

Effect of foam-mat drying conditions on quality of dried Gac fruit (*Momordica cochinchinensis*) aril

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Abstract

The objective of this study was to determine the effect of methylcellulose (MC) concentration and whipping time on the properties of Gac fruit aril foam. The effect of foam mat drying conditions on physicochemical and antioxidant properties of the dried product was also investigated. Gac fruit aril mixed with methylcellulose at a respective mass concentration of 1.0, 1.5 and 2.0% was whipped for 0, 10, 20 and 25 min. The Gac fruit aril foam mats (1, 2 and 3 mm-thick) were dried at 60, 70 and 80°C with a constant air velocity of 0.5 m/s. The optimum condition for forming foam was 1.5% methylcellulose after 25 min whipping. Gac fruit aril foam (1 mm thick) dried at 70°C for 60 min exhibited the greatest amount of lycopene, β -carotene and total phenolic compounds as well as antioxidant activity (assayed by DPPH and ABTS methods) ($p < 0.05$).

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Keywords

Gac fruit

Foam-mat drying

Lycopene

β -carotene

Antioxidant activity

Introduction

Gac fruit, *Momordica cochinchinensis* Spreng is one of the most common tropical plants. It belongs to the melon family (Cucurbitaceae) (Vuong *et al.*, 2006) and has long been used as a traditional medicine and food in Southeast Asia (Iwamoto *et al.*, 1985). Gac fruit aril has an attractive yellowish red colour and contains a large amount of carotenoids, especially β -carotene and lycopene (Aoki *et al.*, 2002; Vuong, 2006; Kubola and Siriamornpun, 2011), which are strong antioxidants (Kha *et al.*, 2011). Consumption of Gac fruit aril is, therefore, considered good for health as it can increase plasma β -carotene and retinal levels (Vuong *et al.*, 2006) and reduce the risk of certain types of cancer (i.e., prostate and lung) (Goula and Adamopoulos, 2005). Gac fruit aril is perishable and has a relatively short shelf-life. The conversion of this part of the fruit into a dried form extends shelf-life and makes it available year round. Dried Gac fruit aril can be prepared using various drying techniques (i.e., tray drying, vacuum drying, spray drying and freeze drying) (Tran *et al.*, 2008; Kha *et al.*, 2010; Kha *et al.*, 2011). Foam-mat drying is another interesting choice for drying Gac fruit aril because it is a simple, low-cost, rapid and lower energy technique.

Foam-mat drying involves the incorporation of air into the liquid or semisolid food by whipping it in the presence of foaming and/or stabilizing

agents; thereby forming stable foam after which the foam is spread in a thin layer and dried in a hot air stream (Rzepecka *et al.*, 1975; Labelle, 1984; Karim and Wai, 1999; Falade and Okocha, 2010). Many researchers reported that the amount of foaming agent and whipping time affected the foam properties (Karim and Wai, 1999; Thuwapanichayanan *et al.*, 2008; Falade and Okocha 2010). Foam-mat dried products have high retention of color, flavor, vitamins and sensory characteristics (Kadam and Balasubramanian, 2011) and are superior to drum dried and spray dried products due to its honey comb structure and better reconstitution ability (Morgan *et al.*, 1961; Hart *et al.*, 1963; Rzepecka *et al.*, 1975; Labelle, 1984). The physicochemical property and phytochemicals content of foam-mat dried products were determined by processing parameters including foam thickness, and drying temperature (Rajkumar *et al.*, 2007; Falade and Okocha 2010; Kadam *et al.*, 2011; Kadam *et al.*, 2012; Kandasamy *et al.*, 2012). Foam-mat drying has been used to dry many agricultural materials including mango pulp (Rajkumar *et al.*, 2007; Kadam *et al.*, 2010; Wilson *et al.*, 2012), tomato juice (Kadam and Balasubramanian, 2011), tamarind pulp (Vernon-Carter *et al.*, 2001), star fruit puree (Karim and Wai, 1999), papaya pulp (Kandasamy *et al.*, 2012), and banana (Sankat and Castaigne, 2004; Thuwapanichayanan *et al.*, 2008). Details on foam-mat drying of Gac fruit aril is not available so the objectives of this study were to

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study the effect of methylcellulose concentration and whipping time on foam properties and to determine the effect of foam thickness and drying temperature on physicochemical and antioxidant properties of foam-mat dried Gac fruit aril.

Material and Methods

Gac fruit aril preparation

Fresh and fully ripe Gac fruits with red color were obtained from the faculty of Agriculture, Khon Kaen University. The fruits were washed with tap water, left to dry at ambient temperature. The Gac fruit were cut into 2 halves. The whole seed covering with aril was removed and the red aril manually separated. All of the red aril was thoroughly mixed to obtain a uniform sample.

Foaming experiment

In this experiment, methylcellulose (MC) was used as a foaming agent. Gac aril (14.7°Brix) was mixed with methylcellulose solution of a certain concentration to form a mixture with different final concentrations of methylcellulose (1.0, 1.5 and 2.0% w/w). The mixtures were then whipped to form foam in a Kitchen Aid mixer (Model ULM-400, USA) at a maximum speed of 1400 rpm for a respective 0, 10, 20 and 25 min. The resulting foam from different conditions was evaluated for foam density, expansion and stability.

The density of foamed Gac fruit aril was determined by dividing the mass of the foam by its volume (Falade and Okocha, 2010).

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

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

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

where V_0 is an initial volume of Gac aril-methylcellulose mixture and V_1 is the volume of foam, ml.

Foam stability was determined according to Karim and Wai (1999) 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 with a constant air velocity of 0.5 m/s for 1 h. Afterwards, the volume

of liquid separated from the foam was recorded.

Foam-mat drying experiment

The stable and homogeneous Gac fruit aril foam was evenly spread on the stainless steel plates (15.5×27 cm.) at a respective thickness of 1, 2 and 3 mm. The ratio of known volume of foam and drying area was used to determine the foam thickness (Rajkumar *et al.*, 2007). The plates (each with a different foam thickness) were put in the drying chamber at 60, 70 and 80°C with a constant air velocity of 0.5 m/s. 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 ± 0.01 g. Drying was terminated when the final moisture content reached ≈ 6.5% (db) (Rajkumar *et al.*, 2007).

Dried product analyses

Moisture content and water activity value

The moisture content of 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.).

Color

The color of foam-mat dried Gac fruit aril was determined using Minolta Chroma meter calibrated with a white standard tile and the results were expressed as L^* (lightness), a^* (redness) and b^* (yellowness). The chroma and hue angle values of dried samples were then calculated using the following expressions (Kha *et al.*, 2011).

$$\text{Chroma} = (a^{*2} + b^{*2})^{1/2} \quad (3)$$

$$\text{Hue angle} = \arctan (b^*/a^*) \quad (4)$$

β -carotene and Lycopene content

The extraction of carotenoids in Gac fruit powder was performed by mixing 1 g of dried sample in 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 as per Kubola and Siriamornpun (2011). The carotenoids contents were analyzed using an HPLC technique (Shimadzu LC-20A, Software CLASS-VP pumps, SPD-M20A diode array detector, Cosmosil C-18 (4.6x250 mm. i.d., 5 μ m)). The mobile phase was composed of methanol (solvent A)/acetonitrile (solvent B)/dichloromethane (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 and 475 nm to determine the respective β -carotene and lycopene contents (Kubola

and Siriamornpun, 2011).

Total phenolics content and antioxidant activity

The procedure for extraction of total phenolics content and antioxidants in Gac 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 decanted into a 30-ml vial. The residue was re-extracted under the same conditions and the supernatant combined and used for total phenolics content and antioxidant activity assays.

The total phenolics content was determined using Folin-Ciocalteu reagent as per Kubola and Siriamornpun (2011) and expressed as gallic acid equivalents per gram of dry weight based on the gallic acid standard curve.

The procedure for the DPPH assay followed the method reported by Thaipong *et al.* (2006) with some modifications. The 3 ml of stock solution containing 0.0024 g DPPH and 100 ml methanol was mixed with 77 μ l deionized distilled water to obtain the working solution. Gac aril extracts (77 μ l) were allowed to react with 3 ml DPPH working 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 according to Thaipong *et al.* (2006) with modifications. 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 \pm 0.02 units at 734 nm using a spectrophotometer. Fresh ABTS⁺ solution was prepared for each assay. The Gac aril sample extracts (10 μ l) 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.

Statistical analysis

The experiments were conducted in triplicate and results were given as means with standard deviations. Analysis of variance and Duncan's new multiple

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

Methylcellulose concentration (%)	Whipping time (min)	Foam density (g/cm ³)	Foam expansion (%)	Volume of liquid released (ml)
1	0	1.00 \pm 0.00 ^a	4.00 \pm 2.75 ^h	6.75 \pm 0.35 ^d
	10	0.97 \pm 0.04 ^b	19.14 \pm 0.32 ^e	6.25 \pm 0.53 ^{cd}
	20	0.92 \pm 0.01 ^b	22.63 \pm 1.03 ^e	5.50 \pm 0.71 ^{cd}
	25	0.84 \pm 0.01 ^d	29.91 \pm 1.86 ^d	4.95 \pm 0.07 ^{def}
1.5	0	1.02 \pm 0.02 ^a	3.47 \pm 0.44 ^h	5.25 \pm 0.35 ^c
	10	0.96 \pm 0.10 ^{ab}	23.48 \pm 1.03 ^e	4.13 \pm 0.53 ^f
	20	0.90 \pm 0.08 ^c	31.04 \pm 0.23 ^d	5.75 \pm 1.06 ^{cd}
	25	0.53 \pm 0.03 ^f	88.70 \pm 1.81 ^e	0.00 \pm 0.00 ^f
2	0	1.00 \pm 0.00 ^a	5.50 \pm 0.63 ^g	7.98 \pm 0.88 ^a
	10	0.86 \pm 0.03 ^d	29.48 \pm 0.35 ^d	4.75 \pm 0.35 ^e
	20	0.64 \pm 0.03 ^e	74.02 \pm 3.68 ^b	1.25 \pm 0.35 ^g
	25	0.52 \pm 0.01 ^f	88.86 \pm 1.75 ^e	0.00 \pm 0.00 ^f

Means within the same column having different letters were significantly different ($p < 0.05$)

range test were performed to identify differences among the means using SPSS software version 19. Statistical significance was accepted at 95% probability.

Results and Discussion

Foam quality

Methylcellulose concentration and whipping time significantly affected Gac aril foam properties (Table 1). An increase in whipping time and methylcellulose concentration resulted in an increase in foam expansion and a decrease in foam density. During whipping, air bubbles were trapped in the foam and gave rise to lower foam density (Karim and Wei, 1999). Therefore, more air was incorporated in the foam as the whipping time increased which resulted in higher foam volume and lower foam density. For example, with 1.5% methylcellulose, the density decreased from 1.02 g/cm³ to 0.53 g/cm³ ($p < 0.05$) and foam expansion increased from 3.47% to 88.70% ($p < 0.05$) when whipping time increased from 0 to 25 min. Falade *et al.* (2003) reported that the more air added in the foam during whipping, the lower the foam density; the more air present in the foam, the higher the foam expansion. Gac aril foams with a higher concentration of methylcellulose (lower density) exhibited higher stability or lower amount of liquid released from the foam than foams with a lower concentration of methylcellulose (higher density) (Table 1). This is because methylcellulose reduces surface tension and interfacial tension in an aqueous system. Furthermore, it encourages the formation of a strong film and stabilizes the interfacial film of the foam system (Karim and Wei, 1999). Gac aril foam samples containing higher amount of methylcellulose, therefore exhibited lower density, higher expansion

Table 2. Effect of foam thickness and drying temperature on moisture content and water activity of dried foam

Foam thickness (mm)	Drying temperature (°C)	Moisture content (% db)	Water activity
1	60	6.59±0.28 ^a	0.279±0.006 ^a
	70	6.59±0.11 ^a	0.279±0.004 ^a
	80	6.58±0.50 ^a	0.279±0.001 ^a
2	60	6.59±0.31 ^a	0.281±0.003 ^a
	70	6.61±0.72 ^a	0.282±0.002 ^a
	80	6.59±0.66 ^a	0.279±0.006 ^a
3	60	6.59±0.48 ^a	0.278±0.006 ^a
	70	6.59±0.01 ^a	0.280±0.000 ^a
	80	6.60±0.01 ^a	0.279±0.000 ^a

Means within the same column having different letters were significantly different ($p < 0.05$)

and stability. The results of the current study are in agreement with the work of Karim and Wei (1999) who reported that as the concentration of methocel increased, the star fruit foam density decreased while its volume increased. Falade *et al.* (2003) also reported that the density of cowpea foam decreased steadily with increased whipping time and the concentration of the foaming agent (i.e., glyceryl monostearate and egg albumin). 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 banana foam (Sankat and Castaigne, 2004) and Alphonso mango foam (Rajkumar *et al.*, 2007).

The current study demonstrated that Gac aril foam with 2.0 % methylcellulose after whipping for 25 min exhibited the lowest density (0.52 g/cm³) and the highest expansion (88.86%) and stability (no liquid released from the foam). A statistical analysis, however, revealed that the density, expansion and stability of Gac aril foam prepared from 1.5 and 2.0 % methylcellulose after 25 min whipping were not significantly different ($p < 0.05$). Therefore, 1.5% methylcellulose and 25 min whipping time were chosen and used to prepare Gac aril foam for drying experiment.

Product quality

Moisture content and water activity of all dried samples ranged from 6.58 to 6.61% (db) and from 0.278 to 0.282 respectively ($p < 0.05$) (Table 2). This is because all drying conditions were terminated when the final moisture content reached 6.5 % (db). It was observed that at 60°C, the time taken for drying 1-mm

Table 3. Effect of foam thickness and drying temperature on lycopene, β -carotene and total phenolics contents of dried foam

Foam thickness (mm)	Drying temperature (°C)	Lycopene content (μ g/g)	β -carotene content (μ g/g)	Total phenolics (mg/g)
1	60	674.26±0.76 ^b	78.97±0.52 ^b	6.95±0.22 ^b
	70	690.16±7.88 ^a	83.43±1.85 ^b	8.93±0.06 ^a
	80	674.39±14.53 ^b	78.28±0.33 ^b	6.45±0.17 ^c
2	60	608.46±2.70 ^d	75.15±1.39 ^{bc}	7.19±0.06 ^b
	70	652.70±9.63 ^c	77.47±1.90 ^{bc}	6.95±0.11 ^b
	80	588.07±0.24 ^e	72.05±3.35 ^d	5.85±0.10 ^d
3	60	583.99±7.93 ^e	71.92±0.86 ^d	5.59±0.41 ^d
	70	594.88±4.69 ^{de}	68.47±0.75 ^e	7.17±0.05 ^b
	80	591.69±7.47 ^{de}	68.63±0.38 ^e	4.89±0.31 ^e

Means within the same column having different letters were significantly different ($p < 0.05$).

of Gac aril foam from an initial moisture content of 510 % (db) to a final moisture content of 6.5% (db) was 85 min. The time taken for the same level of final moisture content was 100 and 120 min for 2-mm and 3-mm foam thickness, respectively. At 70°C, the respective drying times needed to attain the same final moisture content of 6.5% (db) were 60, 80 and 100 min for 1, 2 and 3-mm of foam. At 80°C, it took 40, 45 and 70 min to dry 1, 2 and 3-mm of foam to the same target final moisture content. Foam thickness and drying temperature significantly affected lycopene, β -carotene and total phenolics contents of dried Gac aril foam (Table 3). Drying 1 mm of Gac aril foam at 70°C resulted in the dried foam with the highest contents of lycopene, β -carotene and total phenolics (690.16 μ g/g, 83.43 μ g/g and 8.93 mg/g, respectively) ($p < 0.05$). By comparison, foamed Gac aril dried at other drying conditions exhibited lower amounts of these three values. For example, 3-mm thick foam dried at 60°C contained 583.99 μ g/g lycopene, 71.92 μ g/g β -carotene and 5.59 mg/g total phenolics.

As discussed earlier, drying time to achieve the same final moisture content was determined by drying temperature and foam thickness. Drying 1-mm thick Gac aril foam at 70°C took 60 min to achieve a final moisture content of 6.5% (db) whereas it took 120 min for 3-mm thick foam to dry at 60°C. The results of the current study demonstrated that the respective degradation of lycopene, β -carotene and total phenolics in foamed Gac aril was highly affected by the length of drying time, which in turn was depended on foam thickness and drying temperature. The results of this study were in good agreement with Muratore *et al.* (2008) who reported that damage of lycopene and β -carotene in unprotected semi-dried cherry tomato was attributable to drying temperature and the

Table 4. Effect of foam thickness and drying temperature on antioxidant activity and color value of dried foam

Foam thickness (mm)	Drying temperature (°C)	ABTS (mg/g)	DPPH (mg/g)	Chroma	Hue angle (H°)
1	60	28.05±0.36 ^c	27.63±0.13 ^{ab}	34.25±0.19 ^a	45.18±1.55 ^a
	70	30.18±0.13 ^a	28.21±0.10 ^a	35.61±0.08 ^d	36.17±0.08 ^d
	80	23.58±0.08 ^{ef}	23.29±0.02 ^c	38.76±0.17 ^b	42.78±0.17 ^b
2	60	28.00±0.12 ^c	27.68±3.59 ^{ab}	34.63±0.08 ^e	38.79±0.75 ^c
	70	28.99±0.05 ^b	27.92±0.34 ^{ab}	37.59±1.04 ^c	42.94±0.07 ^b
	80	24.26±1.49 ^e	23.30±0.01 ^c	39.95±0.02 ^a	43.32±0.03 ^b
3	60	25.60±0.13 ^d	25.69±0.10 ^b	37.35±0.12 ^c	37.75±0.01 ^d
	70	27.54±0.02 ^c	26.92±0.06 ^{ab}	39.78±0.12 ^a	43.15±0.28 ^b
	80	23.31±0.19 ^f	23.10±0.19 ^c	40.24±0.33 ^a	45.35±0.08 ^a

Means within the same column having different letters were significantly different ($p < 0.05$)

length of drying. Demiray *et al.* (2013) demonstrated that an increase in drying temperature increased the reaction rate of lycopene, β -carotene and ascorbic degradation in tomato during hot air drying at 60 to 100°C. Kha *et al.* (2011) similarly showed that an increase in hot air drying temperature from 40 to 80°C resulted in a greater loss of carotenoid content of Gac aril powders pretreated in different ways. They therefore concluded that heat treatment was the main reason for carotenoid degradation in this kind of product. Kha *et al.* (2010) also reported that loss of total carotenoid content in spray-dried Gac aril powder containing different amounts of maltodextrin (DE12) significantly increased as inlet temperature increased from 120°C to 200°C ($P < 0.001$).

The antioxidant activities of dried samples (assayed by ABTS and DPPH), as a result of different foam mat drying conditions, are presented in Table 4. The drying condition significantly affected antioxidant activity of dried samples ($p < 0.05$). Product obtained from 1-mm thick foam dried at 70°C for 60 min showed the highest ABTS and DPPH values (30.18 and 28.21 mg/g respectively) while products from other foam mat drying conditions exhibited lower antioxidant activity (in both the ABTS and DPPH assays). The possible reason is that a lower decomposition of lycopene and β -carotene at this drying condition leads to a higher retention of antioxidant activity. 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 to 80°C. Kha *et al.* (2010) also reported that the antioxidant activity of spray dried Gac powder samples was determined by drying temperature and maltodextrin concentration. An increase in spray drying temperature from 120°C to 200°C resulted in a decrease in antioxidant activity of Gac aril powder.

However, Kha *et al.* (2010, 2011) did not indicate the effect of drying time on antioxidant activity of Gac aril powder obtained from hot air drying and spray drying techniques.

Table 4 also presents the color characteristics of the Gac aril powder obtained from different foam mat drying conditions. The statistical analysis indicated that foam thickness and drying temperature significantly influenced chroma and hue angle values of dried Gac aril samples. Chroma represents the color intensity of the sample and this value is calculated by $(a^{*2}+b^{*2})^{1/2}$. The hue angle ranges from 0°(pure red colour), 90°(pure yellow colour), 180°(pure green colour) to 270°(pure blue colour) and this value is calculated by $\arctan(b^*/a^*)$ (Duangmal *et al.*, 2008). The chroma of dried Gac aril samples ranged from 34.25 to 40.24. An increment of drying temperature and foam thickness resulted in a higher chroma value of the samples. This may be because of the higher Maillard reaction which was accelerated by higher temperature and longer drying time. The Hue angle values of all dried Gac aril samples were between 36.17° and 45.35° indicating the yellowish red colour of foam mat dried Gac aril samples. The 1-mm thick Gac foam dried at 70°C for 60 min exhibited the lowest Hue angle (36.17°) indicating the highest red colour of the sample. The possible reason is that it contains a higher lycopene content than the other drying conditions. The results of the current study are consistent with the results of Kha *et al.* (2011), who reported that the Hue angle of Gac aril powder pre-treated with ascorbic acid, sodium bisulfate and blanching and air dried at 40-80°C ranged between 37.91° and 42.05°. They recommended that the desirable hue angle of Gac aril powder should be about 45°.

Conclusion

Incorporation of methylcellulose at a concentration of 1.5% with a whipping time of 25 min would produce a low density, highly stable Gac aril foam. A product quality study revealed that 1-mm thick foamed Gac aril, dried at 70°C for 60 min, had a yellowish-red color and retained the highest amount of bioactive compounds (viz., lycopene and β -carotene) and antioxidant activity (assayed by ABTS and DPPH) when compared to all other foam mat drying conditions.

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