Studies of sugar composition and starch morphology of baked sweet potatoes (*Ipomoea batatas* (L.) Lam)

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Revised: 27 June 2011 / Accepted: 29 June 2011 / Published online: 15 July 2011

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Abstract Sugar composition of seven sweet potato cultivars was successfully analyzed. Fresh CYY95-26 sweet potatoes had the highest (8.41%) total sugar content while TNG73 had the lowest (4.5%). For these fresh sweet potatoes, maltose content was very low (0~0.39%). Because 49.92~92.43% of total sugars were sucrose, sucrose was the major sugar composition of fresh sweet potatoes. After the baking treatment, the total sugar content of baked sweet potatoes was dramatically increased due to the formation of maltose. The maltose content significantly increased from 0~0.39% to 8.81~13.97% on dry weight basis. Therefore, maltose should be included in calculating the total sugar content. Electronic micrographs of fresh sweet potato samples showed that the size of starch granules was generally less than 20 μm . After the baking treatment, starch granules completely gelatinized.

Keywords Sweet potato · Sugar · Maltose · Starch morphology

Introduction

Because sweet potatoes contain substantial amounts of nutrition, they are a very popular food in Asia. Researchers have focused on the bio-functionality of sweet potatoes in the past (Rabah et al. 2004; Rumbaoa et al. 2009). Active ingredients, such as anthocyanins and β -carotenes, have been successfully extracted from raw sweet potatoes (Lien et al. 2010; Vimala et al. 2011; Wu et al. 2008). Changes of physicochemical properties of fresh sweet potatoes during storage have been reported (Huang et al. 1999; Villavicencio et al. 2004; Walter and Palma 1996). However, little information regarding post-harvest handling practices of sweet potatoes has been reported recently.

Cooking methods have a significant impact on nutritional values and sensory characteristics of baked sweet potatoes (Schwartz et al. 1987; Walter 1987). Most baked sweet potato related research papers were published in the 1980s (Hamanni et al. 1980; Purcell et al. 1980; Purcell and Walter 1982; Walter 1987). Picha (1985a, b, 1986a, b, 1987) has published several research papers regarding physicochemical properties of sweet potatoes. Sweet potatoes are usually baked at a temperature of 180~200 °C for 60 or 90 min depending on the root size (Bradbury and Singh 1986; Losh et al. 1981). No other comprehensive studies regarding the effect of baking treatment on the sugar composition of baked sweet potatoes have been carried out.

Tzouros and Arvanitoyannis (2001) and Arvanitoyannis and Vaitisi (2007; 2008a, b) have reported a comparative study of cultivars and cultivation conditions on the effect of physicochemical and sensory characteristics. Because phys-

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icochemical and sensory characteristic are related to the food quality, any change of these properties has to be carefully monitored during the food processing. Physico-chemical property changes of sweet potatoes have been studied in the past (Ahmed et al. 2010; Ahromrit and Nema 2010; Aina et al. 2009). Generally, the sugar composition and starch morphology of sweet potatoes change after the thermal treatment. The sugar content is the key factor for determining the sensory evaluation of baked sweet potatoes (Koehler and Kays 1991). The chemical analysis of sweet potatoes has focused on carbohydrates in the past (Purcell and Walter 1988). The total sugar content of several fresh sweet potato cultivars has been reported to be less than 12% on dry weight basis (Zhang et al. 2002). Glucose, fructose, and sucrose were included in calculating the total sugar content. Maltose was often ignored because fresh sweet potatoes did not contain maltose (Zhang et al. 2002). However, thermal processes introduce the maltose formation of sweet potatoes (Gore 1923; Takahata et al. 1994; Van Den et al. 1986). Therefore, the sugar analysis should consider the formation of maltose caused by the baking treatment.

The thermal treatment changes textural properties of sweet potatoes. Starch granules, which gelatinize at high temperatures, have significant influence on textural properties. The particle size (from 1 μm to 100 μm) and shape of starch granules are related to the starch source (Ezekiel et al. 2010; Hoover 2001; Lindeboom et al. 2004). The study of starch morphology will be useful for understanding the change of textural properties of baked sweet potatoes.

The goal of this study is to understand the influence of baking treatment on the sugar composition and starch morphology of sweet potatoes. Results will be useful for manufacturers to make baked sweet potatoes with a better quality.

Material and methods

Growing of raw sweet potato roots

Seven fresh sweet potato cultivars, CYY95-26, CYY95-66, TARI97-01, TNG57, TNG64, TNG66, and TNG73 were provided by the Taiwanese Agricultural Experimental Station (TARI) Chia-Yi Branch. All cultivars were grown under identical conditions. Each selected sweet potato root weighed approximately 150–200 g.

Baking treatment

Selected sweet potato roots were washed using tap water. They were wrapped using the aluminum foil and evenly placed on a stainless steel tray. An electrical convection

oven (Model No. HW-5899, 1,400 W, Cyuan Cheng Kung, Co., Ltd., Taiwan) was used to bake sweet potatoes. The baking temperature and time were set at 200 °C and 60 min respectively. After baking, baked sweet potato roots were removed from the oven and placed on a stainless steel plate. After removing the sweet potato's skin, these roots were mashed and well-mixed using a grinder to avoid the difference caused by the sample variance.

Moisture analysis

The moisture analysis of sweet potato samples was based on the method provided by Wu et al. (2008). The moisture content (%) was calculated according to the ratio of weight loss to the original sample weight.

Sugar analysis

Five grams of mashed sweet potato were put into a sealed test tube. Five milliliters of 80% ethanol was added and well-mixed. The test tube was placed in a water-bath at 80 °C for 15 min. Subsequently, 2.5 mL of 80% ethanol was added, and the mixture was heated for 15 min. Then another 2.5 mL of 80% ethanol was added, and the mixture was heated for another 15 min. The mixture was filtered using Whatman No. 4 filtering paper. The filtrate was collected. Approximately 5 mL of filtrate was filtered through a 0.45 μm membrane filter before injecting it into the high performance liquid chromatograph (HPLC). The sugar content determination was based on a modified method provided by Picha (1985a). Sugars were separated using the HPLC (Pump model No. LC1150, GBC Scientific Equipment, Dandenong, Australia) with a reverse-phase C-18 column (Model No. LiChrolut RP-18, Merck, Darmstadt, Germany). A refractive index detector (Model No. LC1246K, GBC) was used to analyze the signals. The heating oven temperature was 45 °C. The mobile phase was a mixture of degassed HPLC-grade acetonitrile (80%) and distilled water (20%). The flow rate was 1 mL/min. Four sugar standards, including glucose, fructose, sucrose, and maltose (Sigma Chemical Co, St. Louis, MO, USA), were prepared individually. Each sugar standard was prepared by dissolving 0.01 g of sugar into 1 mL of distilled water.

Electronic micrographs

Samples of fresh and baked sweet potatoes were taken for representative micrographs using the Hitachi TM-1000 tabletop microscope at magnification of 1,000X (Hitachi Corporation, Tokyo, Japan). Sweet potatoes were cut half using a sharp knife. Samples were taken at the center of fresh and baked sweet potatoes. The sample size was 2 × 2 mm with 0.5 mm thickness.

Statistical analysis

The statistical evaluation was performed by running an analysis of variance (ANOVA) with SAS^R (version 9.0, SAS institute Inc., USA). The complete analysis has a 0.05 significance level ($\alpha=0.05$). Sugar content values were mean $\pm$ SD. All tests were carried out in triplicate.

Results and discussion

Moisture analysis

Moisture analysis results of seven sweet potato cultivars are shown in Table 1. The moisture content of fresh sweet potatoes varied from 64.6% to 73.1% depending on cultivars. Results were similar to the previous study reported by Rumbaoa et al. (2009). Although these sweet potatoes are Taiwanese native varieties, their moisture contents are similar to those grown in other regions. After the baking treatment, the moisture content of baked sweet potatoes became approximately 60%. Although sweet potatoes were wrapped with aluminum foil during the baking process, approximately 5–10% moisture was evaporated. Picha (1986b) also reported that the moisture content of six baked sweet potato cultivars varied from 57.9% to 76.4%. Since the moisture content is usually correlated to physicochemical properties, the water loss will eventually affect the sensory characteristic of baked sweet potatoes.

Sugar analysis of fresh sweet potatoes

In previous studies, the sugar analysis of sweet potatoes has focused on glucose, fructose, and sucrose. Zhang et al. (2002) calculated the total sugar content by adding glucose,

fructose, and sucrose together. The total sugar content of fresh sweet potatoes reported by Zhang et al. varied from 4.8% to 12.5% (dry weight basis) depending on varieties. In the present study, total sugar contents of seven fresh sweet potato cultivars were between 4.50 and 8.41% (dry weight basis) which were slightly lower than Zhang's results (Table 2). TNG73 had the lowest total sugar content (4.50%) while CYY95-26 had the highest (8.42%). For these fresh sweet potatoes, maltose content was very low (0–0.39%). TARI97-01 had the highest maltose content of 0.39% (dry weight basis), but CYY95-26 almost didn't contain maltose. For these fresh sweet potatoes, 49.92–92.43% of total sugars were sucrose. As a result, sucrose was determined to be the major sugar composition. Based on total sugars, the sugar content (%) of fresh sweet potatoes is shown in Table 2. For CYY95-26, sucrose was counted for 92.43% of total sugars. Fresh sweet potatoes also contained fructose and glucose. Both fructose and glucose contents were less than sucrose. Meanwhile, all of these fresh sweet potato cultivars contained more glucose than fructose.

The influence of baking treatment on sugar composition

The baking treatment not only reduced the moisture content but also changed the sugar composition of sweet potatoes. Sugar contents of baked sweet potatoes are shown in Table 3. After the baking treatment, the total sugar content of sweet potatoes was dramatically increased due to the formation of maltose. For TNG73, the total sugar content increased from 4.5% to 17.52% after the baking treatment. Baked TNG66 sweet potatoes had the highest total sugar content (19.14%, dry weight basis). For these baked sweet potatoes, the maltose content significantly increased from 0–0.39% to 8.81–13.97% (dry weight basis). However, the sucrose contents slightly decreased except for TNG73. The change of fructose and glucose depended on cultivars. As a result, maltose became the major sugar composition (>50% of total sugars) of baked sweet potatoes (Table 3). Maltose should be included in calculating the total sugar content. Results collected in the present study were different from previous studies reported by Picha (1986b) and Takahata et al. (1992). The thermal treatment had a significant impact on the sucrose degradation (Vanhala and Blond 1999; Simkovic et al. 2003). However, the change of maltose content of baked sweet potatoes has not been reported. More studies are required to understand the mechanism of the maltose formation.

Electronic micrographs

Electronic micrographs of selected fresh sweet potato samples are shown in Fig. 1(a). These samples were all

Table 1 Moisture content (%) of seven sweet potato cultivars

Sweet potato cultivars	Moisture content (%)	
	Fresh	Baked
CYY95-26	68.7 $\pm$ 0.61 ^{az}	67.5 $\pm$ 3.69 ^a
CYY95-66	69.0 $\pm$ 0.78 ^a	57.7 $\pm$ 1.98 ^d
TARI97-01	67.0 $\pm$ 1.88 ^a	59.3 $\pm$ 1.44 ^{cd}
TNG57	70.1 $\pm$ 2.79 ^a	62.5 $\pm$ 0.82 ^b
TNG64	70.2 $\pm$ 2.42 ^a	61.7 $\pm$ 0.96 ^b
TNG66	73.1 $\pm$ 4.74 ^a	62.6 $\pm$ 0.58 ^b
TNG73	64.6 $\pm$ 0.10 ^b	61.1 $\pm$ 1.15 ^{bc}

^z Moisture content values were mean $\pm$ SD of triplicates ($n=3$)

Means within each column followed by the same letter are not significantly different at 5% level by Fisher's protected LSD test

Table 2 Sugar content (%) of fresh sweet potatoes (A) on dry weight basis (B) based on total sugars

Sweet potato cultivars	Fructose (%)	Sucrose (%)	Maltose (%)	Glucose (%)	Total sugars (%)
(A)					
CYY95-26	0.24±0.02 ^{dz}	7.77±0.32 ^a	0.00±0.00 ^c	0.39±0.04 ^c	8.41±0.38 ^a
CYY95-66	0.85±0.03 ^b	3.75±0.47 ^d	0.02±0.01 ^c	1.51±0.08 ^{bc}	6.13±0.58 ^c
TARI97-01	0.66±0.05 ^c	2.62±0.05 ^e	0.39±0.25 ^a	1.59±0.13 ^b	5.26±0.59 ^{cd}
TNG57	0.25±0.02 ^d	4.35±0.01 ^c	0.09±0.02 ^{bc}	0.38±0.03 ^e	5.08±0.06 ^d
TNG64	1.06±0.02 ^a	4.50±0.07 ^c	0.05±0.00 ^{bc}	2.02±0.03 ^a	7.63±0.11 ^{ab}
TNG66	0.56±0.09 ^c	5.48±0.09 ^b	0.30±0.18 ^{ab}	0.98±0.13 ^d	7.33±0.49 ^b
TNG73	0.59±0.04 ^c	2.52±0.13 ^e	0.09±0.06 ^{bc}	1.30±0.13 ^c	4.50±0.09 ^d
(B)					
CYY95-26	2.88	92.43	0.01	4.68	100
CYY95-66	13.93	61.24	0.26	24.57	100
TARI97-01	12.47	49.92	7.35	30.27	100
TNG57	4.95	85.66	1.87	7.53	100
TNG64	13.85	58.99	0.63	26.53	100
TNG66	7.61	74.81	4.13	13.44	100
TNG73	13.19	56.00	1.91	28.90	100

^z Sugar content values are mean ± SD

Means within each column followed by the same letter are not significantly different at 5% level by Fisher's protected LSD test

taken from the center of each sweet potato. Starch granules are in the form of oval-shaped with different sizes. CYY95-26 and TNG66 had some larger starch granules with diameter > 20 µm (pointed by arrows in Fig. 1(a)). Other sweet potatoes contained smaller starch granules. The starch morphology of CYY95-26, TARI97-01, and TNG57 was very similar to each other. TNG64 and

TNG73 had less starch granules than other sweet potatoes. The size and size distribution of starch granules affect the reaction of enzymatic hydrolysis which takes place on the surface of starch granules. Enzymatic reactions result in the degradation of sweet potatoes. Therefore, starch granules have influence on the shelf-life of sweet potatoes.

Table 3 Sugar content (%) of baked sweet potatoes (A) on dry weight basis (B) based on total sugars

Sweet potato cultivars	Fructose (%)	Sucrose (%)	Maltose (%)	Glucose (%)	Total sugars (%)
(A)					
CYY95-26	0.40±0.01 ^{bcz}	7.45±0.02 ^a	8.81±0.41 ^c	0.69±0.08 ^c	17.36±0.34 ^b
CYY95-66	0.48±0.11 ^b	2.79±0.17 ^e	10.85±0.39 ^b	1.05±0.11 ^b	15.17±0.00 ^c
TARI97-01	0.86±0.18 ^a	1.53±0.10 ^f	11.39±1.06 ^b	1.33±0.11 ^a	15.11±0.67 ^c
TNG57	0.26±0.03 ^{cd}	3.95±0.09 ^c	13.97±0.34 ^a	0.46±0.06 ^d	18.65±0.47 ^a
TNG64	0.73±0.04 ^a	2.53±0.19 ^e	11.37±0.41 ^b	1.37±0.06 ^a	16.00±0.71 ^c
TNG66	0.12±0.03 ^{bc}	5.02±0.24 ^b	13.69±0.24 ^a	0.31±0.00 ^d	19.14±0.02 ^a
TNG73	0.41±0.01 ^d	4.34±0.06 ^d	12.00±0.21 ^b	0.77±0.03 ^c	17.52±0.19 ^b
(B)					
CYY95-26	2.30	42.93	50.77	4.00	100
CYY95-66	3.18	18.40	71.51	6.91	100
TARI97-01	5.66	10.14	75.38	8.81	100
TNG57	1.41	21.18	74.92	2.48	100
TNG64	4.58	15.81	71.07	8.54	100
TNG66	0.62	26.23	71.51	1.64	100
TNG73	2.36	24.77	68.48	4.39	100

^z Sugar content values are mean ± SD

Means within each column followed by the same letter are not significantly different at 5% level by Fisher's protected LSD test

(a).

(b).

Fig. 1 Electronic micrographs of (a) fresh and (b) baked sweet potatoes (1,000X, 15KV)

Figure 1(b) shows electronic micrographs of baked sweet potato samples. Since starch granules completely

gelatinized at high temperatures, all starch granules were disappeared after the baking treatment (pointed by arrows

in Fig. 1(b)). The change of starch granules had a significant influence on the texture property which may affect the sensory characteristic of baked sweet potatoes. Generally, baked sweet potatoes have a soft and moist texture. If baked sweet potatoes lost too much moisture, the texture would become stiff and hard. Although Fig. 1(b) did not show a difference between cultivars, these baked sweet potatoes are expected to have a different taste. There are some factors which may also affect the sensory characteristic of baked sweet potatoes.

According to the previous study, the sugar composition of sweet potatoes was significantly affected by the thermal treatment. The change of sugar content was considered to be an important factor for determining the sensory characteristic. However, the interactive influence of sucrose, maltose, glucose, and fructose on the sensory analysis of baked sweet potatoes requires more studies with the use of statistical analysis tools such as principal analysis and cluster analysis.

Conclusions

The influence of baking treatment on the sugar composition and starch morphology of seven sweet potato cultivars was successfully evaluated. Maltose increased dramatically (from 0–0.39% to 8.81–13.97% on dry weight basis) after the baking treatment, and became the major sugar composition (>50% of total sugars) of baked sweet potatoes. Therefore, maltose should be included in calculating the total sugar content. The changes of fructose, sucrose, and glucose of baked sweet potatoes depended on sweet potato cultivars. Starch granules were oval-shaped, and their sizes were generally less than 20 μm . Starch granules completely gelatinized after the baking treatment. Results of this study will be useful for manufacturers to make baked sweet potatoes with a better quality.

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