (Auisakchaiyoung and Rojanakorn, 2015). Foam-mat dried products are comparatively stable against microbiological, chemical and biochemical deterioration and have high retention of color, flavor, vitamin and sensory characteristics (Kadam and Balasubramanian, 2011; Kadam *et al.*, 2012). In addition, foam-mat drying provides an excellent ability to process hard-to-dry materials (Falade and Okocha, 2010; Kadam and Balasubramanian, 2011; Sangamithra *et al.*, 2014). Foam-mat drying is, therefore an alternative and suitable technique for small scale drying industry. Many researchers reported that processing parameters including foam thickness, foam density and drying temperature had affected the physicochemical and microbiological properties of foam-mat dried products (Rajkumar *et al.*, 2007; Thuwapanichayanan *et al.*, 2008; Falade and Okocha, 2010; Kandasamy *et al.*, 2012; Auisakchaiyoung and Rojanakorn, 2015).

As stated earlier, production of dried passion fruit can be performed using various drying techniques (i.e., spray drying, vacuum drying and freeze drying). Details on foam-mat drying of passion fruit aril is not available so the objectives of this current study

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were (a) to determine the effect of methylcellulose concentration and whipping time on foam properties and (b) to investigate the effect of foam thickness and drying temperature on drying behavior, physicochemical, microbiological and antioxidant properties of foam-mat dried passion fruit aril.

Materials and Methods

Preparation of passion fruit aril

Fresh and fully ripe yellow passion fruit (*Passiflora edulis* var. *flavicarpa*) with similar peel colors, commonly used in fruit juice processing were purchased from the market in Phetchabun province, Thailand between July-August, 2015. Within 24 h, they were transported in plastic boxes to the food-processing laboratory, Khon Kaen University, in the Northeast of Thailand. The fruits were washed with tap water, left to dry at room temperature (32±1°C) and then cut into the halves. The whole seed covering with yellow aril was removed and the aril manually separated through a stainless sieve. All of the aril was thoroughly mixed in a bowl mixer to obtain a uniform sample.

Foaming experiment

Methylcellulose (Methocel® MC with 27.5% to 32% methoxyl basis, viscosity range of 300-560 mPa.s for 2% solution in water at 20°C, SIGMA, USA) was used as a foaming agent in this experiment as it is water soluble, enzyme resistant and stable over a large range of pH (3-11). It is non-toxic for humans and not digestible in the body. It stabilizes foams due to its ability to reduce surface and interfacial tensions even use in a small amount. In addition, it does not change the color and flavor of food products (Nasatto *et al*., 2015).

Passion fruit aril (12.40°Brix, pH 3.12) was mixed with methylcellulose solution of a certain concentration to form a mixture with different final concentrations of methylcellulose (0.75%, 1.5%, 2.25% and 3.0% w/w). The mixtures were then whipped to form foam in a mixer (Kitchen Aid, Model ULM-400, USA) at a maximum speed of 1400 rpm for a respective 0 min, 10 min, 20 min and 25 min. The density, expansion ability and stability of the resulting foam from different conditions were evaluated.

The density of foamed passion fruit aril was determined as per Auisakchaiyoung and Rojanakorn (2015) with some modifications. Briefly, 200 ml of foam were transferred into a pre-weighed and tared 250-ml measuring cylinder. The mass of the foam was then recorded. Density of the foam was calculated by dividing the mass of the foam by its volume.

$$Foam\ density = \frac{Mass\ of\ the\ foam\ (g)}{Volumn\ of\ the\ foam\ (ml)} \quad (1)$$

Foam expansion was determined using the following expression (Rajkumar *et al*., 2007):

$$Foam\ expansion = \left(\frac{V_1 - V_0}{V_0}\right) \times 100 \quad (2)$$

where V_o is initial volume of passion fruit aril-methylcellulose mixture and V_1 is the volume of foam, ml.

The stability of the resulting foam was determined according to Auisakchaiyoung and Rojanakorn (2015) with slight modifications. A funnel covered with a conical-shaped 1 mm metal mesh was filled with foam. The resulting foam funnel was placed on a 250 ml measuring cylinder then the apparatus assembly was put in a hot air oven (Memmert, Germany) at 70°C for 1 h. Afterwards, the volume of liquid separated from the foam was recorded.

This experiment was performed in triplicate and the mean values and standard deviation reported.

Foam-mat drying experiment

Passion fruit aril foam was dried using a batch-type cabinet tray dryer. The stable and homogeneous foam was evenly spread on the stainless steel plates (15.5×27 cm.) at a thickness of 1 mm, 2 mm and 3 mm. The foam thickness was determined by using the ratio of known volume of foam and drying area (Rajkumar *et al*., 2007). To prevent sticking of the foamed passion fruit aril after drying the plates were covered with aluminum foil as recommended by Thuwapanichayanan *et al.* (2008). The plates (each with a different foam thickness) were put in the drying chamber at 60°C, 70°C and 80°C with a constant air velocity of 0.5±0.1 m/s. Drying was terminated when the final moisture content reached ~10% (db) (Kadam and Balasubramanian, 2011), which corresponded to water activity of ~0.37. Moisture loss from the foam samples was monitored every 5 min by weighing the sample plates outside the drying chamber using an electric balance with an accuracy of 0±0.01g. The drying experiments were conducted in triplicate. The average values of experimental drying data were used to calculate the drying rate and effective moisture diffusivity.

The effective moisture diffusivity during foam-mat drying of passion fruit aril was determined by using Fick's second law of diffusion. The aril foam mats were assumed to be infinite slabs of known thickness. The equation, which describes the change of moisture content as a function of drying time during falling rate period is expressed as (Thuwapanichayanan *et al*., 2008):

$$MR = \frac{M - M_e}{M_o - M_e} = \frac{8}{\pi^2} exp\left(\frac{-\pi^2 D_{eff} t}{4L^2}\right) \quad (3)$$

where D_{eff} is the effective moisture diffusivity (m^2/s), MR is the moisture ratio, M, M_e and M_o are the average, equilibrium and initial moisture contents (kg/kg db), respectively. L in equation (3) was defined as the thickness of the slab because only the top surface of passion fruit aril foam mat was exposed to the hot air stream (Thuwapanichayanan *et al*., 2008).

As the experimental M_e is very small compared to the M_o and M values, the M_e can be assumed to be zero (Kadam and Balasubramanian, 2011; Wilson *et al*., 2012). Therefore, the moisture ratio can be simplified to:

$$MR = \frac{M}{M_o} \quad (4)$$

Equation 3 can be rewritten as:

$$MR = \frac{M}{M_o} = \frac{8}{\pi^2} exp\left(\frac{-\pi^2 D_{eff} t}{4L^2}\right) \quad (5)$$

The effective moisture diffusivity *(D_{eff})* for each drying condition was determined by fitting equation (5) to the experimental drying data using a nonlinear regression function (SPSS version 19).

Dried product analyses

The moisture content of all dried foam samples was determined according to the AOAC method (2000). Water activity was measured at 25°C using a water activity meter (Aqua Lab, USA.).

The β-carotene of dried foam samples was determined as per Kubola and Siriamornpun (2011) with slight modifications. To extract carotenoids in passion fruit powder, 1 g of dried sample was mixed with 100 ml of a mixture of extraction solvent (hexane/acetone/ethanol: 50:25:25 v/v/v) for 30 min with the help of a magnetic stirrer. The carotenoid contents were analyzed using an HPLC technique (Shimadzu LC-20A, Software CLASS-VP pumps, SPD-M20A diode array detector, Cosmosil C-18 (4.6 x 250 mm. i.d., 5 µm). The mobile phase was composed of methanol (solvent A)/acetonitrile (solvent B)/dichorometane (solvent C) 30:28:42 at flow rate of 1.0 ml/min. The column temperature was 30°C and the absorbance was read at 450 nm to determine the beta-carotene content.

Ascorbic acid content in dried foam samples was determined according to Goulas and Manganaris (2012). Briefly, 0.1 g of dried samples was extracted with 10 ml of 2% meta-phosphoric acid and filtered. One ml of the filtrate was mixed with 9 ml of 2, 6-dichloroindophenol (50 mmol/lit) and the absorbance of the resulting mixture was measured at 515 nm. Ascorbic acid content was quantified using a standard curve and expressed as mg/g dry matter.

The extraction of antioxidants in passion aril powder samples followed the method of Kubola and Siriamornpun (2011); by mixing 1 g of dried samples with 10 ml of 80% methanol for 2 h at ambient temperature on a shaker set at 180 rpm. The resulting mixture was centrifuged at 1400 x g for 20 min then the supernatant was collected in a 30-ml vial. The residue was re-extracted under the same conditions and the supernatant combined and used for antioxidant activity assays. The procedure for the DPPH assay followed the method reported by Thaipong (2006) with some modifications. The stock solution containing 0.0024 g DPPH and 100 ml methanol was prepared. Then 3 ml of stock solution was mixed with 77 µl deionized distilled water to obtain the working solution with an absorbance of 1.1±0.02 units at 515 nm using the spectrophotometer. Passion fruit aril extracts (77 µl) were allowed to react with 3 ml DPPH solution for 15 min in the dark then the absorbance was measured at 515 nm. Methanol (99.95%) was used as the blank. The standard curve was linear between 0.0-0.25 mg Trolox/ml. The results were expressed as Trolox equivalents per gram of dry weight (mg/g).

The ABTS assay was performed as per Thaipong (2006) with modifications. The two stock solutions including 7.0 mM $ABTS^{•+}$ solution and 2.45 mM potassium sulfate solution were prepared. The working solution was prepared by mixing 2 ml of 7.0 mM $ABTS^{•+}$ solution and 1 ml of 2.45 mM potassium sulfate solution and allowing them to react for 12 h at ambient temperature in the dark. The solution was then diluted by mixing $ABTS^{•+}$ solution with 5 mM of phosphate buffered saline to obtain an absorbance of 0.07±0.02 units at 734 nm using a spectrophotometer. Fresh $ABTS^{•+}$solution was prepared for each assay. The passion fruit aril sample extracts (10 µl) were reacted with 1 ml of 7 mM $ABTS^{•+}$ working solution in a vessel and the mixture vortexed for 1 min. The absorbance was measured at 734 nm using a spectrophotometer with 5 mM of phosphate buffered saline as the blank. Antioxidant activity was calculated and expressed as Trolox equivalents per gram of dry weight (mg/g) based on the Trolox standard curve.

All the microbial parameters of freshly prepared passion fruit aril powder (1 day storage in an aluminum foil bag under vacuum condition) were determined as per the methods described by AOAC (2012). About 25 g samples were taken aseptically from each treatment, transferred to sterile plastic pouches and homogenized for 2 min with 225 ml sterile peptone water (0.1%) to make a 10^{-1} dilution using a stomacher Lab-Blender 400 (Seaward, London). Sterile peptone water (0.1%) was used as a diluent for making further dilution. Duplicate plates were prepared for all microbial enumeration and the counts were expressed as numbers of colony forming units per gram (CFU/g). Plate count agar (PCA; Himedia, India) and potato dextrose agar (PDA; Himedia, India) were used to enumerate total plate count and yeast and mould count, respectively, using the pour plate method. The plates were incubated at 37±1°C for 48 h and 25±1°C for 5 days for total microflora and yeast and mould counts, respectively.

Statistical analysis

The experiments were conducted in triplicate and results given as means with standard deviations. Analysis of variance and Duncan's new multiple range test were performed to identify differences among the treatment combination means using SPSS software version 19. Statistical significance was accepted at 95% probability.

Results and Discussion

Effect of methylcellulose concentration and whipping time on foam quality

Foam properties including density, expansion ability and stability were significantly affected by the interaction of methylcellulose concentration and whipping time (Table 1). At any given methylcellulose concentration, an increment of whipping time resulted in a reduction of foam density. In addition, the foam expansion increased with increasing whipping time. Foam volume (i.e. foam expansion) and foam density are commonly used to evaluate whipping properties (Falade *et al.*, 2003). During the whipping process, air bubbles were trapped in the foam and gave rise to lower foam density (Karim and Wei, 1999). Therefore, the more air incorporated during whipping, the lower the foam density; the more air present in the foam, the greater the foam expansion or whippability. For example, with 2.25% methylcellulose, the foam density decreased from 1.02 g/ml to 0.41 g/ml ($p \leq 0.05$) and foam expansion increased from 0.00% to 187.25% ($p \leq 0.05$) when whipping time increased from 0 min to 25 min. Methylcellulose is one of the foaming agents used to form foam because it reduces surface tension and interfacial tension in an aqueous system. In addition, it encourages the formation of a strong film and stabilizes the interfacial film of the foam system (Karim and Wei, 1999). Passion fruit aril foam samples with higher methylcellulose concentration, therefore, exhibited lower density and greater expansion. After 25 min whipping time, as the concentration of methylcellulose increased from 0.75% to 2.25%, foam expansion increased from 109.04% to 187.25% ($p \leq 0.05$) whereas foam density decreased from 0.47 g/ml to 0.41 g/ml ($p \leq 0.05$). It is interesting to note that under similar whipping conditions, the foam expansion increased with increasing methylcellulose concentration until a maximum value was obtained at a methylcellulose concentration of 2.25%. However, increasing the methylcellulose concentration to 3.0% provided the opposite effect; i.e. foam expansion decreased while foam density rose. This may be because increasing methylcellulose concentration to 3.0% would increase the viscosity of the mixture, possibly exceeding the limiting viscosity at which maximum volume of air can be incorporated; this results in a lowering of foam expansion and an increase in foam density (Karim and Wei, 1999).

The results of the current study are in agreement with the work of Auisakchaiyoung and Rojanakorn (2015) who reported that as the concentration of methylcellulose and whipping time increased, the Gac fruit aril foam density decreased while its volume increased. Karim and Wei (1999) reported that as the methocel (a commercial name of methylcellulose) concentration increased, the star fruit foam density decreased whereas its expansion ability increased. In addition, these authors also reported the maximum concentration of methocel to provide the lowest foam density and beyond this concentration the density of the star fruit foam started to increase gradually. The results of Falade and Okocha (2010) revealed that the density of plantain paste foam decreased as the concentration of glyceryl monostearate and whipping time increased and at a higher concentrations of foaming agent, foam density showed steeper curves compared to lower concentrations. Similar trends were reported for Alphonso mango foam (Rajkumar *et al.*, 2007) and papaya pulp foam (Kandasamy *et al.*, 2012).

Foam stability reflects the ability of foam to bind water and is an approach to determine the rate at which the liquid drains from the foam (Kampf *et al.*, 2003). In foam-mat drying, foam stability is very important as the foam should be able to hold its open structure throughout the drying process (Hart *et al.*, 1963; Karim and Wai, 1999). This structure is desirable for rapid drying and good product quality (Karim and Wai, 1999).

In the current study, the stability of the foam (expressed as the amount of liquid water separated

Table 1. Effects of methylcellulose concentration and whipping duration on passion fruit aril foam characteristics

Methylcellulose concentration (%)	Whipping time (min)	Foam density (g/ml)	Foam expansion (%)	Liquid separated (ml)
0.75	0	1.03 ± 0.01^{a}	0.00 ± 0.00^{j}	20.10 ± 0.07^{a}
	10	0.68 ± 0.04^{b}	86.21 ± 0.77^{i}	18.01 ± 1.41^{b}
	20	0.48 ± 0.02^{c}	100.41 ± 3.20^{g}	16.00 ± 1.05^{c}
	25	0.47 ± 0.02^{c}	109.04 ± 3.04^{f}	10.22 ± 0.05^{d}
1.50	0	1.01 ± 0.01^{a}	0.00 ± 0.00^{j}	20.00 ± 0.01^{a}
	10	0.63 ± 0.03^{b}	91.41 ± 5.74^{h}	11.07 ± 1.41^{d}
	20	0.47 ± 0.01^{c}	113.46 ± 3.58^{e}	6.50 ± 0.71^{e}
	25	0.46 ± 0.01^{c}	118.05 ± 3.60^{d}	4.52 ± 0.70^{f}
2.25	0	1.02 ± 0.01^{a}	0.00 ± 0.00^{j}	20.02 ± 0.40^{a}
	10	0.43 ± 0.01^{cd}	127.04 ± 2.16^{c}	1.20 ± 0.03^{g}
	20	0.42 ± 0.01^{d}	141.87 ± 3.60^{b}	0.50 ± 0.01^{hi}
	25	0.41 ± 0.01^{d}	187.25 ± 3.60^{a}	0.00 ± 0.00^{i}
3.00	0	1.03 ± 0.01^{a}	0.00 ± 0.00^{j}	20.18 ± 0.40^{a}
	10	0.48 ± 0.01^{c}	102.04 ± 1.72^{g}	6.32±0.30e
	20	0.44 ± 0.01^{cd}	126.81 ± 1.43^{c}	1.03 ± 0.04^{gh}
	25	$0.44\pm0.03c^{d}$	128.51 ± 1.72^{c}	0.94 ± 0.07^{gh}

Means within the same column having different letters were different ($p\leq0.5$)

from the foam at 70°C for 1 h) was influenced by methylcellulose concentration and whipping time (Table 1). Incorporation of 2.25% methylcellulose concentration after 25 min whipping resulted in the foam with the highest stability as this condition provided the lowest degree of liquid separation.

The results of the current study are in agreement with the work of Auisakchaiyoung and Rojanakorn (2015) who reported that the stability of Gac aril foam increased with increasing methylcellulose concentration and whipping time. Karim and Wai (1999) also reported that the amount of juice separation from the star fruit foam decreased with increasing methocel concentration. Because of the highest foam expansion (187.25%) and stability as well as the lowest foam density (0.41 g/ml), 2.25% methylcellulose after 25 min whipping was considered as the optimum condition for forming passion fruit aril foam and chosen for form-mat drying experiment.

Effect of foam thickness and drying temperature on drying behavior of foamed passion fruit aril

The drying rate of passion fruit aril foam (Figure 1 a–c) indicated a short initial settling down or transition period in the first 5 min after which drying moved into a falling rate period. The drying rate decreased with an increase in foam thickness whereas it increased with increasing temperature (Figure 1 a–c). During the falling rate of the drying process, the predominant mechanism of mass transfer is internal mass diffusion. The rate of water diffusion in the product being dried in the falling rate period increases with increasing temperature, resulting in a higher rate of water removal during drying. This is because as drying temperature increases, the pressure of moisture inside the sample is substantially raised. By comparison, as the equilibrium moisture content of sample diminishes, the driving force or the moisture gradient between the center and the surface of sample is elevated (Jittanit, 2011). During the falling rate, the thinner foam dried faster than the thicker foam. This may be due to the reduced distance the water travels in order to be extracted (Maskan *et al*., 2002). Therefore, drying temperature and foam thickness are controlling factors affecting the drying rate of passion fruit aril foam, particularly in the falling rate period. Many researchers reported that drying agricultural foam mostly took place during the falling rate period (Rajkumar *et al*., 2007; Thuwapanichayanan *et al.*,

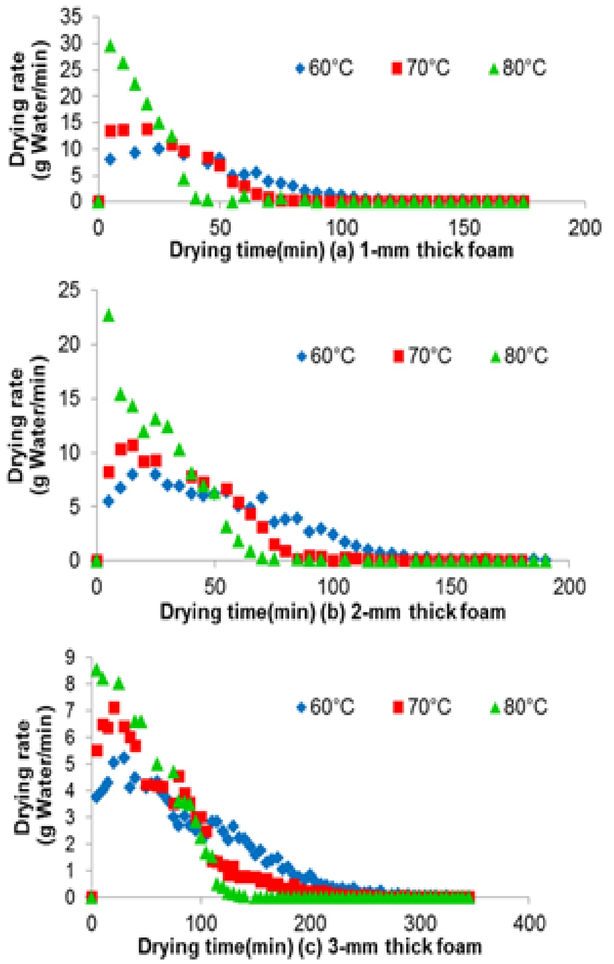

Figure 1. Drying rate of passion fruit aril foam at (a) 1-mm (b) 2-mm (c) 3-mm at different drying temperatures

2008; Kadam and Balasubramanian, 2011).

There was an inversion effect of temperature on drying rate for all foam thicknesses (Figure 1 a–c). For example, the drying rate of 1-mm thick foam at 80°C was higher than that at 70°C and 60°C up to about 35 min. After this point, an increase in temperature resulted in a decrease in the drying rate. This may be because moisture removal inside passion fruit aril foam at 80°C is higher and faster than the others in the first 35 min, thereafter it becomes lower than the others. An inversion point was occurred at about 55 min and 95 min for 2-mm and 3-mm thick foam respectively. The results obtained were in agreement with Akpinar *et al.* (2003) who reported that the drying rate of red pepper slices at 70°C was the highest during the first 75 min of drying and thereafter drying rate at 70°C was lower than those at 55°C and 60°C. Karim and Wai (1999) also reported that an inversion point of temperature on drying rate of star fruit foam dried at 70°C and 90°C was found to be about 35 min. Similarly, Babalis and Belessiotis (2004) found a reverse effect of temperature change on the drying rate after thin-layer drying of figs at

Table 2. Effect of foam thickness and drying temperature on effective moisture diffusivity during drying of passion fruit aril foam

Foam thickness (mm)	Drying Temperature (°C)	Average effective moisture diffusivity (m^2/s)	R^2
1	60	1.06×10^{-7}	0.987
	70	1.70×10^{-7}	0.964
	80	3.19×10^{-7}	0.973
2	60	3.40×10^{-7}	0.983
	70	5.59×10^{-7}	0.972
	80	7.42×10^{-7}	0.968
3	60	5.20×10^{-7}	0.987
	70	7.11×10^{-7}	0.974
	80	1.01×10^{-6}	0.962

55°C, 65°C, 75°C and 85°C for ~10–15 h.

The average effective moisture diffusivity *(D_{eff})* values of all drying conditions ranged between 1.06×10^{-7} m^2/s and 1.01×10^{-6} m^2/s (Table 2). This value increased with both increasing temperature and foam thickness. For 1-mm thick foam, the average effective moisture diffusivity increased from 1.06×10^{-7} m^2/s at 60°C to 3.19×10^{-7} m^2/s at 80°C. For 2-mm and 3-mm thick foams, the average effective moisture diffusivity increased from 3.40×10^{-7} m^2/s to 7.42×10^{-7} m^2/s and from 5.20×10^{-7} m^2/s to 1.11×10^{-6} m^2/s, respectively when drying temperature increased from 60°C to 80°C. In the current study, the drying of foamed passion fruit aril was chiefly occurred in the falling rate indicating that moisture removal from the foam was predominantly governed by diffusion, which is temperature dependent. Similarly, Thuwapanichayanan *et al.* (2008) reported that for certain foam densities, effective moisture diffusivity of banana foam dried at 60°C, 70°C and 80°C increased with increasing temperature. Rajkumar *et al.* (2007) also reported that an increase in effective moisture diffusivity with temperature during thin-layer drying of foamed mango pulp occurred in the range 60°C-75°C. Kadam and Balasubramanian (2011) confirmed that for a certain foam thickness and egg albumin concentration, effective moisture diffusivity of tomato juice foam dried at 60°C, 65°C and 70°C increased with increasing temperature. In addition, these researchers reported that effective moisture diffusivity of tomato juice foam during

Table 3. Effect of foam thickness and drying temperature on ascorbic acid, β-carotene and antioxidant activity of dried foam

Foam thickness (mm)	Drying temperature (°C)	Ascorbic acid (mg/100g)	β-carotene (mg/100g)	DPPH (mg TEAC/100 g)	ABTS (mg TEAC/100 g)
1	60	179.59±3.06^{c}	83.87±0.91^{c}	161.25±8.46^{ab}	216.93±7.95^{bc}
	70	231.28±3.26^{a}	94.61±0.64^{a}	170.64±0.05^{a}	238.87±9.96^{a}
	80	155.16±2.19^{de}	78.87±1.00^{d}	149.60 ± 2.33^{cd}	208.20±5.12^{cd}
2	60	159.97±0.34^{d}	79.52±0.67^{d}	157.41±3.95^{bc}	213.93±4.10^{c}
	70	204.26±2.59^{b}	89.32±0.80^{b}	162.82±6.24^{ab}	230.70±2.03^{ab}
	80	147.16±8.08^{e}	74.33±0.98^{e}	148.08±5.36^{cd}	205.41±3.93^{cd}
3	60	128.52±8.03^{f}	72.51±0.86^{e}	143.88±0.89^{de}	197.76±10.08^{d}
	70	181.90±6.38^{c}	85.07±0.96^{c}	161.29±3.90^{ab}	218.78±3.91^{bc}
	80	127.77±3.78^{f}	70.05±0.63^{f}	133.62±3.08^{e}	194.80±4.55^{d}

Means within the same column having different letters were significantly different ($p \leq 0.5$)

drying ranged between 2.02×10^{-8} m^2/s and 3.04×10^{-8} m^2/s.

In the current study, the average effective moisture diffusivity increased with an increase in foam thickness. This is because at higher foam thicknesses, the internal moisture transfer occurs along a longer distance than at lower foam thicknesses. Rajkumar *et al.* (2007) also reported that at any particular drying temperature, the average effective moisture diffusivity value of mango pulp foam at 3-mm was higher than that of 2-mm or 1-mm. Rosouli *et al.* (2011) similarly reported that garlic slices with higher thicknesses showed higher effective moisture diffusivity values rather than that of lower thicknesses.

It was observed that at 60°C the times taken for drying 1-mm, 2-mm and 3-mm passion fruit aril foam from the initial moisture content of ~510 % (db) to a final moisture content of ~10% (db) were 130 min, 200 min and 305 min, respectively. At 70°C, the respective drying needed to attain the same final moisture content of ~18% (db) were 90 min, 120 min and 275 min for 1-mm, 2-mm and 3-mm foam thickness, respectively. At 80°C, it took 40 min, 45 min and 70 min to dry 1-mm, 2-mm and 3-mm of foam to the same target final moisture content.

Quality of dried passion fruit aril foam

Moisture content and water activity of all dried samples ranged from 10.06% to 10.28% (db) and from 0.375 to 0.378, respectively ($p>0.05$) (data not shown). This is because all drying conditions were terminated when the final moisture content reached ~10% (db). It is clearly seen from Table 3 that the interaction of the 2 factors investigated (viz, foam thickness and drying temperature) significantly affected ascorbic acid and β-carotene contents of dried samples ($p \leq 0.05$). Drying 1-mm passion fruit aril foam at 70ºC resulted in the dried foam with the highest values of ascorbic acid and β-carotene (231.28 mg/100g and 94.61 mg/100g, respectively) ($p \leq 0.05$). By comparison, foamed passion fruit aril dried at other drying conditions exhibited lower amounts of these two values ($p \leq 0.05$). As discussed earlier, drying time to achieve the same final moisture content was determined by drying temperature and foam thickness. Drying 1-mm thick passion fruit aril foam at 70ºC took 90 min to achieve the final moisture content of ~10% (db) whereas it took 305 min for 3-mm thick foam to dry at 60ºC. These results demonstrated that the respective degradation of ascorbic acid and β-carotene in foamed passion fruit aril was highly influenced by the length of drying time, which in turn was depended on both foam thickness and drying temperature. The results of the current study are in good agreement with Auisakchaiyoung and Rojanakorn (2015) who reported that degradation of lycopene and β-carotene in dried Gac aril foam was attributable to drying temperature and the length of drying. Kadam *et al.* (2010) also reported that the length of drying and drying temperature (65°C-85°C) significantly affected ascorbic acid and total carotene contents of foam-mat dried mango powder containing milk as a foaming agent. Similar results were reported by Kadam *et al.* (2012) who demonstrated that the ascorbic acid content of foam-mat dried pineapple powder was determined by drying temperature (65°C-85°C) and drying time. Muratore *et al.* (2008) also reported that degradation of lycopene and β-carotene in unprotected semi-dried cherry tomato was affected by both drying time and drying temperature. Demiray *et al.* (2013) demonstrated that an increment of drying temperature increased the degradation rate of lycopene, β-carotene and ascorbic acid in tomato during hot air drying at 60°C to 100ºC.

The antioxidant activities of dried samples (assayed by ABTS and DPPH) were significantly influenced by the interaction of foam thickness and drying temperature (Table 3). Dried sample obtained from 1-mm thick foam dried at 70ºC for 90 min showed the highest ABTS and DPPH values (238.87 mg TEAC/100g and 170.64 mg TEAC/100g respectively) ($p \leq 0.05$). This may be because a lower loss of major antioxidant compounds including ascorbic acid and β-carotene at this drying condition leads to a lower decomposition of antioxidant activity. The results of the current study are in agreement with Auisakchaiyoung and Rojanakorn (2015) who reported that dried Gac fruit aril foam with the highest lycopene and β-carotene contents exhibited the highest antioxidant activity measured by ABTS and DPPH assays. Kha *et al.* (2011) reported that the loss of antioxidant activity of Gac aril powder (in both the ABTS and DPPH assays) increased when the air-drying temperature was increased from 40°C to 80ºC

The total viable count of freshly prepared foam-mat dried passion fruit aril obtained from all foam-mat drying conditions ranged between less than 10 CFU/g and 7.6×10^2 CFU/g, whereas the yeast and mold count for all drying conditions was less than 10 CFU/g (data not shown). The fresh passion fruit aril showed 3.1×10^4 CFU/g and 1.7×10^3 CFU/g for total plate count and yeast and mold count, respectively. This clearly indicated that foam-mat drying process of passion fruit aril reduced the microbial load. Similar results were reported in foam-mat drying of mango (Kadam *et al*., 2010) and pineapple (Kadam *et al*., 2012). In the current study, total plate count and yeast and mold count of all dried passion fruit aril foam samples were within permissible limits (less than 1×10^3 CFU/g for total plate count and less than 50 CFU/g for yeast and mold count) as specified by Thai Industrial Standard (TIS) No. 1137-2550 for the powders for industrial use (Khamjae, 2015). The foam-mat dried passion fruit aril samples produced in this current study were, therefor considered safe as far as national and international standards of microbial safety are concerned.

Conclusion

Addition of methylcellulose at a mass concentration of 2.25% with a whipping time of 25 min would produce the low-density, highly stable passion fruit aril foam. Drying passion fruit aril foam with 1-mm, 2-mm and 3-mm thickness at 60°C, 70°C and 80°C mostly occurred in the falling rate period with lower drying rates occurring at lower drying temperatures and higher foam thicknesses. Effective moisture diffusivity ranged between 1.06×10^{-7} m^2/s and 1.01×10^{-6} m^2/s: the value increased with increasing drying temperature and foam thickness. A product quality study revealed that 1-mm thick foamed passion fruit aril, dried at 70ºC for 90 min, retained the highest amount of bioactive compounds (viz., ascorbic acid and β-carotene) and antioxidant activity when compared to all other foam mat drying conditions. Foam-mat drying process of passion fruit aril greatly reduced microbial load and dried product obtained was considered safe.

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