International Food Research Journal 21(5): 2099-2107 (2014)
Journal homepage: *http://www.ifrj.upm.edu.my*

Physico-chemical and flowability characteristics of a new variety of Malaysian sweet potato, VitAto Flour

[1]Mohd Hanim, A. B., [2*]Chin, N. L. and [2]Yusof, Y. A.

[1]*Technology Promotion and Development Centre, Malaysian Agricultural Research and Development Institute, 43400 Serdang, Selangor, Malaysia*
[2]*Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*

Article history

Received: 24 November 2013
Received in revised form: 23 March 2014
Accepted: 27 March 2014

Keywords

VitAto
Sweet Potato
Flour
Pasting
Flowability

Abstract

Proximate, functional and pasting properties of a new variety of sweet potato, VitAto, flour, known for its high vitamin A contents, were compared with two other commercial sweet potatoes, Bukit Naga and Okinawan, flour available in Malaysia. The recoveries of each sweet potato from milling were not significantly different at about 20% but in proximate analysis, the VitAto presented the highest protein (5.7%) and dietary fiber (14.8%) contents with more energy 399.6 kcal/100 g produced. The VitAto flour has average particle size of 132.04 µm. The pasting temperature of the VitAto flour was 65°C, with highest setback and trough viscosity values of 530.90 and 197.20 mPa.s, respectively. The flour is classified as easy flowing and stable powders. This study provides information which helps in the handling, packing and storage of sweet potato flours. It also shows that the VitAto flour has an array of functional, pasting and proximate properties that can facilitate its uses in many areas with better nutritional properties.

Introduction

Sweet potato (*Ipomoea batatas*) is widely grown throughout the tropics and warm temperate regions of the world. It is valued for its short growing period of 90 to 120 days, thus becoming a very important crop in developing countries. According to the United Nation's Food and Agriculture Organisation (FAO) report (1984), sweet potato is one of the seven crops in the world which produce over 135 hundred million metric tons of edible food products in the world annually. Apart from being a staple crop for some parts of the world, e.g. Papua New Guinea, Philippines, Tonga and Solomon Islands, sweet potato plays a multitude of varied roles in the human diets, being either supplemental or a luxury food. This is because of its nutritional qualities, which are important in meeting human nutritional needs including carbohydrates, vitamins A and C, fibers, iron, potassium and high quality protein (Mais and Brennan, 2008).

In Malaysia, sweet potato ranks second among the tuber crops next to cassava and has been cultivated on small scale since the 17th century. The Malaysian Agricultural Research and Development Institute (MARDI) has introduced the VitAto, a new variety of sweet potato in June 2007, the culmination of a 10 years breeding program aimed at developing nutritionally more superior sweet potato varieties. The cultivation of the VitAto is outstanding in its yield performance, even on marginal soils such as tin-tailings, BRIS (Beach Ridges Interspersed with Swales) and acid sulphate soils with appropriate agronomic amendments, surpassing currently grown orange-fleshed varieties in Malaysia. The VitAto is rich in beta carotene (2066 mg/100 g) and vitamin C (1.33 mg/100 g), dietary fiber content (2.49 g/100 g) and has low glycemic index of 54 (Mahmood *et al.*, 2007). These good nutritional qualities of VitAto make it a very good supplement food for Malaysians.

Processing of sweet potato into flour is the most satisfactory method of creating a product that is not only functionally adequate, but also remains stable for an extended period without spoilage. Sweet potato flour can be used in production of cakes, muffins, cookies and noodles, extruded snacks and chiffons (Zainun *et al*., 2005). The commercial use of sweet potato flour has been limited, although it has great potentials as industrial crops which increases the revenue of farmers and processors, and improves economy. In view of the increasing utilization of sweet potato in composite flours for various food formulations, their functional properties are assuming greater significance. Such properties of plant foods are determined by the molecular composition and structure of the individual components and their interactions with one another.

Most studies on sweet potato flours and starches

*Corresponding author.
Email: *chinnl@upm.edu.my*
Tel: +603 89466353; Fax: +603 8946 4440

are on granular characteristics, proximate analysis, functional composition and pasting properties. A broad analysis by Tian *et al*. (1991) shows that sweet potato varieties have different crystalline patterns of amylose contents ranging from 8.5 to 38%, water-binding capacities of 66.3 to 211.6%, gelatinization temperatures of 63 to 74°C and pasting temperatures from 66 to 86.2°C. Part of this variability is attributed to its genetic variation. Noda *et al*. (2002) observed an increase in gelatinization temperature and average granule size with increased soil temperature. Therefore, different varieties of sweet potato at different regions would give dissimilar functional properties. As a new variety, the VitAto was examined to gain more information on its physiochemical characteristics, pasting behavior and flowability in the attempt to broaden its usage in the food industry. The two commercial varieties of sweet potato compared were the Bukit Naga (orange) and Okinawan (purple) varieties in Malaysia.

Materials and Methods

Materials

Tubers of three varieties of sweet potato, the VitAto, Bukit Naga and Okinawan were purchased from farmers of the Department of Agriculture Malaysia under the Crop, Vegetable and Farm Cluster Project or Projek Berkelompok Tanaman, Sayuran dan Ladang Kampung Tanjung Sepat located at Kuala Langat, Selangor, Malaysia. The Bukit Naga variety was also developed by MARDI and cultivated mainly at Kuala Langat, Selangor Malaysia. The Okinawan variety was originated from America but it is well-known in Japan and has become one of the common commercially sweet potato variety cultivated in Malaysia.

Production of sweet potato flours

The production of flour followed the methods of Zainun *et al.* (2005). Grade B tubers, which are in the size range of 150-449 g/tuber were selected. The tubers were washed with water to remove adhering mud and dirt. Washed tubers were cut into strips using a slicer machine (RG-61, Hallde, Sweden) to increase surface area of tubers before drying. The sweet potato strips were soaked into 0.2% sodium metabisulphite for 30 minutes to stop browning reaction and produce fine flour later. The strips were dried in a cabinet drier (M-412294, Sanyo Electric, Japan) at 60°C until final moisture content was below 5%. The dried strips were milled in a universal miller (UM50-SS, Safe World, Malaysia) and sieved through a 300 µm mesh. The flours were packed in polyethylene bags and stored in a chiller (LF-817LD, Aseco, Taiwan) at 5-10°C until further analysis. The yield of each sweet potato flour was calculated from the percentage ratio of weights of flour and tuber. Figure 1 illustrates the flow process of sweet potato flour processing.

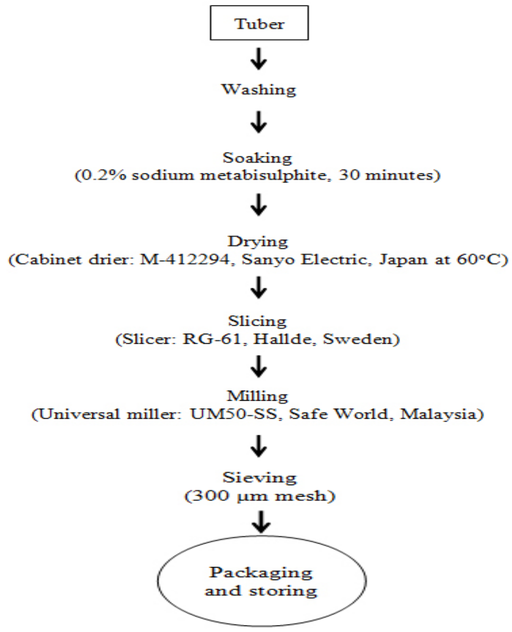

Figure 1. Flow diagram of sweet potato flour processing

Color of flours

Colorimetric measurements of flours were determined in triplicates following methods of Jangchud *et al.* (2003) using a color reader (CR-10, Konica Minolta, Japan) as L, a, and b values. The L value states the positions on the white/black axis, the a value the position on the red/green axis and the b value the position on the yellow/blue axis.

Proximate composition of flours

Proximate composition of sweet potato flours including moisture, protein (N × 6.25), crude fat, dietary fiber, and ash contents were determined in duplicates using procedures 2.2.01, 4.2.05, 4.5.01, 32.1.17 and 33.5.05, respectively, of the AOAC (1995) methods. Carbohydrate was calculated by subtracting the sum of the moisture, crude protein, total fat and ash from 100%. Energy was calculated as the total of multiplied weights (grams) of crude protein, carbohydrate, total fat and dietary fiber with factors of 4, 4, 9 and 2, respectively (Maclean *et al*., 2003).

Characteristics measurement of flours

The pH of flours was determined following methods of Ashogbon and Akintayo (2012). Five grams of flours sample was weighed and filled into a beaker and mixed with 20 mL of distilled water. The resulting suspension was stirred for 5 minutes and left to settle for 10 minutes. The pH of the water phase was measured using a calibrated pH meter for triplicated samples.

Bulk density was determined following methods of Wang and Kinsella (1976). Ten grams of flours sample were weighed into a 50 mL measuring cylinder. The sample was packed by gently tapping the cylinder on the bench top from a height of 5 cm. The volume of the sample was recorded.

$$\text{Bulk Density} = \frac{\text{weight of sample}}{\text{volume of sample after tapping}} \quad (g/cm^3) \qquad (1)$$

The particle size distributions of flours sample were measured using a particle size analyzer (Mastersizer 2000, Malvern, United Kingdom). Before the measurement, the background reading for water was recorded as the calibration and each sample was added until an obscuration of 18-20% was achieved (Aprianita *et al*., 2009).

The water absorption index (WAI), water solubility index (WSI) and swelling power (SP) were determined as described in Anderson *et al.* (1970). Each flour sample of 4.5 g was suspended in 30 mL of water in a tared 60 mL centrifuge tube. The slurry was shaken with a glass rod for 1 minute at room temperature and centrifuged at 3000 × g for 10 minutes. The supernatant was poured carefully into a tared evaporating dish and evaporated overnight at 110°C.

$$\text{Water Absorption Index (WAI)} = \frac{\text{wet sediment weight}}{\text{dry sample weight}} \qquad (2)$$

$$\text{Water Solubility Index (WSI, \%)} = \frac{\text{dry supernatant weight}}{\text{dry sample weight}} \times 100 \qquad (3)$$

$$\text{Swelling Power (SP)} = \frac{\text{wet sediment weight}}{\text{dry sample weight} \times \left(1 - \frac{\text{WSI (\%)}}{100}\right)} \qquad (4)$$

Pasting properties of flours

Pasting properties of flours sample were measured using a rheometer (AR-G2, TA Instruments, New Castle, USA) equipped with a starch pasting cell, which operated like a rapid visco-analyzer. The sample of 25 mL (7% w/w flour-water mixture) was equilibrated at 50°C for 1 minute, heated from 50 to 95°C at 6°C/minute, held at 95°C for 5 minutes, cooled to 50°C at 6°C/minute, and held at 50°C for 2 minutes. The speed was 960 rpm for the first 10 seconds and 160 rpm for the remaining of the experiment. The pasting properties of each sample were inferred from acquired diagrams including the peak time, peak viscosity, setback, breakdown and final viscosity (Aprianita *et al.*, 2009).

Flowability analysis of flours

Flow properties of flours were determined by following methods described in Benkovic and Bauman (2009) using the Powder Flow Analyzer attached to a texture analyzer (TA-XT plus, Stable Micro Systems, Surrey, UK). The Powder Flow Analyzer is a cylindrical glass vessel (120 mm height and 50 mm internal diameter) with a specific rotating blade (48 mm diameter and 10 mm height), which is able to go up and down, in right or left rotation. The flowability properties were evaluated during the displacement of the rotating blade inside the container, filled with the powdered sample in a controlled manner. The tests performed were the cohesion test, powder flow speed dependency test (PFSD test) and caking test. For each experiment, a fixed sample volume of 160 mL was weighed for the three tests. The three tests run in sequence and were repeated thrice. The conditioning cycle at the beginning of the test is a cycle where the blade moves downward and then upward through the powder column at a tip speed of 50 $mm.s^{-1}$ without reading the measurement. This is to remove user loading variation. Testing cycle starts when the instrument starts to measure force reading.

In the cohesion test, the instrument performed a two cycle sample conditioning step before the test cycle. Figure 2(a) illustrates the general diagram of a cohesion test. The compaction property was examined when the rotating blade moved downwards creating a positive force curve and the cohesion property when it moved upwards creating a negative force at a tip speed of 50 $mm.s^{-1}$. The cohesion coefficient was recorded as the area in the negative part of y-axis resulted by the complete movement cycles of the blade. The cohesion index was calculated by dividing the cohesion coefficient with the sample weight. The samples were then categorized from its hardness from free flowing to extremely cohesive based on the cohesion index.

For the PFSD test, it also started with two conditioning cycles which were then followed by cycles running at a tip speed of 10, 20, 50, 100 and two final cycles of 10 $mm.s^{-1}$ continuously. Figure 2(b) illustrates the general diagram of a PFSD test. The six lines represent the six cycles at different tip speed. The area under the positive part of the curve is the work of compaction. Flow stability was calculated by dividing the mean compaction of the first two 10 $mm.s^{-1}$ cycles by the compaction coefficient of the last 10 $mm.s^{-1}$ cycles.

The caking test which began with two conditioning cycles first had its blade leveled at the top of the powder column and measured the height of the column before moving down into the powder while compacting it with blade tip speed of 20 $mm.s^{-1}$. When the blade reached the required force of 750 g, the height of the powder cake was recorded before it sliced up through the powder at 10 mm.s^{-1}. This compaction cycle was repeated another four more times. During the last compaction cycle, the force required for the blade to cut through the formed powder cake was measured and recorded as cake strength or work required (g.mm) to cut the cake. The mean cake strength is the average peak force to cut the cake and was expressed in grams. Figure 2(c) illustrates the general diagram of the caking test. The positive forces on the diagram represent the compaction forces of the five cycles. The cake height ratio (current cycle cake height divided by initial column height) was recorded to give information about the settlement and compaction of the powder column.

Statistical analysis

The entire experiment was completed in triplicates except for the proximate analysis which was in duplicates. The MINITAB Statistical software (Release 16, Minitab Inc., USA) was used to perform single factor analysis of variance (ANOVA). Tukey's test was performed to compare differences among the mean values at a confidence level of 0.05.

Results and Discussion

Yield of sweet potato flours

The percentage VitAto flour yield obtained from the tuber was 19.74%, which was less than the Okinawan flour at 23.98% and very close to the Bukit Naga flour at 20.15%. The low recoveries of the flours were due to the drying process in order to achieve moisture content of 5% for a safe storage period.

Color of flours

The color of VitAto was orange with the reading of L = 73.3±0.06, a = 15.0±0.15 and b = 29.9±0.21. The L was significantly lower while a and b values were significantly higher than the Bukit Naga flour with color reading of L = 74.2±0.12, a = 11.3±0.06 and b = 29.3±0.42. The lower L reading of VitAto flour gave a darker orange color compared to the orange color of Bukit Naga flour. The Okinawan flour which was dark purple in color had reading of L = 61.6±0.46, a = 13.6±0.21 and b = 12.6±0.06. The colors of the flours were similar to their tuber flesh.

Proximate composition of flours

The proximate compositions of sweet potato flours are shown in Table 1. There was no significant difference between the VitAto and Bukit Naga flour for moisture and ash contents. However, the VitAto flour has the highest protein content of 5.7% compared

Table 1. Proximate compositions of sweet potato flours

Parameter	VitAto	Bukit Naga	Okinawan
Moisture (g/100g)	4.60 ± 0.00^{b}	4.40 ± 0.14^{b}	5.15 ± 0.07^{a}
Ash (g/100g)	3.15 ± 0.07^{a}	3.20 ± 0.00^{a}	2.75 ± 0.07^{b}
Crude protein (g/100g)	5.70 ± 0.00^{a}	3.85 ± 0.07^{a}	3.50 ± 0.00^{b}
Fat (g/100g)	0.20 ± 0.00^{a}	0.70 ± 0.00^{a}	0.20 ± 0.00^{b}
Dietary fiber (g/100g)	14.80 ± 0.00^{a}	11.20 ± 0.00^{c}	11.30 ± 0.00^{b}
Carbohydrate (g/100g)	86.35 ± 0.07^{c}	87.85 ± 0.21^{b}	88.40 ± 0.00^{a}
Energy (kcal/100g)	399.60 ± 0.28^{a}	395.50 ± 0.57^{b}	392.00 ± 0.00^{c}

All means present the average of two independent replications. Values followed by the different superscript in each row are significantly different (P < 0.05)

Table 2. Functional properties of sweet potato flours

Parameter	VitAto	Bukit Naga	Okinawan
pH	5.66 ± 0.03^{c}	5.93 ± 0.03^{a}	5.85 ± 0.02^{b}
Bulk density (g/cm^3)	0.626 ± 0.00^{c}	0.667 ± 0.00^{b}	0.715 ± 0.00^{a}
Particle size d_{50} (μm)	132.04± 0.89^{b}	147.21± 2.72^{a}	99.98± 0.88^{c}
Specific surface area (m^2/g)	0.165 ± 0.00^{a}	0.157 ± 0.00^{b}	0.139 ± 0.00^{c}
Water absorption index	2.692 ± 0.10^{a}	2.679 ± 0.09^{a}	2.596 ± 0.16^{a}
Water solubility index (%)	14.079 ± 0.37^{a}	13.978 ± 0.12^{a}	13.400 ± 0.27^{a}
Swelling power	3.133 ± 0.10^{a}	3.114 ± 0.11^{a}	2.997 ± 0.18^{a}

All means present the average of two independent replications. Values followed by the different superscript in each row are significantly different (P < 0.05)

to the Bukit Naga and Okinawan at protein contents of 3.85% and 3.5%, respectively. The value was also higher than the sweet potato from Thailand (1.9%) and Australia (3.15%) as reported by Jangchud *et al.* (2003) and Aprianita *et al.* (2009). The difference in the protein content can be attributed to the climatic conditions. Studies showed that the content of the main nutrients in BRIS soil where the studied sweet potatoes were cultivated are low in nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg) and calcium (Ca). This is due to the sandy structure of the soil which causes rapid leaching of these nutrients (Toriman *et al*., 2009). However, VitAto was able produce high protein content in this type of soil. High protein content of flour is known as strong flour that can improve the overall structure of baked goods (Guoquan *et al*., 2011).

With a lower fat content of 0.2% found in the VitAto and Okinawan flours versus 0.7% of the Bukit Naga, these potato flours are not susceptible to quick rancidity. These values are confirmed lower in comparison to the results reported by Jangchud *et al.* (2003) where the orange and purple sweet potato flours have 0.7% and 0.4% fat content, respectively. Other report by Ramesh Yadav *et al.* (2006) stated that sweet potato from India has higher fat content of 1%.

The dietary fiber value of 14.8% in VitAto flour was the highest among the other two flours. This suggests that it is a better source for good health since it has an impact on food by reducing the rate of glucose breakdown and absorption, hence avoiding an excess of glucose in the human body and facilitating the steady breakdown of carbohydrates and release of glucose (Brennan and Samyue, 2004). Despite having the lowest carbohydrate content compared with the other two flour, VitAto flour has the highest energy of 399.6 kcal/100 g. The high energy in VitAto flour is due to its high protein content. This flour seems suitable to be used in protein snack bar, a type of food that needed ingredient with high protein and

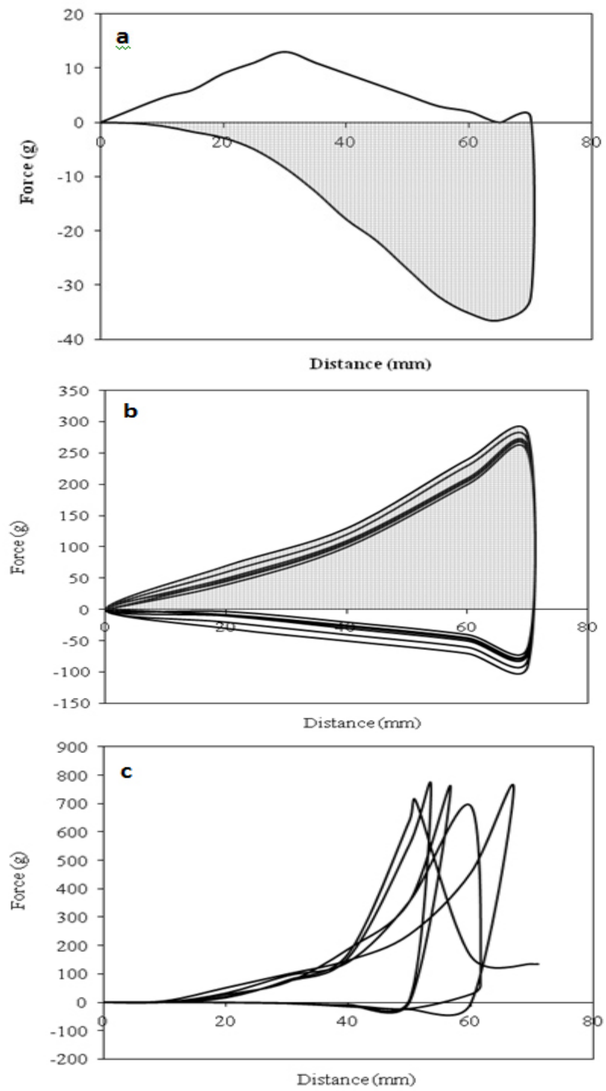

Figure 2. The general diagram of (a) cohesion test, (b) PSFD test and (c) caking test for sweet potato flours

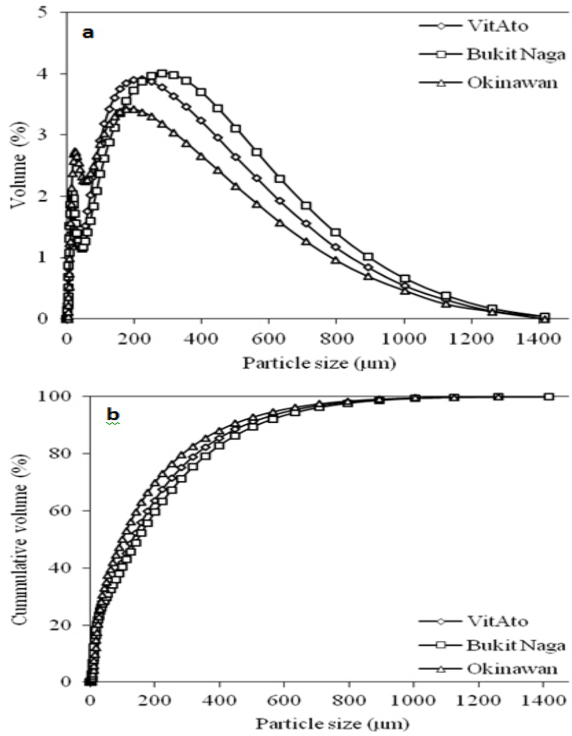

Figure 3. Particle size of sweet potato flours for (a) volume distributions and (b) cumulative volume distributions

dietary fiber contents whilst generating high energy (Loveday *et al*., 2009).

Characteristics measurement of flours

The values for pH, bulk density, granule size, specific surface area, water absorption index, water solubility index and swelling power are summarized in Table 2. pH is an important property in starch industrial applications, being used generally to indicate the acidic or alkaline properties of liquid media. The pH values for the all three sweet potatoes flour were ranging from 5.66 to 5.92 indicating that the sweet potato flours have low acid content. The VitAto flour has the lowest bulk density 0.626 g/cm^3 compared to Okinawan and Bukit Naga flours with 0.715 g/cm^3 and 0.667 g/cm^3, respectively. Flour with higher bulk density has smaller particle size.

The particle size of starch is one of the most important characteristics, which may influence other physicochemical properties such as swelling power, flour flowability and water-binding capacity (Singh *et al.*, 2003). Figure 3(a) shows the particle size distributions of sweet potato flours. The particle size distribution of sweet potato flours was found to be of bipolar curve shape at mean diameter and also an additional peak at small particle diameters. This bipolar distribution result is similar with the sweet potato flours reported by Aprianita *et al.* (2009) where the presence of the smaller peak at a smaller particle size is due to the isolated starch granules that probably arise due to the increase of powder extraction rate during milling. Figure 3(b) illustrates the cumulative volume distributions at various ranges of particle size. All the three sweet potato flours had high volume cumulative at particle size between 100 to 500 µm.

The VitAto flour granules had significantly higher specific surface area than the Bukit Naga and Okinawan flour. With these factors in mind, the use of VitAto may be applicable for several different applications within the food industry, particularly products that require starch that offers a smaller particle size allowing for smooth textured starch gel (Tattiyakul *et al.*, 2006). Other studies have also indicated that the fine granules starch can improve binding and reduce breakage of a snack product (Huang *et al.*, 2006).

Water absorption index is an indicator of the ability of flour to absorb water. It depends on the availability of hydrophilic groups that bind water molecules and on the gel-forming capacity of macromolecules. Imbibition of water is an important

Table 3. Pasting characteristics of sweet potato flours

Parameter	VitAto	Bukit Naga	Okinawan
Peak temperature (°C)	65.00± 0.00[c]	66.00± 0.00[b]	72.00± 0.00[a]
Peak time (min)	3.67± 0.00[c]	3.83± 0.00[b]	4.83± 0.00[a]
Peak viscosity (mPa.s)	1164.73± 229.23[a]	1236.53± 505.17[a]	811.70± 400.28[a]
Trough viscosity (mPa.s)	197.20± 33.99[a]	147.80± 9.26[ab]	101.59± 11.19[b]
Final viscosity (mPa.s)	728.10± 3.97[a]	407.33± 16.90[b]	232.97± 7.44[c]
Breakdown (mPa.s)	967.53± 238.30[a]	1088.73± 500.86[a]	710.11± 406.38[a]
Setback (mPa.s)	530.90± 36.72[a]	259.53± 23.15[b]	131.38± 9.45[c]

All means present the average of two independent replications. Values followed by the different superscript in each row are significantly different (P < 0.05)

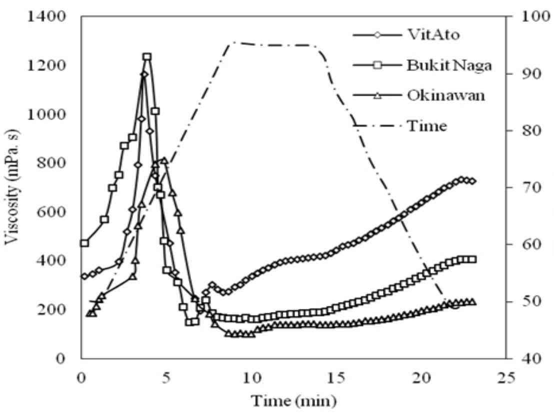

Figure 4. Pasting properties of sweet potato flours

functional trait in foods such as dough. It is important to estimate the amount of water in order to make good dough in food processing. In this study, the water absorption index and water solubility index of the three sweet potato flours were not significantly different. However the values were higher than the sweet potato varieties reported by Ahmed *et al.* (2010) at 2.41 and 2.43%, respectively suggesting the studied sweet potato flours needed more water for dough making.

Swelling of starch granules is the first stage in the initiation of changes in hydration-related properties. It indicates the ability of starch to absorb water and increase in size. The test shows that the swelling power of sweet potato flours were not significantly different with each other. The values were also higher from the sweet potato reported by Ahmed *et al.* (2010) at 2.46. As comparison, swelling power values of starches from rice cultivar were in the range of 2.11 to 3.68 whilst swelling power from wheat flour were in the range of 7.5 to 10.8 (Ashogbon and Akintayo, 2012; Mukasa *et al*., 2005). The high swelling power in studied sweet potato flours makes it suitable for producing food product with gelatinized granules remains essentially intact. Such example of this kind of food is the noodle production (Chen *et al*., 2003).

Pasting properties of flours

The pasting properties of VitAto flour were very similar with Bukit Naga flour as illustrated in Figure 4. All the starch-water mixtures revealed an increase in viscosity during the heating process. This was mainly due to the swelling of starch granules. After the peak was achieved, a decrease in viscosity was observed owing to the breakdown of swollen granules due to continual heating and shearing. The viscosity increased again during the cooling period when the exuded amylose molecules started to aggregate.

From Table 3, the pasting temperature (PT) of VitAto flour is 65°C, Bukit Naga flour 66°C and Okinawan flour 72°C. Noda *et al.* (1996) reported that the pasting temperature of sweet potato starches was 75°C. PT of different flours varies due to various sizes of the starch granules. Larger starch granules are associated with lower pasting temperature and high swelling properties (Jangchud *et al*., 2003). In this observation, Okinawan flour had smaller granules size than VitAto and Bukit Naga flour, thus may have contributed to the higher pasting temperature. Higher pasting temperature also indicates a greater structural rigidity of the flour (Aprianita *et al*., 2009).

Peak viscosity (PV) is the maximum viscosity attained by starch during gelatinization. It indicates the water binding capacity of the starch granule. The lower PV of 811.70 mPa.s of the Okinawan was influenced by lower rigidity of starch granules, which in turn caused instability and consequently disruption upon the heating and stirring treatment. On the other hand, VitAto and Bukit Naga flours have better PV of 1164.73 and 1236.53 mPa.s, respectively.

Trough viscosity (TV), which represents the lowest viscosity upon heating of the sweet potato flours were presumably observed at the end of heating at 95°C. The VitAto flour has the highest TV value of 197.20 mPa.s compared to Bukit Naga and Okinawan flour with the values of 147.80 and 101.59 mPa.s, respectively. The presence of high protein content in the VitAto flour might have prolonged the starch swelling and gelatinization process leading to a steady increase of viscosity during the heating period with no apparent breakdown. This result indicates that the VitAto flour may be suitable for use in food products that require continuous thermal processing such as food for elderly and children (Aprianita *et al.*, 2009).

Final viscosity (FV) indicates the ability of the starch to form a viscous paste. VitAto flour had the highest FV value of 728.10 mPa.s compared to the other two varieties of flour. Breakdown viscosity (BV) is measurement of the vulnerability or susceptibility of the cooked starch to disintegration. The high breakdown in viscosity will reduce the ability of the starch sample to withstand heating and shear stress during cooking. From the observation, there were no significantly differences of BV for the three sweet potato flours.

The setback value of VitAto flour was 530.90

Table 4. Flow properties, cake strength and mean cake strength of sweet potato flours

Parameter	VitAto	Bukit Naga	Okinawan
Cohesion coefficient	836.93 ± 13.45^{b}	937.11 ± 39.54^{a}	914.67 ± 23.46^{ab}
Cohesion index	12.88 ± 0.21^{ab}	13.39 ± 0.56^{a}	12.20 ± 0.31^{b}
Flow stability	0.96 ± 0.05^{a}	0.97 ± 0.02^{a}	0.95 ± 0.01^{a}
Cohesion coefficient 50 mm s^{-1}	953.07 ± 74.74^{a}	992.02 ± 46.79^{a}	935.30 ± 23.92^{a}
Cake strength (g mm)	2144.78 ± 52.92^{a}	1489.54 ± 358.53^{b}	1284.10 ± 249.87^{b}
Mean cake strength (g)	147.46 ± 8.32^{a}	123.28 ± 5.46^{b}	87.10 ± 4.23^{c}

All means present the average of three independent replications. Values followed by the different superscript in each row are significantly different (P < 0.05)

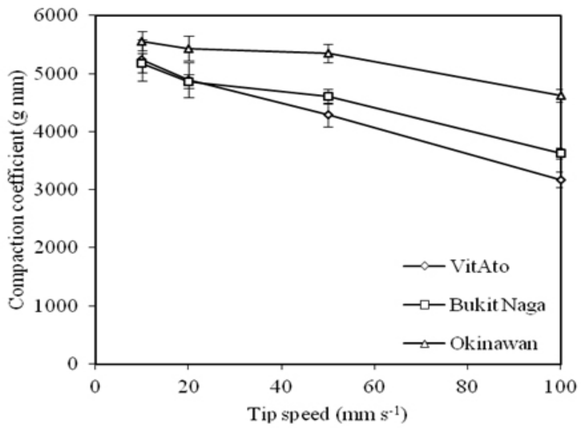

Figure 5. Compaction coefficients of sweet potato flours

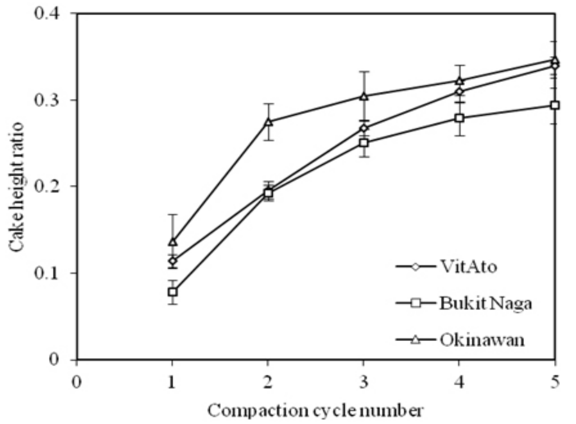

Figure 6. Caking height ratio to compaction cycle number of sweet potato flours

mPa.s, which was significantly higher than the other two varieties of sweet potato flour. High setback value gave lower retrogradation during cooling and the lower staling rate of the products made from the starch.

Flowability analysis of flours

The measurement of powder flowability is important because they intrinsically affect its behavior during storage, handling and processing. The flowability of flour and their flow behavior under pressure, temperature and humidity are important in handling and processing operations, such as storage in hoppers and silos, transportation, formulation and mixing, compression and packaging (Teunou *et al*., 1999).

Table 4 shows that all flours were categorized as easy flowing powders with cohesion index between 11 and 14. From the particle size analysis, the smallest particle size (d_{50}) was Okinawan at 99.98 µm followed by the VitAto and Bukit Naga flours at 132.04 and 147.21 µm, respectively. Powder with smaller particle size is more cohesive and their flowability is more difficult. The rationale behind this reduction in flowability at smaller particle sizes is the increased surface area per unit mass of flour. There is more surface area or surface contacts available for cohesive forces, in particular, and frictional forces to resist flow. However, Okinawan showed a smaller cohesion index compared to VitAto. Benkovic and Bauman (2009) reported the similar patterns on their probiotic dairy powders that had rich fiber content. This explains the higher cohesion index of VitAto flour which has higher dietary fiber content than the Okinawan flour. Flow stability index value close to 1 indicates that the powder has not changed significantly during the test. If the flow stability index value is less than or greater than 1, the powder has undergone changes during the test. Since all of the flours have the flow stability value close to 1, they are considered as stable powder.

All of the flours showed a dependent flow tip speed to the decreasing in compaction coefficient as illustrated in Figure 5. A decrease in compaction coefficient with increasing flow speed means that the flours become freer flowing. The smaller size particle flour will become freer flowing flour. However VitAto flour had less value of compaction coefficient at the higher tip speed compared to Bukit Naga flour despite its smaller particle size. This again is probably due to its higher dietary fiber content than the Bukit Naga flour.

Caking is a deleterious phenomenon by which amorphous food powders are transformed into a sticky undesirable material, resulting in loss of functionality and lowered quality. Cake strength depends on number of factors, i.e. packing efficiency, particle to particle interactions and moisture content (Benkovic and Bauman, 2009). Table 4 shows that the VitAto flour had the highest cake strength of 2144.78 g.mm and mean cake strength of 147.46 g compared to Bukit Naga and Okinawan flours. As such, it requires a proper packaging system for storage at the low moisture content conditions.

Figure 6 illustrates that cake height ratio all of the flours increased with the number of compaction cycle. Strongly increasing cake height ratio indicates that flour has a high tendency to cake and is likely to have high cake and mean cake strength. Similar patterns were reported by Benkovic and Bauman (2009) and Janjatović *et al*. (2011) on their infant formula powders and soup concentrate premixes, respectively. Flour that has little or no tendency to cake will show no changes in cake height ratio. Hence, all three flours in this study require a proper packaging system to avoid quality issues.

Conclusions

The VitAto flour has a recovery of 19.74%, which is not significantly different with other two commercial sweet potato flours available in Malaysia. Besides having high beta carotene content, the VitAto flour also has better nutritional values and energy. VitAto flour has high specific surface area granules which suggest its suitability for snack food products. The VitAto is high in protein and has low pasting temperature which makes it stable for products that require continuous thermal processing. In flowability analysis, the sweet potato flours are categorized as easy flowing and stable powders. They are also prone to caking, hence proper packaging system and low moisture content condition during storage and processing are advised.

References

Ahmed, M., Sorifa, A. M. and Eun, J. B. 2010. Effect of pretreatments and drying temperatures on sweet potato flour. International Journal of Food Science and Technology 45 (4): 726-732.

Anderson, R., Conway, H. and Peplinski, A. 1970. Gelatinization of corn grits by roll cooking, extrusion cooking and steaming. Starch/Stärke 22 (4): 130-135.

AOAC, 1995. Official methods of analysis of AOAC International. AOAC International.

Aprianita, A., Purwandari, U., Watson, B. and Vasiljevic, T. 2009. Physico-chemical properties of flours and starches from selected commercial tubers available in Australia. International Food Research Journal 16 (4): 507-520.

Ashogbon, A. and Akintayo, E. 2012. Morphological, functional and pasting properties of starches separated from rice cultivars grown in Nigeria. International Food Research Journal 19 (2): 665-671.

Benkovic, M. and Bauman, I. 2009. Flow properties of commercial infant formula powders. World Academy of Science, Engineering and Technology 54: 495-499.

Brennan, C. and Samyue, E. 2004. Evaluation of starch degradation and textural characteristics of dietary fiber enriched biscuits. International Journal of Food Properties 7 (3): 647-657.

Chen, Z., Schols, H. and Voragen, A. 2003. Physicochemical properties of starches obtained from three varieties of Chinese sweet potatoes. Journal of Food Science 68 (2): 431-437.

GuoQuan, L., QianXin, G., Preedy, V., Watson, R. and Patel, V. 2011. Use of sweet potato in bread and flour fortification. Flour and Breads and Their Fortification in Health and Disease Prevention: 407-416.

Huang, C. C., Lin, M. C. and Wang, C. C. 2006. Changes in morphological, thermal and pasting properties of yam (*Dioscorea alata*) starch during growth. Carbohydrate Polymers 64 (4): 524-531.

Jangchud, K., Phimolsiripol, Y. and Haruthaithanasan, V. 2003. Physicochemical properties of sweet potato flour and starch as affected by blanching and processing. Starch/Stärke 55 (6): 258-264.

Janjatović, D., Benković, M., Srečec, S., Ježek, D., Špoljarić, I. and Bauman, I. 2011. Assessment of powder flow characteristics in incoherent soup concentrates. Advanced Powder Technology 23 (5): 620-631.

Loveday, S. M., Hindmarsh, J. P., Creamer, L. K. and Singh, H. 2009. Physicochemical changes in a model protein bar during storage. Food Research International 42 (7): 798-806.

Maclean, W., Harnly, J., Chen, J., Chevassus-Agnes, S., Gilani, G., Livesey, G., et al. 2003. Food Energy-Methods of Analysis and Conversion Factors. Paper presented at the Food and Agriculture Organization of the United Nations Technical Workshop Report.

Mahmood, R., Ibrahim, N., Mohd. Nasir, S., Pin, C. H. and Hamzah, R. 2007. Varieti ubi keledek baru (The variety of new sweet potato). Agromedia, 23, p. 4-8 Kuala Lumpur: Malaysian Agricultural Research and Development Institute.

Mais, A. and Brennan, C. S. 2008. Characterisation of flour, starch and fibre obtained from sweet potato (kumara) tubers, and their utilisation in biscuit production. International Journal of Food Science & Technology 43(2): 373-379.

Mukasa, Y., Campbell, C., Honda, Y. and Suzuki, T. 2005. Comparison of flour swelling power and water-soluble protein content between self-pollinating and cross-pollinating buckwheat. Fagopyrum 22: 45-50.

Noda, T., Kimura, T., Otani, M., Ideta, O., Shimada, T., Saito, A., et al. 2002. Physicochemical properties of amylose-free starch from transgenic sweet potato. Carbohydrate Polymers 49 (3): 253-260.

Noda, T., Takahata, Y., Sato, T., Ikoma, H. and Mochida, H. 1996. Physicochemical properties of starches from purple and orange fleshed sweet potato roots at two levels of fertilizer. Starch/Stärke 48 (11-12): 395-399.

Ramesh Yadav, A., Guha, M., Tharanathan, R. and Ramteke, R. 2006. Changes in characteristics of sweet potato flour prepared by different drying techniques. LWT-Food Science and Technology 39 (1): 20-26.

Singh, J., Singh, N., Sharma, T. and Saxena, S. 2003. Physicochemical, rheological and cookie making properties of corn and potato flours. Food Chemistry 83 (3): 387-393.

Tattiyakul, J., Asavasaksakul, S. and Pradipasena, P. 2006. Chemical and physical properties of flour extracted from Taro *Colocasia esculenta* (L.) Schott grown in different regions of Thailand. Science Asia 32 (3): 279-284.

Teunou, E., Fitzpatrick, J. and Synnott, E. 1999. Characterisation of food powder flowability. Journal

of Food Engineering 39 (1): 31-37.
Tian, S., Rickard, J. and Blanshard, J. 1991. Physicochemical properties of sweet potato starch. Journal of the Science of Food and Agriculture 57 (4): 459-491.
Toriman, H., Mokhtar, B. and Gazim, M. B. 2009. Analysis of the physical characteristics of bris soil in Coastal Kuala Kemaman, Terengganu. Research Journal of Earth Science 1: 1-6.
Wang, J. and Kinsella, J. 1976. Functional properties of novel proteins: Alfalfa leaf protein. Journal of Food Science 41(2): 286-292.
Zainun, C., Salma, O. and Hamidah, H. 2005. Organoleptic acceptability and nutritional properties of the sweet potato based traditional cakes produced using sweet potato flour. Journal of Tropical Agricultural and Food Science 33 (2): 211-219.