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Original Article

Effect of carrier type and concentration on the properties, anthocyanins and antioxidant activity of freeze-dried mao [*Antidesma bunius* (L.) Spreng] powders

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ABSTRACT

Mao fruit [*Antidesma bunius* (L.) Spreng] is an excellent source of anthocyanins, which are flavonoid pigments that provide a number of physiological benefits. Mao is a seasonal fruit and drying its juice has benefits in prolonging its shelf life, facilitating its transportation and extending the usage of mao powder. Freeze drying is a process widely used to produce fruit juice powders that are sensitive to heat in order to maintain their quality. A major problem in drying fruit juice is powder stickiness. In this research, drying carriers (maltodextrin and gum arabic at 25%, 30% or 35%) were added to improve the qualities of mao juice powder. The results showed that the addition of both carriers could improve the physical qualities of mao powders, and as the carrier concentration increased, the physical qualities increased, whereas the bioactivity qualities including the total anthocyanins content (TAC) and antioxidant activities tended to decrease. Powders with maltodextrin had better water solubility index and solubility time values than those of gum arabic. As a result, this work supported maltodextrin at 35% as a drying agent for mao powder production which produced a TAC of 2.63 mg/g and high-performance liquid chromatography determination indicated that the anthocyanins in the mao powder were delphinidin (1.10 mg/g) and cyanidin-3-O-glucoside (0.78 mg/g), with neither pelargonidin nor malvidin being detected.

Introduction

Mao or mamao fruit [*Antidesma bunius* (L.) Spreng] is classified in the family Phyllanthaceae and grows well in a variety of soil types, especially in dipterocarp forests; it is commonly found in Africa, Australia, a group of islands in the Pacific Ocean and tropical Asia, whereas in Thailand, it is typically found in the Northeast (Butkhup and Samappito, 2008). Mao is a shrub plant with a height of 5–10 m and normally flowers in the rainy season, having young fruits that are dark green and turn to orange-red, dark red and deep purple in the fully ripened stage in the late rainy season (August–October) (Nuengchamnong and Ingkaninan, 2010). Ripe mao fruits are a great source of anthocyanins and taste sweet to slightly sour. Anthocyanins are phytochemicals that provide a number of physiological benefits (including antioxidant, anti-inflammatory, anti-apoptotic and anti-carcinogenic activities), reduce the risk of type-2 diabetes and prevent LDL cholesterol oxidation and coronary heart disease (Butkhup and Samappito, 2008; Shipp and Abdel-Aal, 2010).

Anthocyanins belong to the class of phenolic compounds collectively named flavonoids. They are found in vegetables, fruits and flowers, and provide colors that are red, purple and blue. Although anthocyanins are interesting natural compounds that are used as food colorants due to their bright attractive colors, water solubility and many health benefits, they are sensitive to various factors such as temperature, light, pH and oxygen (Tonon et al., 2010). Several researchers have revealed techniques for improving the stability of anthocyanins and extending their shelf life and have used encapsulation techniques to produce fruit powders such as from the anthocyanins in freeze-dried strawberries (Mosquera et al., 2012), spray-dried blackberries (Ferrari et al., 2013), and grape juice (Gurak et al., 2013).

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Encapsulation using freeze drying is a good technique for preserving natural extracts that are sensitive to high temperature such as anthocyanins, prolonging their shelf life at room temperature and helping in handling and transportation. This process includes entrapping the desired product in a carrier to protect it from adverse environmental conditions (such as temperature, light, moisture and oxygen). Nevertheless, different carriers provide powders with different properties, depending on the structure and the characteristics of each carrier (Nayak and Rastogi, 2010).

In the food industry, common carriers used for encapsulation are polysaccharides, lipids and some proteins. As anthocyanins are hydrophilic colorants and water soluble, maltodextrin and gum arabic are usually chosen as carriers because they have low viscosity and high solubility in water (Fazaeli et al., 2012). Maltodextrins are oligosaccharides produced by the hydrolysis of starch, which consist of β-D-glucose units linked mainly by glycosidic bonds (1 → 4). Their properties depend on the dextrose equivalent (DE), which is a measure of the degree of hydrolysis of the starch in reducing sugars and it is defined as the percentage of anhydrous dextrose of a totally dry substance. Pure dextrose has a DE value of 100 and that of starch is 0 (Nayak and Rastogi, 2010). Gum arabic or acacia gum is the exudate from *Acacia senegal* and *Acacia seyal* trees (Patel and Goyal, 2015) and is a complex heteropolysaccharide with a highly ramified structure, consisting of a main chain formed of D-galactopyranose units joined by β-D glycosidic bonds (1 → 3); side chains with variable chemical structures formed from D-galactopyranose, L-rhamnose, L-arabinofuranose, and D-galacturonic acid are linked to the main chain β-(1 → 6) bonds (Righetto and Netto, 2005). They are generally added to fruit juices to increase the glass transition temperature (Fabra et al., 2011) resulting in reduced hygroscopicity and stickiness of fruit powders (Syamaladevi et al., 2012).

The objective of this study was to determine the effect of different carriers (maltodextrin and gum arabic) and their concentration on the properties, total anthocyanins content (TAC) and antioxidant activity based on 2,2′-dipheny-l-picrylhydrazyl (DPPH), 2,2′-azino-bis (3-ethylbenzothiazoline-6- sulfonic acid) (ABTS) and ferric reducing ability of plasma (FRAP) assays of freeze-dried mao powders. The selected mao powder was analyzed to indicate the types of anthocyanins using high-performance liquid chromatography (HPLC).

Materials and methods

Materials

Maodong (family *Phyllanthaceae*, genus *Antidesma*) was purchased from an orchard in Loei province, northeastern Thailand. Mao fruits with a dark red and purple color were selected and washed with water to remove any remaining sand or dirt and to reduce the initial microbial load, soaked with chlorine (50 ppm) for 30 min and washed with water again. The samples were kept in plastic bags, frozen and stored in a −18 °C freezing room until used.

Chemicals

Maltodextrin with DE 10–12 (Thai Food and Chemical; Bangkok, Thailand) and gum arabic (Chemipan; Bangkok, Thailand) were used as the carriers. Cyanidin-3-O-glucoside chloride and pelargonidin chloride were purchased from ChromaDex (Irvine, CA, USA). Delphinidin chloride from Extrasynthese (Genay, France). 2,2′-Dipheny-l-picrylhydrazyl (DPPH), 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS), iron (II) sulfate, 2,4,6-tris(2-pyridyl)-s-triazine (TPTZ), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (trolox), 2,6-di-tert-butyl-4-methyl-phenol (BHT) and ascorbic acid (vitamin C) and malvidin chloride were purchased from Sigma-Aldrich (St. Louis, MO, USA). Potassium chloride, iron (III) chloride, boric acid, citric acid, sodium carbonate and disodium hydrogenphosphate were purchased from Ajax Finechem (Auckland, New Zealand). Hydrochloric acid and formic acid were purchased from Merck (Darmstadt, Germany), sodium acetate hydrate from Carlo Erba (Milan, Italy) and acetonitrile from RCI Labscan (Bangkok, Thailand). Deionized water was made using a WaterPro Ro (Labconco Corporation, Kansas City, MO, USA).

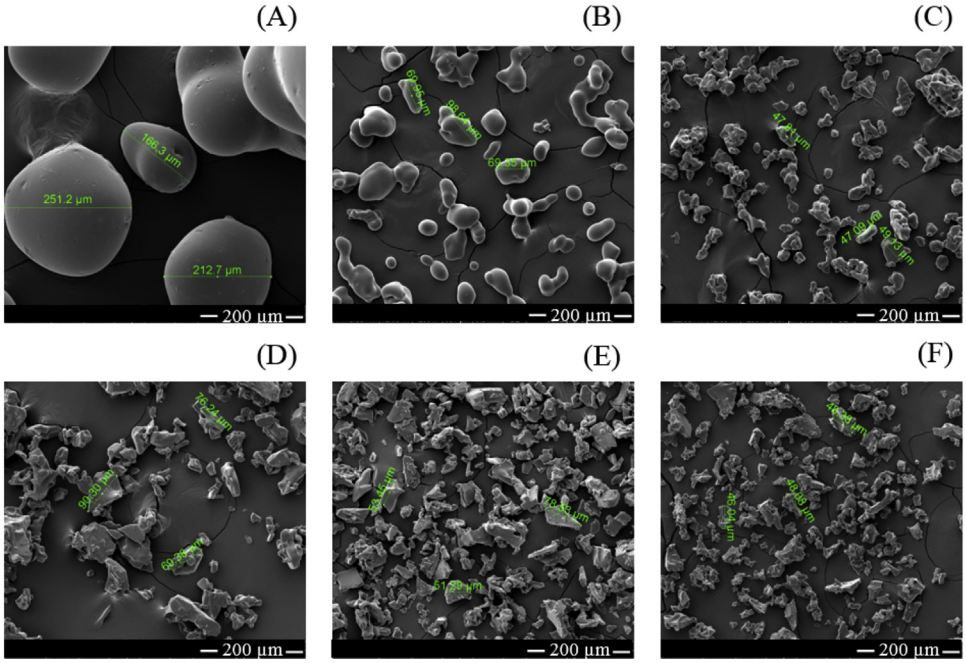

Fig. 1. Typical micrographs of mao powder containing various types and concentrations of carriers: (A) 25% maltodextrin, (B) 30% maltodextrin, (C) 35% maltodextrin, (D) 25% gum arabic, (E) 30% gum arabic and (F) 35% gum arabic.

Juice preparation

Frozen mao fruits were transferred to a refrigerator (4 °C) overnight before use, and later the mao fruits were squeezed using a juice extractor (GS 1000; Green Star; Anaheim, CA, USA), and vacuum filtered through a 230-mesh silk screen cloth.

Experimental design

The experimental design for the mao powder production was a full factorial with the two factors being carrier type (maltodextrin and gum arabic) and carrier concentration (25, 30 or 35% weight per weight; w/w). Each carrier was added to the juice and stirred using a magnetic stirrer (C-MAG HS 7; IKA; Konigswinter, Germany) until the mixture was homogeneous. Later, the mixtures were frozen at −80 °C (Forma 88000 series upright freezer; Thermo Scientific; Waltham, WA, USA) before being freeze-dried using a freeze dryer (Supermodulyo-230; Thermo Scientific; Waltham, WA, USA) at −65 °C and 6.5×10^{-1} mbar pressure for 29 h. The dried samples were ground into powder, packed separately in aluminum foil and kept in desiccators for further analysis.

Analytical methods

Powder properties

Mao powders of all treatments were determined for their properties consisting of color characteristics, water activity (a_w), moisture content, degree of caking, bulk density, water solubility index (WSI), solubility time, pH, hygroscopicity, TAC, individual anthocyanins, antioxidant activity, size and shape.

The color values in the CIE $L^*C^*h^o$ system were measured in reflectance mode using a spectrophotometer Minolta CM-3500d (Konica Minolta Inc.; Tokyo, Japan), under a standard illuminant D_{65} with a standard observer angle of 10°.

The a_w was determined using an Aqua Lab (Series 3 TE; Decagon Devices; Pullman, WA, USA).

The moisture content was analyzed by drying at the temperature of 100 ± 5 °C in the oven until a constant weight was obtained (AOAC, 2000).

The degree of caking was measured using the method modified by Martinelli et al. (2007). Mao powder (1.5 g) was transferred to a stainless-steel sieve (32 mesh), and then shaken for 5 min in a shaking apparatus (Retsch; Haan, Germany) at room temperature (25–30 °C). The powder that passed through the sieve was weighed and the degree of caking was calculated using Equation (1):

$$\text{Degree of caking } (\%) = c/d \times 100 \quad (1)$$

where d is the total amount of mao powder used and c is the amount of mao powder left on the sieve after sieving, with all weights in grams.

The bulk density was determined using the method described by Kha et al. (2010). Mao powder (2 g) was transferred to a 10 mL graduated cylinder and the cylinder was held on a vortex vibrator at position 2 (Vortex-2 genie; Scientific Industries; Bohemia, NY, USA) for 1 min. The bulk density was calculated by dividing the mass of the powder by the volume it occupied in the cylinder.

The pH was measured by dissolving 5 g mao powder with 25 mL deionized water at 25 °C, and then using a pH meter (Cyberscan 2500; Eutech; Singapore) (Kha et al., 2010).

The WSI was determined using the method modified by Kha et al. (2010). Mao powder (2.5 g) and deionized water (30 mL) were mixed in a 50 mL centrifugal tube, incubated at 37 °C for 30 min and centrifuged at 9000 revolutions per minute for 20 min (Universal 320 R; Hettich, Germany). The supernatant was collected for drying at 100 ± 5 °C in an oven until a constant weight was obtained. The WSI (%) was calculated as the percentage of dried supernatant with respect to the amount of the original 2.5 g sample of mao powder.

The solubility time was determined using a method modified from Goula et al. (2004). Mao powder (2 g) and deionized water at 26 °C (50 mL) were added to a 250 mL beaker. The mixture was agitated using a magnetic stirrer at position 2 (C-MAG HS 7; IKA; Staufen, Germany). The solubility time was recorded as the time until the mao powder had completely dissolved.

Hygroscopicity was evaluated according to Cai and Corke (2000). Mao powder (1 g) was placed in a container (2200 mL) with NaCl saturated solution (75%RH). The sample was kept at 25 °C for 1 wk before weighing. Hygroscopicity was expressed as the grams of adsorbed moisture per 100 g of dry matter.

Mao powder was attached to aluminum stubs using carbon tape, coated under vacuum with gold and examined using a scanning electron microscope (Quanta 450; FEI; Eindhoven, the Netherlands), operated at 12.5 kV with a working distance of 9.4–9.6 mm and 250 × magnification. The size of the objects was measured using an installed image analysis program (xT microscope control).

Anthocyanins content

Two types of anthocyanin analysis were performed: the total anthocyanins content (TAC) and individual anthocyanins using HPLC. The TAC was determined using the pH-differential method (Worsltad et al., 2005). Absorbance was measured using a spectrophotometer (UV/VIS Uvmini-1240; Shimadzu; Kyoto, Japan) at 510 and 700 nm. Reverse osmosis water was used as a blank. The TAC was calculated using Equation (2) and expressed as cyanidin-3-O-glucoside in milligrams per gram of sample.

$$\text{TAC}(\text{mg/g}) = (A \times MW \times DF \times 1{,}000 \times V)/(\varepsilon \times l \times g) \quad (2)$$

where A is the absorbance $= (A_{510}-A_{700})_{\text{pH 1.0}} - (A_{510}-A_{700})_{\text{pH 4.5}}$, ε is cyanidin-3-O-glucoside molar absorbance (26,900 L/mol/cm), l is the cell path length (1 cm), MW is the molecular weight of anthocyanins (449.2 g/mol), v is the solution volume (L), g is the weight of sample (g) and DF is the dilution factor.

Cyanidin-3-O-glucoside, delphinidin, pelargonidin and malvidin were quantified using HPLC (Shimadzu; Kyoto, Japan) with an Inertsil ODS-3 C_{18} packed column (ID 5 μm, 250 × 4.6 mm). The HPLC analysis method was modified from the method of Salazar-González et al. 2012. The acetonitrile to 4.5% formic acid ratios were applied at a rate of 1.5 mL/min in proportions of 10:90, 13:87 and 100:0 during 0 min, 11 min and 21 min, respectively, and measured at 520 nm. A standard solution of individual anthocyanin, suspended in ethanol:water (50:50), was injected to evaluate the area under the curve corresponding to 50–250 μg/mL of anthocyanins. This area was used to correlate the area observed on the chromatogram to calculate the amount of individual anthocyanin corresponding to individual anthocyanin.

Antioxidant activity

Many assays have been introduced to measure antioxidant capacity, with each assay applying different mechanisms. Antioxidant activities of mao powders were determined using DPPH, ABTS and FRAP assays and compared with butylated hydroxytoluene (BHT) and vitamin C.

The DPPH assay was slightly modified from Floegel et al. (2011). A solution of 1 mM DPPH in methanol:water (80:20) was stirred for 40 min. The DPPH solution was diluted with 80% methanol to an absorbance of 0.700 ± 0.02 at 517 nm. Then, the DPPH solution 2.95 mL and diluted Mao juice powder solution (0.5 mL) was added to a test tube. The mixture was kept in the dark for 30 min. The absorbance was measured at 517 nm using the spectrophotometer.

The results were calculated as the percentage of free radical scavenging using Equation (3) and compared to a standard curve of trolox concentrations, which were expressed in milligrams trolox equivalents per gram of sample.

$$\%\text{DPPH inhibition} = [(Ac - Abc) - (As - Abs)]/(Ac - Abc) \times 100 \quad (3)$$

where *Ac*, *Abc*, *As* and *Abs* are the absorbance of the control, the blank control, the sample and the blank sample, respectively.

The method for investigating ABTS radical cation scavenging activity was modified from Re et al. (1999). The ABTS radical cation was generated by mixing 7 mM ABTS and 2.45 mM potassium persulfate solution in the proportion 2:1; the mixture was kept in the dark and refrigerated for 12 h. The ABTS solution was diluted with ethanol until its absorbance at 734 nm was in the range 0.700 ± 0.02. Later, 2 mL of ABTS solution and 20 μL of mao solution were reacted in the dark for 6 min. The absorbance was measured at 734 nm using the spectrophotometer. The results were calculated as the percentage of free radical scavenging using Equation (4) and compared to a standard curve of trolox concentrations, which were expressed in milligrams of trolox equivalent per gram of sample.

$$\%\text{ABTS inhibition} = [(Ac - Abc) - (As - Abs)]/(Ac - Abc) \times 100 \quad (4)$$

where *Ac*, *Abc*, *As* and *Abs* are the absorbance of the control, the blank control, the sample and the blank sample, respectively.

The FRAP assay was modified from Benzie and Strain (1996). The FRAP reagent was generated by mixing 300 mM acetate buffer:iron reagent solution:$FeCl_3.6H_2O$:deionized water in the ratio 100:10:10:12 (v/v). The FRAP reagent (1.8 mL) was heated to 37 °C, then deionized water (180 μL) and mao solution (60 μL) were added. The mixture was shaken and incubated at 37 °C for 4 min. The absorbance was measured at 593 nm using the spectrophotometer. The measurement was compared to a standard curve of $FeSO_4$ concentrations and expressed in μmol of $FeSO_4$ per gram of sample.

Statistical analysis

Analysis of variance was used for the determination of significant variables using the SPSS software (version 12; SPSS Inc.; Chicago, IL, USA) at a confidence level superior to 95% ($p < 0.05$). Differences between means were evaluated using Duncan's new multiple range test. All measurements were done in triplicate.

Results and discussion

Mao juice contains sugars and several organic acids that contribute to its stickiness and the high agglomeration of mao powder after freeze drying. Therefore, this research studied the effect of carrier type and concentration on the powder properties, anthocyanins contents and antioxidant activities of mao powders. The results indicated that both the type and concentration of carriers affected the properties of mao powders as a whole. For the color, a_w, degree of caking, pH, WSI, solubility time, bulk density and antioxidant activity by DPPH assay, there were interactions between the carrier type and concentration (Table 1).

Powder properties

Color is an important attribute of any food or beverage as it can indicate quality as well as improve the appearance. All mao powders were produced under the same operating conditions, so the differences in the properties of the powders depended on the carrier type and concentration. The color of mao powders with all carrier types was purple (hue angles (h^o) were in the range 331.66–343.45). Increasing the carrier concentration tended to increase the lightness (L*) from 22.45 to 43.35 for maltodextrin and from 32.33 to 42.18 for gum arabic, since both maltodextrin and gum arabic were white shades and gum arabic was slightly yellowish so that when they were mixed with mao juice, the color was slightly changed.

Table 1
Color values of mao powders.

Treatment	L*	C*	h°
25% MD	22.45 ± 3.48^{d}	14.89 ± 0.90^{d}	337.09 ± 0.96^{b}
30% MD	29.36 ± 3.01^{c}	16.18 ± 1.04^{cd}	334.53 ± 1.01^{c}
35% MD	43.35 ± 1.50^{a}	18.04 ± 0.70^{b}	332.56 ± 2.26^{cd}
25% GA	32.33 ± 0.37^{c}	20.82 ± 0.66^{a}	343.45 ± 1.17^{a}
30% GA	37.52 ± 0.18^{b}	18.62 ± 0.49^{b}	337.83 ± 1.03^{b}
35% GA	42.18 ± 2.90^{a}	17.37 ± 0.51^{bc}	331.66 ± 1.05^{d}

MD = maltodextrin; GA = gum arabic.
$^{a-d}$ mean values with different lowercase superscript letters within each column denote significant differences ($p < 0.05$) and values are mean ± SD.

The a_w values of mao powders were in the ranges 0.149–0.353 and 0.171–0.266 for maltodextrin and gum arabic, respectively (Table 2). Increasing the carrier concentration tended to lower the a_w values, even though these values of mao powders with 25% and 30% maltodextrin were not significantly different. Nevertheless, the a_w values of all treatments were still within the expected range of dried products (below 0.6), which indicated that these products were safe from microbial growth (Subtil et al., 2014).

There was no interaction between carrier type and concentration regarding the moisture content. Mao powders with gum arabic had a higher moisture content (6.32%) than those with maltodextrin (5.08%). These results were in agreement with Ferrari et al. (2013) who found that blackberry powder produced with 7% maltodextrin had a significantly lower moisture content compared to blackberry powder produced with 7% gum arabic or a blend of both carriers (3.5% maltodextrin + 3.5% gum arabic) due to the differences between the chemical structure of both carriers—gum arabic is a complex heteropolysaccharide with a ramified structure, containing short chains and hydrophilic groups. As the carrier concentration increased, the moisture content of the powders tended to decrease although the moisture contents of mao powders with 25% and 30% maltodextrin were not significantly different.

Among all samples, mao powders with a high carrier concentration had a low moisture content and a_w resulting in a longer shelf life as there was less free water available for the growth of microorganisms and for the promotion of caking.

As the carrier concentration decreased, the moisture content and degree of caking increased, as the powder agglomerated with a high moisture content, which could be observed in the SEM micrographs. The degree of mao powder caking was in the range 21.26–85.04%, with the highest value at a low carrier concentration—for example, with 25% maltodextrin (85.04%) and 25% gum arabic (35.11%). According to Martinelli et al. (2007), the addition of maltodextrin and gum arabic in lemon juice powders reduced the degree of caking from 34.77% to 21.11% and 24.16%, respectively.

The bulk density of the mao powders was in the range 0.50–0.65 g/mL (Table 2). An increase in the maltodextrin concentration led to a significant decrease in the bulk density of the powder, while the bulk densities of the powders with different gum arabic concentrations were slightly different.

The pH values of mao powders were in the range 3.98–4.07 (Table 3), which was hardly affected by the carrier type and its

Table 2
Water activity, moisture content, degree of caking and bulk density of mao powders.

Treatment	Water activity	Moisture content (%)	Degree of caking (%)	Bulk density (g/mL)
25% MD	0.353 ± 0.027^{a}	5.85 ± 0.28^{ab}	85.04 ± 12.42^{a}	0.63 ± 0.02^{a}
30% MD	0.360 ± 0.039^{a}	5.86 ± 0.71^{ab}	59.67 ± 0.33^{b}	0.65 ± 0.00^{a}
35% MD	0.149 ± 0.044^{d}	3.53 ± 0.62^{c}	35.41 ± 4.68^{c}	0.50 ± 0.00^{c}
25% GA	0.266 ± 0.003^{b}	6.96 ± 0.04^{a}	35.11 ± 3.79^{c}	0.55 ± 0.02^{bc}
30% GA	0.229 ± 0.057^{bc}	6.59 ± 0.97^{ab}	25.63 ± 5.00^{cd}	0.56 ± 0.04^{b}
35% GA	0.171 ± 0.054^{cd}	5.41 ± 1.19^{ab}	21.26 ± 2.45^{d}	0.53 ± 0.05^{bc}

MD = maltodextrin; GA = gum arabic.
[a-d] mean values with different lowercase superscript letters within each column denote significant differences ($p < 0.05$) and values are mean ± SD.

Table 3
pH, water solubility index, solubility time and hygroscopicity of mao powders.

Treatment	pH	Water solubility index (%)	Solubility time (s)	Hygroscopicity (g/100 g)
25% MD	4.03 ± 0.01^{b}	91.64 ± 1.59^{b}	175.89 ± 10.05^{d}	16.88 ± 1.22^{b}
30% MD	4.07 ± 0.04^{a}	95.44 ± 1.78^{a}	171.11 ± 24.52^{de}	15.73 ± 1.01^{b}
35% MD	4.03 ± 0.02^{b}	96.87 ± 0.77^{a}	131.78 ± 2.34^{e}	17.03 ± 0.5^{b}
25% GA	3.98 ± 0.02^{c}	89.75 ± 0.96^{b}	501.11 ± 22.20^{c}	22.35 ± 0.18^{a}
30% GA	4.00 ± 0.01^{bc}	90.22 ± 0.55^{b}	555.00 ± 32.33^{b}	22.21 ± 1.32^{a}
35% GA	4.03 ± 0.01^{b}	89.29 ± 1.02^{b}	631.33 ± 27.74^{a}	22.02 ± 1.48^{a}

MD = maltodextrin; GA = gum arabic.
[a-e] mean values with different lowercase superscript letters within each column denote significant differences ($p < 0.05$) and values are mean ± SD.

concentration. This finding was in agreement with the results of Kha et al. (2010) who found that the pH of the Gac fruit aril powder was not significantly different ($p > 0.05$) among various maltodextrin concentrations (10%, 20% and 30%).

Solubility is an important property of powders that can be used to determine how easily the powder can be reconstituted in water at room temperature as it may be rehydrated before being used as a food ingredient or for food coloring (Syamaladevi et al., 2012). Moreover, the carrier type and concentration strongly affected the powder solubility.

Mao powders had WSI values in the range 89.29–96.87% (Table 3), similar to those of black glutinous rice bran powders in the range 76.23–91.79% (Laokuldilok and Kanha, 2015) and pomegranate juice powders in the range 92–95% (Yousefi et al., 2011). These values result from mao powder being rich in anthocyanins, which are highly soluble in water, as well as maltodextrin and gum arabic. Mao powder with maltodextrin had a higher WSI than with gum arabic, which has emulsifying properties since it has a low protein content (Cano-Chauca et al., 2005; Fazaeli et al., 2012). An increased concentration of gum arabic made no significant difference to the WSI of the powders, while increasing the concentration of maltodextrin led to an increase in the WSI. The highest WSI was in the powders with 30% and 35% maltodextrin (95.44% and 96.87%, respectively). Ahmed et al. (2010) reported that encapsulated purple sweet potato flours with higher concentrations of maltodextrin had higher WSI values than those encapsulated with lower concentrations.

The lowest solubility time was found in mao powders produced using 30% and 35% maltodextrin with values of 171.11 and 131.78, respectively. Mao powders with maltodextrin dissolved much faster than the powders with gum arabic due to maltodextrin's smaller size and its less complex molecular structure. Increasing the carrier concentration had significant effects on the solubility time of powders.

Freeze-dried powder easily absorbs moisture from its surroundings, which results in stickiness in the powder. The addition of maltodextrin and gum arabic to the sample before freeze drying provided desirable powder properties. The addition of carrier in fruit juice most likely modified the balance of hydrophilic and hydrophobic sites and reduced water absorption (Martinelli et al., 2007). Between the two carrier types, mao powder with maltodextrin was less hygroscopic than when gum arabic was used, because the glass transition temperature of gum arabic is lower than that of maltodextrin, which resulted in a more hygroscopic product (Nurhadi et al., 2012). Nevertheless, different carrier concentrations were not significantly different between the values of hygroscopicity. Tonon et al. (2008) reported that the lowest hygroscopicity values of açai powder were obtained when the highest maltodextrin concentration was used.

Morphology

Examination of the SEM micrographs showed the mao powders had irregular structures and several sizes because the dried samples were ground in a blender (Fig. 1). There were pores suffused in the powder, which occurred during the freezing process as ice crystals were generated and were later removed during the freeze-drying process (Franceschinis et al., 2014). The mao powder with 25% maltodextrin showed the biggest size as the powder agglomerated with a high moisture content (Paternina, 2014). The particle size of the powders was in the range 46–251 μm. The particle size of both carriers decreased with increased carrier concentration. Farias et al. (2007) found that all the powders had a smooth surface, but the ones with gum arabic had a more flake-like structure. Moreover, the particles produced using maltodextrin had greater diameters as they formed. According to Ferrari et al. (2013), blackberry powder particles produced using maltodextrin was bigger than with gum arabic because of the strong adherence of smaller particles to larger ones.

Anthocyanins content

Increasing the maltodextrin and gum arabic concentrations reduced the TAC (from 3.34 to 2.63 mg/g and from 3.47 to 2.34 mg/g, respectively), since their TACs were diluted with carrier. The carrier type had no significant effect on the TAC (Table 4). According to Khazaei et al. (2014), different compounds of wall materials (maltodextrin and gum arabic) in freeze-dried saffron petal extract did not show any significant differences in terms of stabilizing anthocyanins ($p < 0.01$).

Table 4
Total anthocyanins content and antioxidant activities of mao powder.

Treatment	TAC (mg/g)	DPPH (mg trolox equivalents/g)	ABTS (mg trolox equivalents/g)	FRAP (μmol $FeSO_4$/g)
25% MD	3.34 ± 0.17^{a}	18.60 ± 0.49^{a}	19.16 ± 0.97^{a}	155.64 ± 3.47^{b}
30% MD	2.71 ± 0.14^{bc}	16.69 ± 0.45^{b}	16.13 ± 0.23^{bc}	130.28 ± 6.08^{c}
35% MD	2.63 ± 0.25^{bc}	15.13 ± 0.57^{c}	14.77 ± 0.38^{cd}	117.65 ± 3.04^{d}
25% GA	3.47 ± 0.24^{a}	19.51 ± 0.39^{a}	17.02 ± 1.10^{b}	160.86 ± 2.63^{a}
30% GA	2.86 ± 0.26^{b}	16.82 ± 0.32^{b}	13.90 ± 1.66^{d}	133.27 ± 5.93^{c}
35% GA	2.34 ± 0.22^{c}	14.11 ± 0.82^{d}	11.54 ± 1.85^{e}	119.32 ± 7.64^{d}

MD = maltodextrin; GA = gum arabic; TAC = total anthocyanins content, DPPH = 2,2′-dipheny-l-picrylhydrazyl, ABTS = 2,2′−azino-bis (3-ethylbenzothiazoline-6-sulfonic acid), FRAP = ferric reducing ability of plasma.
[a-e] mean values with different lowercase superscript letters within each column denote significant differences ($p < 0.05$) and values are mean ± SD.

Table 5
Total anthocyanins content and individual anthocyanins content of mao juice powder with 35% maltodextrin.

Carrier	TAC (mg/g)	Individual anthocyanins from HPLC analysis			
		Cyanidin-3-O-glucoside (mg/g)	Delphinidin (mg/g)	Pelargonidin (mg/g)	Malvidin (mg/g)
35% maltodextrin	2.63 ± 0.25	0.78 ± 0.05	1.10 ± 0.12	nd.*	nd.*

TAC = total anthocyanins content; HPLC = high-performance liquid chromatography.
* nd. means not detected.

The TAC of powder with 35% maltodextrin was 2.63 mg/g and HPLC determination indicated that the anthocyanins in mao powder were delphinidin and cyanidin-3-O-glucoside (1.10 mg/g and 0.78 mg/g, respectively). However, pelargonidin and malvidin were not found (Table 5). Nuengchamnong and Ingkaninan (2010) found cyanidin-3-sophoroside, delphinidin-3-sambubioside and pelargonidin-3-malonyl glucoside in mao (*Antidesma thwaitesianum* Muell.) fruit wine. Moreover, Jorjong et al. (2015) indicated that the major anthocyanins in mao-luang (*Antidesma bunius*) were cyanindin, followed by malvidin, pelargonidin and delphinidin.

Antioxidant activity

The antioxidant activities of mao powder were investigated using DPPH, ABTS and FRAP assays and only the results from the DPPH assay produced any interaction between carrier type and concentration, although each assay used different mechanisms in antioxidant determination. ABTS and DPPH assays are methods to evaluate the ability of the antioxidant compounds by transferring a hydrogen atom or an electron (MacDonald-Wicks et al., 2006), while a FRAP assay measures the ability of the antioxidant in reducing the ferric-tripyridyltriazine (Fe^{III}−TPTZ) complex to the ferrous (Fe^{II}) form at low pH (Benzie and Strain, 1996). Nevertheless, all assays showed the same trends in their results—the antioxidant capacity decreased with an increase in the carrier concentration or it could be considered as a dilution effect (Table 4). Tonon et al. (2010) reported that spray-dried açai powders produced with maltodextrins and gum arabic were not significantly different with respect to both the anthocyanins content and antioxidant activity.

The antioxidant activities of mao powder with 35% maltodextrin were compared to a commercial antioxidant (BHT) and a natural antioxidant (vitamin C). The results showed that the mao powder had significantly lower antioxidant capacity (lower milligram trolox equivalents/g and FRAP values) compared to the commercial and natural products. BHT and vitamin C had an antioxidant capacity higher than mao powder by 5 times and 8 times, respectively, using DPPH assay, 5 times and 17 times, respectively, using ABTS assay and 10 times and 100 times, respectively, using FRAP assay (Table 6).

In conclusion, maltodextrin and gum arabic at high concentrations were appropriate additives in mao powder as their a_w values were less than 0.2 and both the TAC and antioxidant activity values were fairly similar. However, their antioxidant activities tended to decrease as the concentration increased. Thus, 35% maltodextrin is recommended for the production of mao powder because of its better properties in term of moisture content, WSI, solubility time and hygroscopicity, which are important qualities for a product, and most of all, it has a lower cost. HPLC analysis indicated that the anthocyanins in mao powder were delphinidin and cyanidin-3-O-glucoside.

Table 6
Antioxidant activities of mao powder with 35% maltodextrin compared with BHT and vitamin C.

Carrier/Standard	DPPH[a] (mg trolox equivalents/g)	ABTS[a] (mg trolox equivalents/g)	FRAP[a] (μmol $FeSO_4$/g)
35% maltodextrin	15.13 ± 0.57^{c}	14.77 ± 0.38^{c}	117.65 ± 3.04^{c}
BHT	80.89 ± 0.81^{b}	76.63 ± 0.87^{b}	1251.60 ± 110.67^{b}
Vitamin C	124.09 ± 1.39^{a}	254.61 ± 4.50^{a}	$12,296.85 \pm 165.70^{a}$

BHT = 2,6-di-tert-butyl-4-methyl-phenol; DPPH = 2,2′-dipheny-l-picrylhydrazyl; ABTS = 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid); FRAP = ferric reducing ability of plasma.
[a] Mean values with different lowercase superscript letters within each column denote significant differences ($p < 0.05$) and values are mean ± SD.

Conflict of interest

The authors declare that there are no conflicts of interest.

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