Evaluation of Physicochemical Properties of Spray Dried Bael Fruit Powder During Storage

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***Abstract*—This study investigates the effects of accelerated storage conditions of spray dried bael fruit powder. The spray dried powder (particle diameter of 51.03 µm) was sealed in aluminum laminated polyethylene bag and storage for further analysis. Storage parameters included accelerated storage temperatures (35 ℃ and 45 ℃), and storage times (0, 2, 4, 6, and 8 weeks). The results showed that accelerated storage temperatures and extended storage times affected the physicochemical and antioxidant properties of the spray dried powder. Water activity (a_w), moisture content, and bulk and tapped density of the spray dried powder were significantly ($p<0.05$) increased. However, the final a_w of the spray dried powder did not exceed 0.6 indicating that the powder was shelf-stable. The antioxidant activity of the spray dried powder stored at 35 ℃ and 45 ℃ was significantly ($p<0.05$) reduced after the 2nd week of storage. Color was not affected by accelerated storage conditions.**

***Index Terms*—Bael fruit, spray drying, storage, physicochemical, antioxidant properties**

I. Introduction

Bael (Aegle marmelos) is a one of tropical plants which possesses highly nutritious [1], [2]. Bael fruit is high in natural antioxidants and bioactive compounds (e.g., flavonoids, phenolics, and ascorbic acid). Bael fruit is also used for traditional indigenous medicine.

Spray drying is widely used in an industrial process for encapsulating heat sensitive compounds [3]. It has been used to produce various types of dried powder such as banana [4], cherry [5], and pineapple [6]. Spray dried powder is easy for handling, transportation, and packaging due to its reduced weight or volume [7]. Maltodextrin and sucrose have been used as encapsulating agents, which reduce the stickiness of spray dried powder [8]. Currently, fructose oligosaccharide (FOS) and maltitol has been considered for spray dried powder due to having a low Glycemic Index (GI) [9].

Physicochemical, microbiological and nutritional properties of spray dried powder are altered during storage because of the water mobility in the food substrate [10], [11]. According to Andreas *et al*. [12], the absorbent moisture powder was promoted under different environmental storage conditions. Glucose and fructose in spray dried fruit powder are responsible for strong interaction with the water molecule, affecting to the stability of shelf life [13]. Previous research have been evaluated the effects of different storage temperatures included refrigerated (4 ℃) and ambient (25 ℃) temperature to the quality and physiochemical properties of spray dried fruit powders [1]. However, studies involving the effects of accelerated storage temperature on the stability of spray dried bael fruit powder, especially the degradation of antioxidants, are limited. This study thus investigates the effects of accelerated storage temperatures (35 ℃ and 45 ℃) and storage times (0, 2, 4, 6, and 8 weeks) on the physiochemical and antioxidant properties of spray dried bael fruit powder.

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II. Material and Methods

A. Material

Dried bael fruit was purchased from Thailand's northeastern province of Nakhon Ratchasima. The moisture content was less than 7%.

B. Bael Fruit Juice Preparation and Spray Drying

Dried bael fruit was extracted using distilled water at 100 ℃ for 45 min. The extracts were then filtered to obtain the bael fruit juice. Total solid content of the juice was 4.0 °brix. Maltodextrin, sucrose, maltitol, and FOS were added into the juice. The mixtures were spray dried (Spray dryer, Niro A/S-gladsaxevej 305, Denmark) at an inlet and outlet temperature of 120 ℃ and 75 ℃, respectively. The bael fruit powder weighing 10 g were sealed under aerobic conditions in aluminum laminated polyethylene bag. The packed powder was store at elevated temperatures of 35 ℃ and 45 ℃. Analyses were carried out at 0, 2, 4, 6, and 8 weeks for water activity (a_w), moisture content, appearance (color), bulk and tapped density, solubility, and antioxidant activity.

C. Analytical Method

1) Chemical composition, particle size distribution, and microstructure analysis

Chemical composition of a spray dried power was analysis according to the method of AOAC method [14].

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The particle size distribution of the powder was measured using a particle size distribution analyzer (Horiba, LA 920, Kyoto, Japan). Scanning electron microscopy (SEM, JSM-6010LV, JEOL, Japan) was used to determine the microstructure of the powder.

2) Water activity, moisture content, bulk density, and tapped density

Water activity (a_w) of spray dried bael fruit powder was measured using a water activity meter (Aqualab CX-2, Decagon Devices, Inc., USA) at 25 ℃. AOAC method [14] was used to determine moisture content of the sample. Bulk and tapped density were experimented following Saikia *et al*. [3] procedures. Briefly, a 1 g sample was added into a 10 mL graduated cylinder, and measured the volume occupied by the sample as bulk density. Cylinder was then tapped manually for 50 times and the volume occupied by the sample was measured as tapped density. The results were expressed as g/mL.

3) Solubility

The solubility of spray dried bael fruit powder was determined following the method of Saikia *et al*. [3]. A 5 g powder was mixed with distilled water at a ratio of 1:10, and stirred for 1 h at room temperature. The mixture was then centrifuged at 2,500 rpm for 10 min (Centrifuge, Thermo Scitific, Sorvall Legend XTR, Germany). The supernatant was collected, dried and weighed. The solubility was calculated by dividing the weight of supernatant after drying by the weight of initial sample, times 100.

4) Dispersibility

The dispersibility was measured following Hassan [15] procedure with some modifications. A 2 g power was added into 100 mL distilled water. The mixture was magnetic stirrer for 10s. It was withdrawn using a syringe and then centrifuged at 2,000 rpm for 5 min. The dispersibility was expressed by measuring the optical density of the supernatant at 520 nm on UV-Vis spectrophotometer (Shimazu, UV-2600, Japan).

5) Determination of DPPH activity

The DPPH radical scavenging activity of spray dried bael fruits powder was measured according to Molyneux [16] with some modifications. Approximately, a 200 mg the powder was mixed and dissolved in 2 mL methanol, and then filtered to subject the extracts. Approximately, 100 μL of extracts were added to 1.4mL DPPH radical solution (10^{-4}M), and stored in dark room for 30 min. The absorbance was set at 517nm by using a UV-Vis Spectrophotometer. The same analysis was performed to Trolox methanol solution standard in varying concentration from 0 to 100μM. Analyses were performed in triplicate and the results were expressed in μmol Trolox equivalent antioxidant scavenging per g dry weight sample.

6) Determination of ABTS activity

The ABTS free radical scavenging was generated by oxidation of ABTS with potassium persulfate as indicated by Roberta *et al*. [17]. The cation radical solution (ABTS+), 75 μL was added to 225 μL of each extract in 96-well plate. The mixture was incubated for 20 min and measured at absorbance at 734 nm. The results were calculated according to calibration curve for Trolox (0–100 μM). ABTS values were expressed as in μmol Trolox equivalent antioxidant scavenging per g dry weight sample.

7) Color characteristics

The color of the powder was measured using colorimeter (ColorQuest XE®, Hunter Associates Laboratory, Inc., VA, USA). The results are expressed in accordance with the CIE Lab: L* value measures the lightness, a* value measures the red and green color hue, while b* value is used for determination of yellow and blue color hue. The instrument was calibrated against a standard black and white reference tiles.

D. Statictical Analysis

All analyses were carried out in triplicate, and the results expressed as the mean ± standard deviation. One-way analysis of variance (ANOVA) was used to analyze the differences among group means. Tukey-HSD multiple comparison was used to compare the means, given the 5% significance level ($p<0.05$) Minitab® 17 (Minitab Inc., USA).

III. Results and Discussion

A. Physiochemical and Microstructural Properties of Spray Dried Bael Fruit Powder

In this study, protein, lipid, and carbohydrate levels of spray dried bael fruit powder were 0.63, 1.22, and 95.26% (dry weight basis), respectively. The particle diameter of the powder was approximately 51.03 μm, indicating a good handling and reconstitution properties [18]. Morphology of the microspheres illustrated globular shape with the appearance of shrink on the surface (Fig. 1).

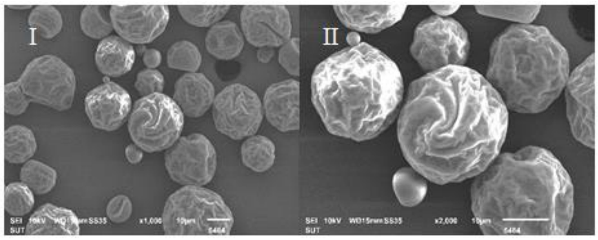

Figure 1. SEM images of spray dried powder: I, and II denote the magnifications are 1,000x and 2,000x, respectively.

B. Effect of Storage Conditions on Water Activity and Moisture Content of Spray Dried Bael Fruit Powder

Water activity (a_w) varying between 0.2-0.4 is considered as basic parameter for commercialized instant powders [19]. Its value indicates oxidative stability of the product against hydrolytic reactions, lipid oxidation, and auto-oxidation [20]. In Fig. 2, the initial a_w of the sample was 0.27. This was similar to previous reported for different spray dried fruit powders. In this study, a_w of the powder was significantly ($p<0.05$) affected by accelerated storage temperatures of 35 ℃ and 45 ℃ after 2nd week of storage. Elevated storage temperature of 45 ℃ slightly increased the a_w from 0.27 to 0.33. a_w of the powder noticeably increased after extended the storage time to 12 weeks at 35 ℃ storage (0.56). The finding was consistent with Gabas *et al*. [21] who reported that the a_w tends to increase with increase of temperature and storage time. Chiou and Langrish [22] also reported that strong adsorbent moisture powder is favored by lower temperatures, causing an increase in a_w.

Moisture content is also related with environmental storage conditions. Moisture represents the change in a_w [23]. The initial moisture content of spray dried bael fruit powder was 2.58% (Fig. 3). After extended storage time to 10 weeks, moisture content of the powder significantly ($p<0.05$) increased from 2.58% to 4.68% under storage temperature of 35 ℃, while slightly increased from 2.58% to 3.02% at 45 ℃ storage. Extended storage time to 12 weeks increased in moisture content of the powder to 5.34% and 3.17% at 35 ℃ and 45 ℃ storage, respectively. Higher moisture content of the stored powder at 35 ℃ possible suggested a greater permeability towards moisture gained during storage. Similar result was also reported for spray dried papaya at storage temperature of 38 ℃. Mishra *et al*. [24] and Mishra *et al*. [25] reported that the moisture content of mango soy fortified yoghurt powder was gradually increased during accelerated storage (38±1 ℃, 90% RH). In short, elevated storage temperature of 45 ℃ slightly influenced on moisture content of the powder, while the final moisture content of the stored powder at 35 ℃ significantly increase.

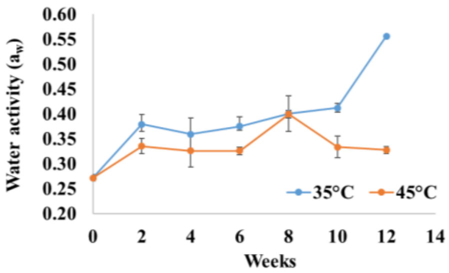

Figure 2. Water activity of spray dried bael fruit powder as affected by storage temperature and time.

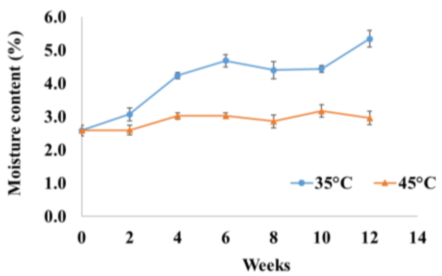

Figure 3. Moisture content of spray dried bael fruit powder as affected by storage temperature and time.

C. *Effect of Storage Conditions on DPPH and ABTS Free Radical Scavenging Activity of Spray Dried Bael Fruit Powder*

Table I presented the effect of storage conditions on the radical scavenging activity of spray dried bael fruit powder during 8 weeks storage. The initial DPPH and ABTS free radical scavenging of the powder was 1.84 µmol TEAC/g and 1.96 µmol TEAC/g, respectively. Accelerated storage temperature and time showed statistically significant effect ($p<0.05$) on the DPPH and ABTS scavenging activities. Reduction on scavenging activity was probably due to high temperature storage affecting the antioxidant compounds [26]. However, during 4th-8th week of 35 ℃ and 45 ℃ storage, the DPPH and ABTS scavenging activities of the powder were not significantly different ($p>0.05$). Similar result also reported for spray dried papaya powder [24].

TABLE I. EFFECT OF STORAGE CONDITIONS ON ANTIOXIDANT SCAVENGING OF SPRAY DRIED BAEL FRUIT POWDER.

Storage (week)[1]	DPPH (µmol TEAC/g)[1]		ABTS (µmol TEAC/g)[2]	
	35 ℃	45 ℃	35 ℃	45 ℃
0	1.84±0.02[a]	1.84±0.02[a]	1.96±0.00[a]	1.96±0.00[a]
2	1.22±0.90[b]	1.22±0.20[b]	1.94±0.00[b]	1.94±0.00[a]
4	1.23±0.17[b]	1.21±0.10[b]	1.77±0.00[c]	1.77±0.00[b]
6	1.24±0.16[b]	1.22±0.02[b]	1.77±0.00[c]	1.75±0.08[b]
8	1.21±0.05[b]	1.19±0.04[b]	1.76±0.00[c]	1.75±0.00[b]

[1,2] Different letters in each column denote statistically significant differences between treatments ($p<0.05$). The values are the mean of three replications ±standard deviation.

D. *Effect of Storage Conditions on of Solubility, Bulk Density, Tapped Density, and Dispersibility of Spray Dried Bael Fruit Powder*

The solubility of the powder was not significantly different during accelerated storage temperature of 35 ℃ and 45 ℃ for 8 weeks (Table II (A) and (B)). These results indicated that storage temperature and time did not affect on the solubility of the powder. Similar results also reported for the solubility of milk protein powder in increasing storage time and storage temperature [2].

The bulk and tapped density is also important parameter affecting the functional properties of the instant powder. In this study, the bulk density increased significantly when the powder was stored at 35 ℃ and 45 ℃ after 8 weeks. The finding is consistent Tontul and and Topuz [18] who documented that increase in bulk density is a result of increasing in moisture content and a_w. Meanwhile, tapped density was significantly increased after 2nd week of storage at 35 ℃ and 45 ℃. Typically, high bulk density related to high tapped density. However, in this study, these results did not well correlate. The results could be explained due to promoting the removal water content under high storage temperature tending to reduce the stickiness, especially high sugar content spray dried powder.

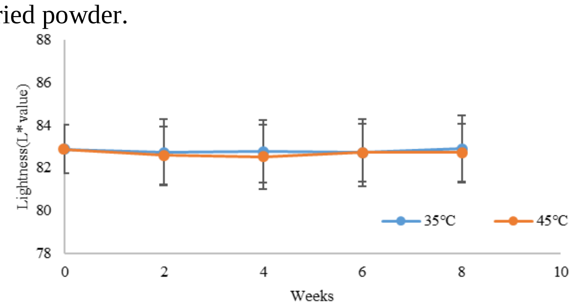

Figure 4. L* of spray dried bael fruit powder as affected by storage temperatures and time.

TABLE II. EFFECT OF STORAGE CONDITIONS ON PHYSIOCHEMICAL PROPERTIES OF THE POWDER: (A) STORAGE AT 35 ℃ AND (B) STORAGE AT 45 ℃.

Storage (week)[1]	(A) Storage at 35 ℃[1]			
	Solubility (%)	Bulk density (g/ml)	Tapped density (g/ml)	Dispersibility
0	99.88±0.06	0.56±0.02^{a}	0.72±0.03^{c}	0.031±0.00^{a}
2	97.53±0.88	0.59±0.01^{b}	0.78±0.00^{a}	0.017±0.01^{b}
4	98.92±0.33	0.62±0.03^{c}	0.78±0.05^{a}	0.022±0.01^{c}
6	97.86±2.36	0.66±0.07^{d}	0.75±0.05^{b}	0.022±0.01^{c}
8	99.88±0.10	0.63±0.00^{c}	0.75±0.00^{b}	0.010±0.01^{d}
Storage (week)[1]	(B) Storage at 45 ℃[2]			
	Solubility (%)	Bulk density (g/ml)	Tapped density (g/ml)	Dispersibility
0	99.88±0.06	0.56±0.02^{a}	0.72±0.03^{b}	0.031±0.00^{a}
2	97.79±1.25	0.62±0.01^{b}	0.78±0.02^{a}	0.015±0.00^{c}
4	99.39±0.20	0.65±0.01^{b}	0.78±0.00^{a}	0.017±0.00^{c}
6	99.76±0.05	0.68±0.04^{c}	0.78±0.01^{a}	0.023±0.00^{b}
8	99.61±0.29	0.74±0.14^{d}	0.78±0.00^{a}	0.022±0.00^{b}

[1,2] Different letters in each column denote statistically significant differences between treatments ($p<0.05$). The values are the mean of three replications ± standard deviation.

E. Effect of Storage Conditions on Color Characteristics of Spray Dried Bael Fruit Powder

Color is one of the important quality parameters that affects the acceptability of the final product (Chen, 2009). In this study, the lightness (L*) of spray dried bael fruit powder is shown in Fig. 4. The initial L*, redness (a*), and yellowness (b*) were 82.9, 3.80, and 20.4, respectively. During accelerated storage for 8 weeks, L* slightly varied between 82.7-82.9, and 82.6-82.9 for storage at 35 ℃ and 45 ℃, respectively. The a* and b* were between 3.8-4.0 and 3.8-4.3, and 20.4-21.2 and 20.4-21.6 for storage at 35 ℃ and 45 ℃, respectively. These results indicated that accelerated storage temperature did not affect to the color of the sample. By the way, elevated storage temperature possibly increased the rate of oxidation, affecting in rising a* and lowering L* of the sample [26].

IV. CONCLUSION

This study investigated the effects of accelerated storage temperatures (35 ℃ and 45 ℃) and storage times (0-8 weeks) on physicochemical and antioxidant activity of the spray dried bael fruit powder. The results showed that extended storage times under elevated storage temperature increased the a_w, moisture content, and bulk and tapped density of the powder, while the antioxidant activity was reduced. Color quality was still unchanged during storage. Storage temperature of 35 ℃ strongly affected in increase a_w of the powder. However, the final a_w of the powder did not exceed 0.6 for both storage temperatures.

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