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Effect of Chemical Treatments to Reduce the Bitterness and Drying on Chemical Physical and Functional Properties of Dietary Fiber Pomelo Powder from C*itrus grandis* (L.) Osbeck Albedo

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ABSTRACT

The pomelo albedo was selected from three cultivars—Kao Nampung (KNP), Thongdee (TD) and Kao Yai (KY). KNP was a suitable cultivar for preparing dietary fiber powder because it had high crude fiber content and the limonin and naringin contents were lower than for TD and KY. Limonin and naringin are the main bitter components of pomelo albedo which need to be reduced. Three chemicals were used to reduce the bitterness of the pomelo albedo—NaCl (1%, 3%, 5%), $CaCO_3$ (1%, 3%, 5%) as well as various pH levels using 0.1 N NaOH solution (pH 7, 8 and 9). The results showed that all chemicals treatment could reduce the limonin and naringin contents ($P \leq 0.05$) but adjusting the organoleptic quality to pH 7 had the highest odor score and the lowest score for bitterness. Two drying methods were studied: freeze drying was conducted at -40 °C for 14 hr and the three conditions for tray drying were 50 °C for 5.5 hr, 60 °C for 4.5 hr and 70 °C for 2 hr. The freeze dried pomelo albedo powder had better physical, chemical and functional properties than the samples that were tray dried ($P \leq 0.05$). The water holding capacity and swelling capacity of the dietary fiber pomelo albedo powder were compared with commercial cellulose (carboxymethyl cellulose). It was found that the pomelo albedo dietary fiber powder had better functional properties than the commercial cellulose based on scanning electron microscopy. Thus, dietary fiber pomelo albedo powder can be used as a functional ingredient or in industrial applications using food products.

Keywords: pomelo albedo, limonin, naringin, dietary fiber powder

INTRODUCTION

Currently, there is increasing interest in personal health especially the presence of fiber in food products, a diminution in their calorific content and in all food that can supply fiber as part of the daily food intake (Grigelmo-Miguel and Martin-Belloso, 1999; Yusop *et al*., 2014). Dietary fiber plays an important role in human health because it is associated with the prevention, reduction and treatment of some diseases such as diverticular, hypercholesterolemia, colorectal cancer and coronary heart diseases (Francisco *et al.*, 2007). Hongu and Phillips (1990) suggested consumers read nutrition labels to find out exactly how much fiber is in favorite products as the

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recommended intake is 20 to 35 g of fiber per day per person or 10–13 g per 1,000 kilocalories of diet.

Dietary fibers are varied by the preparation method, different sourcing, their chemical composition and physicochemical characteristics and by the processing method. Cereals and vegetable are sources of high dietary fiber formulated food product and are currently being developed. Grigelmo-Miguel and Martin-Belloso (1999) suggested that dietary fiber is a significant constituent of many fruit and vegetables. By-products from fruit and vegetables are available in large quantities and some could also be useful for processing into dietary fiber. Larrauri (1999) reported in processing high dietary fiber powders, the main technological steps mentioned are wet milling, washing, drying and dry milling. Citrus fruit is a good choice to modify the dietary fiber as orange, lime, lemon and grapefruit are materials containing many compounds with fiber and antioxidant activity especially in the albedo of these fruit (Larrauri, 1999; Ghasemi *et al*., 2009; Pichaiyongvongdee, 2013). Pomelo—*Citrus grandis* (L) *Osbeck*—is the largest of all citrus fruit and is one of Thailand's economic plants with many cultivars grown in Thailand such as Tong Dee, Kao Yai, Kao Paen, Kao Nampheung, Kao Tanggkya, Kao Hom, Kao Phuang and Pattavee (Pichaiyongvongdee and Haruenkit, 2009). Saengthongpinit (2008) reported that Kanpeansan Commercial Co, Ltd produced about 0.3 $t.d^{-1}$ of pomelo peel. The main uses of pomelo fruit in food industries include fresh fruit and fresh juice but since the juice yield of pomelo fruit is less half of the fruit weight (28.48–38.71 ml per 100 g), very large amounts of by product wastes, such as peel are produced (Pichaiyongvongdee and Haruenkit, 2009) The weight of pomelo albedo ranged from 30 to 50 g per 100 g of the whole fruit (Pichaiyongvongdee and Haruenkit, 2009). Mostly, pomelo peel or only the albedo is thrown out without further use. Therefore a value-added application is strongly recommended. Traditionally pomelo albedo has been used as dietary fiber in various functional foods like bakery products, yam, beverages, meat and fish products (Yusop *et al*., 2014). In addition, pomelo albedo contains some antioxidants as phenolic compounds and antioxidant capacity are naturally present in all pomelo fruit and the amount varies depending on the cultivar and the tissue. For example, Pichaiyongvongdee (2013) reported that the total content of phenolic compounds was 1,896.15 µg per gram dry weight (DW) and the antioxidant capacity (from 2,2-diphenyl-2-picrylhydrazyl or DPPH assay) was 64.18%. However, the albedo of pomelo contains bitter principal compounds with Pichaiyongvongdee and Haruenkit (2009) reporting the concentration of limonin 133.58–352.72 parts per million, ppm) and naringin (10,065.06–28,508.01 ppm) being detected at amounts that exceeded customer acceptance. Kimbal and Norma (1990) found that the threshold point for the sensory detection of limonin was 5–6 ppm, whereas naringin bitterness was detected at 800 ppm (Rouseff, 1988). Therefore, several methods for the reduction of the bitterness in dietary fiber from citrus fruit have been reported. For example, Attavanich and Anprung (2003) used a solution at pH 7 with C*itrus reticulata* Blanco peel to remove the bitterness. Sansawat (2006) used a ratio of 3:1 (volume per weight, v/w) of 95% ethanol:orange pomace. Namkham (2011) applied with salt at the ratio of 1:0.5 (weight per weight, w/w) for pomelo albedo:salt, and then applied fermentation for 12 hr. Naowakul *et al*. (2013) reported two steps that used a solution at pH 7 for a holding time of 20 min and then a holding time with 95% ethanol for 48 hr. All methods could reduce the bitterness of the citrus fruit but some methods used high concentrations of chemicals that may contaminate the citrus fruit and some methods used holding times of more than 24 hr to reduce the bitterness. Thus, the objectives of the current study were to determine whether the bitterness in pomelo albedo could be reduced using three chemicals under varied conditions, that is NaCl, $CaCO_3$ and various pH levels (pH 7, 8 and 9) using 0.1 N NaOH solution and one of two drying methods—freeze drying and tray drying (50 °C, 60 °C and 70 °C) and their effects on the physical, chemical and functional properties of the dietary fiber from pomelo albedo.

MATERIALS AND METHODS

Materials

Three pomelo cultivars of *Citrus grandis* (L.) Osbeck were collected from orchards in two provinces being Thong Dee (TD) and Kao Nampheung (KNP) in Nakhon Pathom province, Thailand and Kao Yai (KY) in Samut Songkhram province, Thailand. The pomelo albedo was manually separated and cut into pieces of approximately 1×1×1 cm before use.

For chemical analysis, each sample of pomelo albedo was processed in a blender (Model A 327 R7; Moulinex; Écully, France) and then dried at -40 °C in a freeze dryer (model LyoPro 3000, Heto-Holten A/S; Allerød, Denmark) for 12–15 hr until the moisture content was less than 10%. Next, the samples were ground in a mill. The milled pomelo albedo was separated for particle size analysis using sieves. The separated particles that were smaller than 150 µm (mesh 100) were vacuum packed and kept at -20 °C for further analysis.

Sample preparation

Reduction of bitterness

The manually cut pomelo albedo (1×1×1 cm) samples were washed and dried. The dried samples were treated with nine different conditions to reduce bitterness: NaCl (1%, 3%, 5%); $CaCO_3$ (1%, 3%, 5%); and pH 7, 8 and 9 using 0.1 N NaOH solution. The ratio of the pomelo albedo solution was 1:10 (w/v). The sample was left in the solution for 24 hr and then the liquid was removed and samples were washed with water. Each sample was steamed for 10 min before centrifugation for 30 min to produce a product called debittered pomelo albedo. Pomelo albedo samples from the cultivar that was considered to be the least bitter after the debittering process were then subjected to different drying conditions.

Drying conditions

The pomelo albedo was prepared and treated to reduce the bitterness. Four drying conditions were compared—freeze drying at -40 °C and tray drying at 50, 60 and 70 °C. Each dried sample was milled and sieved so that the separated particles were smaller than 150 µm (mesh 100) and this product was called dietary fiber powder from pomelo albedo.

Physicochemical analysis

The pH of each sample was measured using a digital pH meter (CG 842; Schott GmbH; Mainz, Germany) The color analysis of the dietary fiber was performed using a Handy Colorimeter (Minolta Camera Co.; Osaka, Japan) following the system of the CIE L* a* b* (Minolta, 1993). The water activity (Aw) of the dietary fiber was measured using a portable water activity meter (AW Sprint TH 500; Novasina AG; Lachen, Switzerland).

Proximate analysis

The contents of protein, fat, crude fiber, moisture, ash and carbohydrate were estimated according to AOAC International (2005).

Soluble, insoluble and total dietary fiber determination

Soluble dietary fiber (SDF), insoluble dietary fiber (IDF) and total dietary fiber (TDF) were estimated according to AOAC International (2000).

Limonin and naringin content of the pomelo dietary fiber

Samples of 5 g of the dietary fiber were weighed and then extracted with 20 mL of methanol by shaking for 1 min with a Vortex Mixer, followed by centrifugation at 4,500×*g* for

30 min. The extract was passed through a 0.22 μm nylon filter prior to the high performance liquid chromatography (HPLC) analysis.

Determination of limonin and naringin by high performance liquid chromatography

Limonin and naringin were determined by a reverse-phase HPLC method. The system consisted of an HPLC system (series 200; PerkinElmer; Waltham, MA, USA) with quaternary hydraulic pumps—a C_{18} column (4.5 × 50 mm, pore size 3 μm—a C_{18} guard column and an ultraviolet detector with a computerized recorder/integrator (Total Chrom TM workstation Version 6.2.0, PerkinElmer; Waltham, MA, USA). For limonin, the mobile phase consisted of acetonitrile:deionised water (45:55) with a flow rate of 0.7 $mL.min^{-1}$. The injection volume of the sample was 20 μL. The detection wavelength was 210 nm (a modified method from Sun *et al.*, 2005). For naringin, the mobile phase consisted of acetonitrile:deionised water (25:75) with a flow rate of 0.7 $mL.min^{-1}$ and the injection volume was 20 μL. The detection wavelength was 280 nm (a modified method from Kanaze *et al.*, 2003).

Standards

Limonin ($C_{26}H_{30}O_8$) and naringin ($C_{27}H_{32}O_{12}$) were purchased from Sigma-Aldrich Chemical Co. (St. Louis, MO, USA). Standard solutions were prepared weekly, limonin by diluting the stock of limonin solution to 15, 20, 40, 60 and 80 ppm with the mobile phase and naringin by diluting the stock solution to 50, 100, 200, and 300 ppm with the mobile phase. Standard curves were used for the calculation of limonin and naringin in the extracts. The linear regression equations for the curves for limonin and naringin were $y = 18{,}058x$ with a correlation coefficient (r^2) value of 0.998 and $y = 22{,}302x$ with an r^2 value of 0.998, respectively.

Preparation of methanol extracts of the pomelo dietary fiber

The pomelo dietary fiber (1 g) was extracted with 20 mL of methanol (w/v), in a shaker at 6,000 rpm for 30 min at 80 °C and then the extract was filtered through Whatman No.4 filter paper and the extract was stored in an amber-colored bottle at -4 °C for determination of the total polyphenol content and antioxidant activity assays (Tsai *et al.*, 2007).

Total polyphenol content

The total polyphenol content in the pomelo albedo extract was determined by the Folin-Ciocalteu method (Shen *et al.*, 2009). Each sample (0.4 mL) was added to 2 mL of 10% Folin- Ciocalteu reagent. After 4 min, 5% Na_2CO_3 (1.6 mL) was added to the mixture and allowed to stand for 30 min before measurement. The absorbance was measured at 765 nm using an ultra violet-visible light spectrophotometer (model 1601; Shimadzu Corp.; Kyoto, Japan). The total polyphenol was expressed as millgrams of gallic acid equivalent (GAE) per milliliter.

Antioxidant activity using a free radical scavenging assay

The stable DPPH radical was used for determination of free radical-scavenging activity of the pomelo albedo extracts (a modified method from Zigoneanu *et al.*, 2007). Different concentrations of each extract were added, at an equal volume, to a solution of DPPH (200μM). After 30 min at room temperature, the absorbance was recorded at 515 nm. The antioxidant activity (DPPH) was expressed as micro molar (μM) Trolox equivalent.

Measurements of functional properties

The functional properties measured were: water holding capacity (WHC) using centrifugation according to the Ang (1991a) method; oil holding capacity (OHC) using centrifugation according to the Ang (1991b) method and swelling capacity (SWC) using the method of Robertson *et al.* (2000).

Sensory evaluation

The samples were tested using 50 trained panelists recruited from Suan Dusit Rajabhat University, Bangkok, Thailand. The pomelo albedo (control) was compared to the pomelo albedo with reduced bitterness using approximately 30 g of each sample in separate 100 mL white plastic cups each labeled with a random three-digit code to avoid bias. Samples were served randomly in two sessions (five samples per session). The intensities of sensory attributes consisting of odor, texture and bitterness taste were quantified using a 10 cm line scale (Meilgaard *et al*., 2007).

Statistical analysis

Data were analyzed using Duncan's multiple range test to establish multiple comparisons of the mean values at the 95% confidence level (P = 0.05). The statistical software program SPSS 16.0 was used to perform all statistical calculations.

RESULTS AND DISCUSSION

Chemical composition of the pomelo albedo

The results of the chemical composition of the three pomelo albedo cultivars are presented in Table 1. The moisture, protein and fat contents were 2.85–3.80%, 5.41–9.60% and 0.43–0.71% dry basis, respectively. Both white (KY and KPN) and pink (TD) pomelo albedo were good sources of antioxidant activity (DPPH) and high crude fiber content which were 93.66–95.35 μM and 74.05–77.25% dry basis, respectively.

The limonin and naringin contents were 253.46–415.93 ppm and 17,927–25,944.99 ppm dry basis, respectively. The presence of high concentrations of limonin and naringin in pomelo albedo is a great problem in its processing into food products. In general, consumers can detect bitterness at a very low concentration (6 ppm) of limonin (Kimball and Norman, 1990).

The main characteristics of the commercialized fiber product are: total dietary fiber content above 50%, moisture content lower than 9%, low lipids content, low calorific value and neutral flavor and taste (Larrauri, 1999). Based on these criteria, the limitation of pomelo albedo as a dietary fiber product was the presence of bitterness compounds. Thus, KNP was the selected cultivar for further experimentation, due to its limonin and naringin contents being lower than in KY, its high crude fiber content, its color was more yellowish white and the albedo thickness was higher than in KY and TD (Pichaiyongvongdee and Haruenkit, 2009). For these reasons KNP was a suitable cultivar for use.

Table 1 Mean (±SD) chemical composition of three tested pomelo albedo cultivars (dry weight basis).

Parameter	Cultivar		
	Thong Dee	Kao Nampheung	Kao Yai
Moisture (%)	2.85±0.08	3.59±0.03	3.80±0.02
Protein (%)	9.60±1.55	5.87±0.36	5.41±0.27
Fat (%)	0.71±0.06	0.43±0.09	0.46±0.01
Crude fiber (%)	74.05±0.09	77.25±1.56	74.85±0.21
Ash (%)	4.72±0.03	3.74±0.10	3.52±0.05
Carbohydrate (%)	7.27	9.12	11.96
Limonin (ppm)	415.93±3.36	253.46±2.51	279.45±4.56
Naringin (ppm)	25,944.99±31.38	17,927±29.98	19,085±18.56
Total phenolic content (mg gallic acid per g dry basis)	13.1079±0.27	9.07±0.38	10.25±0.20
Antioxidant activity (DPPH) (μM)	95.35±0.25	93.66±0.10	94.67±0.50

ppm = Parts per million; DPPH = 2,2-diphenyl-2-picrylhydrazyl.

Effect of chemical treatment on reduction of bitterness in pomelo albedo

The limonin and naringin present in all pomelo tissue are the main cause of bitterness. The highest contents of limonin were detected in the seeds followed by the albedo and flavedo, whereas the highest contents for naringin were detected in the albedo, flavedo and segment membranes, respectively (Pichaiyongvongdee and Haruenkit (2009). Reduction of the limonin and naringin contents in intact pomelo fruit using ethylene was reported by Pichaiyongvongdee and Haruenkit (2011). Treating the albedo with chemicals before use is worth trying.

The effect of the chemicals NaCl (1%, 3%, 5%) and $CaCO_3$ (1%, 3%, 5%) and a pH adjustment (pH 7, 8, 9) on reducing the bitterness (limonin and naringin content) of pomelo albedo were investigated. All treatments could significantly reduce the bitterness ($P \leq 0.05$) to varying degrees according to the treatments shown in Table 2. It was clear that naringin was more sensitive to the treatment and its reduction was greater. With conditions of 5% $CaCO_3$ and pH 9, the limonin was reduced the most and there was no significant difference between the treatments. The limonin was decreased by 28.62% (for 5% $CaCO_3$) and 28.17% (for pH 9), while 1% NaCl and 3% NaCl had an inferior effect on limonin reduction.

All conditions could reduce the naringin content by more than 80%. This might have been due to naringin being soluble in water (Horowitz and Gentili, 1977), whereas Yoon *et al.* (1997) reported that flavonoid is not soluble at pH 6.5 or lower. It was only soluble in pH 7 and was insoluble in a pH greater than 7. The results confirmed that there was a reduction in the naringin content in the pomelo albedo at pH 7, whereas the H_2O (control) had pH 6.6.

The reduction in the limonin content (7.74–28.62%) was lower than for naringin (78.04–93.64%) due to the limonin being more soluble in chloroform, acetonitrile and glacial acid and slightly soluble in water (Maier *et al.*, 1977).

The results showed that all treatments could reduce the limonin and naringin contents of pomelo albedo, but the debittering was adjusted to a pH of 7 to test the organoleptic acceptance and ensure that the consumption suitability had the highest score for the odor and the lowest score of bitterness (Table 3). NaCl showed an inferior effect on the odor and texture and $CaCO_3$ showed an inferior effect on bitterness. Thus, debittering of pomelo albedo by adjusting the pH to 7 resulted in

Table 2 Mean values (±SD) for chemical treatments to reduce limonin and naringin in pomelo albedo (Kao Nampheung).

Treatment condition	Limonin (ppm, DW)	Naringin (ppm, DW)
Pomelo albedo (fresh)	253.46±2.51	17,942.95±8.58
H_2O (control)	233.87±3.48 ^{a}, (7.74%)	3,938.57±13.13 ^{a},(78.04%)
1% NaCl	227.27±3.12 ^{a}, (10.33%)	2,788.54±2.48 ^{b}, (84.45%)
3% NaCl	212.53±3.81 ^{b}, (16.14%)	2,288.38±4.25 ^{c}, (87.24%)
5% NaCl	201.77±4.55 ^{c}, (20.39%)	2,018.91±5.39 ^{d}, (88.75%)
1% $CaCO_3$	199.24±1.75 ^{c}, (21.39%)	1,868.72±2.36 ^{e}, (89.58%)
3% $CaCO_3$	197.53±3.57 ^{c}, (22.06%)	1,806.53±1.65 ^{f}, (89.93%)
5% $CaCO_3$	180.93±1.37 ^{d}, (28.62%)	1,550.92±4.88 ^{g}, (91.35%)
pH 7	204.08±4.08 ^{c}, (17.51%)	1,264.69±4.60 ^{h}, (92.95%)
pH 8	196.76±5.43 ^{c}, (22.37%)	1,147.27±5.84 ^{i}, (93.60%)
pH 9	182.06±2.73 ^{d}, (28.17%)	1,141.15±1.83 ^{i}, (93.64%)

ppm = Parts per million; DW = Dry weight.

pomelo albedo being useful in the drying process of dietary fiber.

Effect of drying process on characteristics of dietary fiber

The effect of different drying conditions on the physicochemical properties, chemical properties and functional properties of dietary fiber from the debittered pomelo albedo are shown in Table 4.

Physicochemical properties

Drying is a process that consumes both time and energy and is the most expensive step in dietary fiber production (Larrauri, 1999) Therefore, a suitable drying method is essential. The process extends the shelf life of the product by preventing the growth of microorganisms (Larrauri, 1999). The results of the current study showed that the yield range of dietary fiber obtained from the different drying methods was 14–17%. Color is the important quality parameter of dietary fiber that affects consumer's acceptability (Grigelmo-Miguel and Martin-Belloso, 1999). The value of L* (80.13) for the freeze-dried sample was higher than from tray drying (75.93–78.12) which indicated a lighter color from freeze drying. The

Table 3 Mean (±SD) organoleptic scores of pomelo albedo (control) compared to pomelo albedo (Kao Nampheung) with chemical-reduced bitterness.

Treatment	Odor	Texture	Bitterness
H_2O (control)	1.61±0.33^{d}	8.48±0.75^{a}	2.16±0.45^{b}
1%NaCl	2.05±0.69^{d}	1.20±0.67^{d}	2.21±0.46^{ab}
3%NaCl	1.75±0.91^{d}	1.03±0.48^{d}	2.20±0.34^{ab}
5%NaCl	2.53±0.98^{cd}	1.97±0.31^{c}	2.50±0.26^{a}
1%$CaCO_3$	4.06±0.87^{ab}	6.57±1.22^{b}	2.30±0.20^{ab}
3%$CaCO_3$	4.76±0.83^{a}	6.94±0.76^{b}	2.30±0.24^{ab}
5%$CaCO_3$	4.43±2.48^{a}	6.54±1.32^{b}	2.29±0.37^{ab}
pH 7	4.84±1.30^{a}	6.25±0.76^{b}	1.77±0.22^{c}
pH 8	3.84±0.40^{ab}	6.63±0.51^{b}	1.81±0.29^{c}
pH 9	3.40±0.64 ^{b}	6.50±0.80^{b}	1.85±0.24^{c}

a–d = Different lowercase superscript letters in the same column indicate values are significantly different ($P \leq 0.05$).Intensities of sensory attributes use a10 cm line scale to indicate the best quality of odor, texture and bitterness.

Table 4 Effects of drying process on mean (±SD) physicochemical characteristics of dietary fiber powder from pomelo albedo (Kao Nampheung).

Drying process	Physicochemical property					Chemical property			
	Yield (%)	Color L*	Color a*	Color b*	Water activity	Moisture (%)	Limonin (ppm, DW)	Naringin (ppm, DW)	Crude fiber (%, DW)
Pomelo albedo (Fresh)	-	85.18±0.81^{a}	1.43±0.27^{a}	3.56±0.28^{b}	0.963±0.01^{a}	85.61±0.07^{a}	253.46±2.51	17,942.35±29.98	-
Freeze drying - 40 °C for 14 hr	17.31	80.13±1.11^{b}	0.25±0.21^{b}	3.08±0.45^{b}	0.460±0.01^{c}	6.12±0.08^{c}	182.70±3.43^{c} (22.41%)	1,434.26±3.39^{a} (92.01%)	88.50±0.45
Tray drying 50 °C for 5.5 hr	15.28	75.93±1.12^{d}	1.2±0.67^{a}	5.11±0.47^{a}	0.654±0.02^{b}	9.28±0.48^{b}	230.76±2.69^{a} (2.00%)	1,319.89±3.33^{c} (92.64%)	83.51±0.49
Tray drying 60 °C for 4.5 hr	14.29	78.12±0.26^{c}	1.37±0.15^{a}	5.38±0.40^{a}	0.397±0.01^{d}	5.68±0.40^{c}	213.81±3.28^{b} (9.19%)	1,355.09±2.63^{b} (92.44%)	80.99±0.09
Tray drying 70 °C for 2 hr	14.19	78.08±0.56^{c}	1.31±0.20^{a}	5.36±0.36^{a}	0.377±0.02^{e}	5.38±0.27^{c}	208.25±2.81^{b} (11.55%)	1,120.92±5.16^{d} (93.75%)	81.59±0.21

ppm = Parts per million; DW = Dry weight.
a–d = Different lowercase superscript letters in the same column indicate values are significantly different ($P \leq 0.05$).
Values in parentheses indicate the mean % of limonin and naringin reduction.

a* and b* values of the freeze-dried sample were 0.25 and 3.08, respectively, which were lower than for the tray dry samples (1.2–1.37 and 5.11–2.36, respectively). Thus the color of the tray-dried samples was slightly brown caused by pigment degradation, in particular by chlorophylls and the browning reaction (Maillard reaction) when the dietary fibers were heat-treated.

The pomelo albedo was subjected to four drying conditions—freeze drying and tray drying at 50 °C for 5.5 hr, 60 °C for 4.5 hr and 70 °C for 2 hr. The dietary fiber obtained had Aw values in the range 0.37–0.65 and a pH range of 4.43–4.75. These parameters are important with regard to the safety quality of the product. Dried food should have an Aw value less than 0.6 and a moisture content lower than 10% to avoid microbial growth as most bacteria prefer a pH range of 6.5–7.5 while molds and yeast prefer a pH range of 5–6 (Larrauri, 1999).

Chemical properties

During dehydration of the pomelo albedo, the water losses resulted in a moisture content in the pomelo albedo dietary fiber (5.38–9.28%) that was lower (86.61%) compared to the values of fresh pomelo albedo. Moisture content is strongly related to improving the quality of food and it can control microbial growth (Larrauri, 1999).

Larrauri, (1999) reported that the main characteristic of the commercialized fiber product was that it should have a dietary fiber content above 50%. The crude fiber content of the dietary fiber pomelo albedo was in the range 81.59–88.50%.

The reduction in the limonin content (22.41%) in the dietary fiber powder following freeze drying was more than by tray drying (2.00–11.55%). This may have resulted from limonoate-A-ring lactone (the non bitter form), being changed to limonin (the bitter form) when the albedo was broken and catalyzed by high temperature (Maier *et al.,* 1977). The naringin behaved slightly differently with the different drying conditions used. Temperature had no effect on naringin due to the structure of naringin being stable and not changing form. Thus, based on the current study, naringin can be reduced by more than 90% under all drying conditions.

Functional properties

The WHC and SWC play important roles in maintaining the quality of food products as they influence the formation of texture in food (Zayas, 1997). The WHC and SWC of the dietary fiber after freeze drying (17.48 g water per gram fiber, 21.83 g per gram fiber, respectively) were higher than the dietary fiber after tray drying (13.66–16.16 g water per gram fiber, 17.86 g per gram fiber, respectively) due to the high drying temperatures breaking down the cell membrane as evidenced by the scanning electron microscopy and the higher level of commercial carboxymethyl cellulose (CMC, with WHC of 9.19 g water per gram fiber, SWC of 13.01 g per gram fiber, respectively). The dietary fiber obtained from the current study had a rough surface area because the surface contained fat, protein and carbohydrate. In contrast, CMC had a smooth surface as shown in Figure 1. This characteristic supports the good functional properties of pomelo albedo dietary fiber. Thus, it confirms the suitability of dietary fiber made from pomelo albedo powder as a source of functional ingredient or for application in food products.

CONCLUSION

This study examined dietary fiber powder prepared from pomelo albedo after several different treatments to reduce the bitterness of the pomelo albedo. The KNP cultivar was suitable for preparing dietary fiber powder because of its high crude fiber content and low limonin and low naringin contents. Debittering was achieved by adjusting the pH to 7 using 0.1 N NaOH solution. A ratio of pomelo albedo:solution was 1:10 (w/v) could reduce the bitterness (limonin and naringin) and produced a better odor and texture with no bitter acceptance scores. The debittered pomelo albedo after freeze drying at -40 °C for 14 hr gave better chemical and functional properties of the dietary fiber in terms of the high crude fiber content (88.50%) than from tray drying (80.51–83.50%). The insoluble dietary fiber (IDF), soluble dietary fiber (SDF) and IDF/SDF were 38.18%, 37.96% and 1.01, respectively. The IDF/SDF ratio was consistent with those previously reported (1–2.3) by Spiller (1993). The freeze-dried fiber had good antioxidant activity (DPPH) (83.37 µM), low Aw (0.46), low moisture content (6.12%) and low fat content (0.43%). The functional properties were: WHC (17.48 g water per gram fiber), OHC (7.46 g oil per gram fiber) and SWC (21.83 g per gram fiber). Overall, it could be concluded that albedo

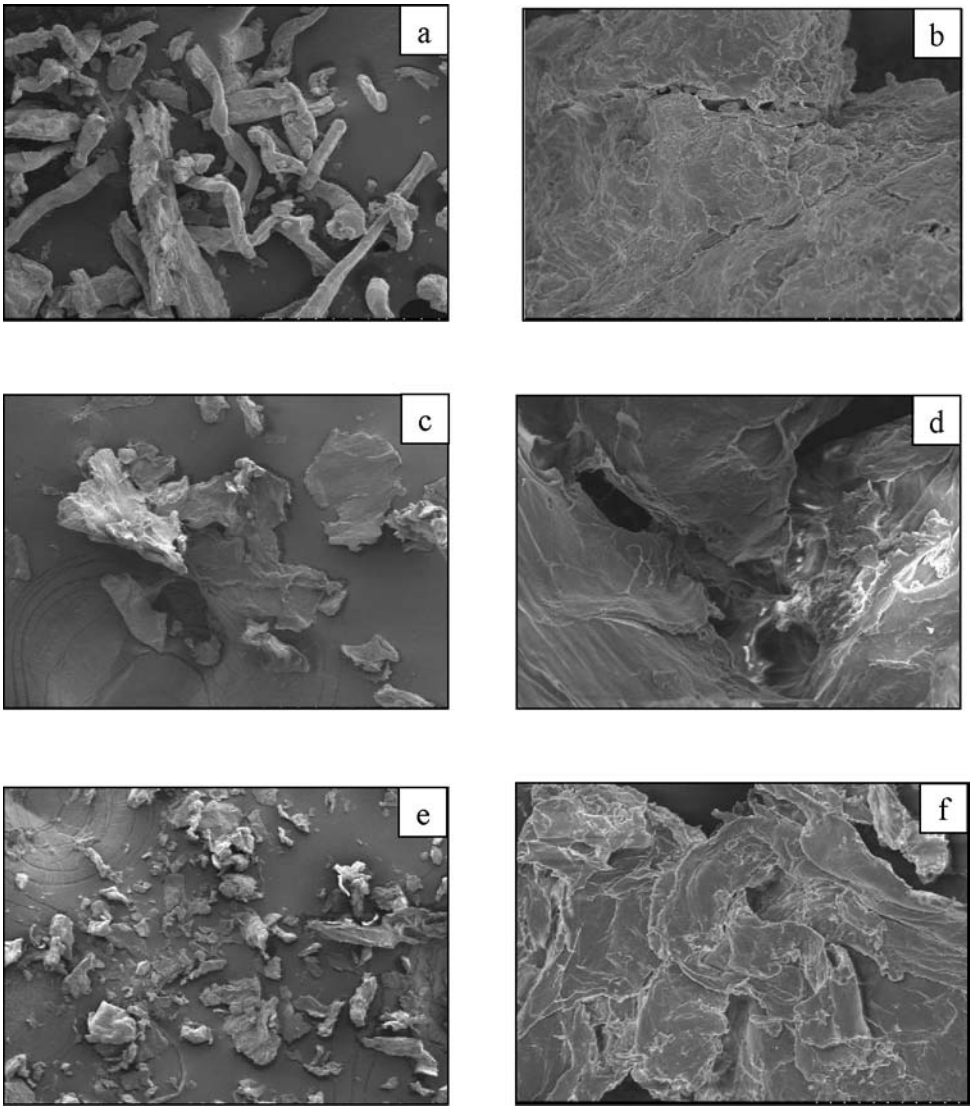

Figure 1 Scanning electron microscopy: (a) Commercial carboxymethyl cellulose (250×); (b) Commercial carboxymethyl cellulose (2,000×); (c) Dietary fiber pomelo albedo powder from freeze drying at -40 °C for 14 hr (250×); (d) Dietary fiber pomelo albedo powder from freeze drying at -40 °C for 14 hr (2,000×); (e) Dietary fiber pomelo albedo powder from tray drying at 70 °C for 2 hr (250×); (f) Dietary fiber pomelo albedo powder from tray drying at 70 °C for 2 hr (2,000×).

pomelo is a suitable by-product for use in the food industry. Further studies are required into the storage of dietary fiber powder and its use in processed food products, such as ice cream and beverages.

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