Changes in sugar composition during baking and their effects on sensory attributes of baked sweet potatoes

Chin-Feng Chan · Chih-Ming Chiang · Yung-Chang Lai ·
Che-Lun Huang · Shu-Chen Kao · Wayne C. Liao

Revised: 3 November 2012 / Accepted: 22 November 2012 / Published online: 5 December 2012
© Association of Food Scientists & Technologists (India) 2012

Abstract The objective of this study was to evaluate the influence of sugar composition on the sensory attributes of seven baked sweet potatoes. The sugar composition was analyzed using high performance liquid chromatography. Results showed that the total sugar content of baked sweet potatoes increased significantly because of the formation of maltose. The maltose content dramatically increased after baking, and became the major sugar component of baked sweet potatoes. On the other hand, baked sweet potatoes were evaluated on a 7-point hedonic scale for sensory analysis. Overall acceptability results showed that the panelists preferred baked CYY95-26 and TNG66 over the other baked varieties. Because the correlation between overall acceptability and sweetness was the highest ($r=0.69$, $p<0.01$), sweetness was determined as the most important factor determining the overall acceptability of baked sweet potatoes. Although sugar composition changed on baking, the overall acceptability of baked sweet potatoes was highly associated with the sucrose content.

Keywords Sweet potatoes · Sugar composition · Sensory · Sucrose

C.-F. Chan
Department of Applied Cosmetology, Hung Kuang University,
Taichung, Taiwan

C.-M. Chiang
Department of Hotel and Restaurant Management, Ching Kuo
Institute of Management and Health, Keelung, Taiwan

Y.-C. Lai · C.-L. Huang
Agricultural Research Institute, Chia-Yi Agricultural Experiment
Station, Chia-Yi, Taiwan

S.-C. Kao · W. C. Liao (✉)
Department of Nursing, Chang Gung University of Science
and Technology, 2, Chia-Pu Rd. West, Putz,
Chia-Yi, Taiwan 613
e-mail: bio.liao@msa.hinet.net

Introduction

Sweet potatoes (*Ipomoea batatas* (L.) Lam) contain substantial amounts of nutrients, such as vitamin C and β -carotenes, and are a very important food source in Asia and developing countries (Lien et al. 2012; Rumbaoa et al. 2009). Baking is the most popular method of cooking sweet potatoes (Collins et al. 1995). Consumers enjoy the pleasant odor and flavor of baked sweet potatoes. Although chemical composition analysis of sweet potatoes has been previously documented (Ahmed et al. 2010; Ahromrit and Nema 2010; Aina et al. 2009; Picha 1985; Picha 1986; Vimala et al. 2011), little information on the effect of baking has been reported (Lai et al. 2011).

Sweet potatoes are usually baked at 180–220 °C for 60–90 min, depending on tuber size (Bradbury and Singh 1986; Losh et al. 1981). Baking changes the sugar composition and starch morphology of sweet potatoes, resulting in a sweet odor and a soft texture (Lai et al. 2011; Tiu et al. 1985). Although one of the major characteristics of sweet potato flavor is sweetness, volatile components of baked sweet potatoes have seldom been reported (Purcell et al. 1980). Data correlating sugar composition and sensory characteristics will assist manufacturers in producing baked sweet potatoes with better quality. The results of this sensory study can additionally be used to predict the overall acceptability (Saxena et al. 2011).

Starch is the major carbohydrate found in sweet potatoes, and comprises approximately 20 % of the fresh tuber (Aina et al. 2009). Baking breaks down starch granules to form disaccharides and monosaccharides. Although the sugar composition of sweet potatoes mainly depends on the type of cultivar (Aina et al. 2009), Koehler and Kays (1991) reported that the taste of baked sweet potatoes was mainly determined by their sugar content. Previous studies revealed that fresh sweet potatoes contained sucrose, glucose, and fructose (Picha 1986) but not maltose (Zhang et al. 2002).

Sucrose is the major sugar component of fresh sweet potatoes (Zhang et al. 2002) and the most important sugar for predicting sweetness (Corrigan et al. 2000). However, baking changes the sugar composition. For example, sucrose is degraded by thermal treatments (Claude and Ubbink 2006; Simkovic et al. 2003). Therefore, it is necessary to understand the sugar composition and effects of baking for studying the sensory attributes of baked sweet potatoes.

The purpose of this study is to analyze the sugar composition of baked sweet potatoes, and correlate these results with those of the evaluation of sensory attributes of baked sweet potatoes. The major factor influencing the overall acceptability of baked sweet potatoes was subsequently determined.

Materials and methods

Sample preparation

Seven fresh sweet potato varieties, including CYY95-26, CYY95-66, TARI97-01, TNG57, TNG64, TNG66, and TNG73, were provided by the Taiwanese Agricultural Experimental Station (TARI) Chia-Yi Branch where the longitude, latitude, and altitude are E120.468049, N23.484503, and 79 m respectively. These varieties were chosen because of their popularity in Taiwanese markets. All varieties were planted in November 2009 in a field at TARI and harvested in March 2010. The growing period in 2009 and 2010 was considered as the dry season in Chia-Yi, Taiwan. Physical characteristics of these seven fresh sweet potato varieties are shown in Table 1.

After field harvest of sweet potatoes, 25 tubers (each weighing 175 ± 25 g) were randomly selected for each variety. Of these, five tubers were cut manually into small cubes (approximately $0.5 \times 0.5 \times 0.5$ cm) and heated to 105 °C for 16 h in a vented convection oven (Purcell and Water 1988). The moisture content was calculated as the percentage ratio of each tuber's dry weight to its fresh weight. In this study, the sugar composition analysis results were all based on dry weight.

Baking process

For each sweet potato variety, ten unpeeled sweet potato tubers were wrapped in an aluminum foil and weighed. These tubers were placed in a baking oven (model No. HW-5899, 1400W, Cyuan Cheng Kung, Co., Ltd., Taiwan) preheated to 200 °C and baked for 90 min. After baking, the tubers were placed on a stainless steel plate to cool. After cooling to room temperature, each tuber was reweighed and moisture content was calculated. For each variety, five of the baked sweet potato tubers were peeled and then mashed

Table 1 Sugar content of fresh and baked and moisture, skin color and flesh color of fresh seven sweet potato varieties (F: fructose; S: sucrose; M: maltose; G: glucose; TS: total sugars = F + S + M + G ($n=3$))

Sweet potato cultivars	Sugar content (%) fresh				Sugar content (%) baked				Moisture content (%)	Skin color	Flesh color
	F	S	M	G	TS	F	S	M			
CYY95-26	0.08±0.01 ^a	2.43±0.1 ^f	0.01±0 ^a	0.12±0.01 ^a	2.63±0.10 ^c	0.13±0.01 ^c	2.42±0.01 ^g	2.86±0.13 ^a	68.7±0.6 ^a	Reddish orange	Reddish orange
CYY95-66	0.26±0.01 ^d	1.16±0.15 ^c	0.01±0 ^a	0.47±0.03 ^d	1.90±0.15 ^{b,c}	0.20±0.05 ^d	1.18±0.07 ^c	4.59±0.17 ^c	69.0±0.8 ^a	Red	Purple
TARI97-01	0.22±0.02 ^c	0.87±0.05 ^b	0.13±0.08 ^b	0.52±0.04 ^{d,e}	1.74±0.10 ^b	0.35±0.07 ^e	0.62±0.04 ^a	4.64±0.43 ^{b,c}	67.0±1.9 ^a	Red	Purple
TNG57	0.09±0.01 ^a	1.54±0.01 ^d	0.03±0.01 ^b	0.14±0.01 ^a	1.80±0.02 ^b	0.10±0.01 ^b	1.54±0.04 ^d	5.43±0.13 ^d	70.1±2.8 ^a	Brownish yellow	Orange
TNG64	0.28±0.01 ^d	1.21±0.02 ^c	0.01±0 ^a	0.54±0.01 ^e	2.04±0.02 ^c	0.27±0.02 ^{d,e}	0.95±0.07 ^b	4.25±0.15 ^b	70.2±2.4 ^a	Brownish red	Reddish orange
TNG66	0.17±0.03 ^{b,c}	1.63±0.03 ^e	0.09±0.05 ^b	0.29±0.04 ^b	2.18±0.08 ^d	0.05±0.01 ^a	1.92±0.09 ^f	5.24±0.09 ^d	73.1±4.7 ^a	Brownish yellow	Reddish orange
TNG73	0.18±0.01 ^b	0.75±0.04 ^a	0.03±0.02 ^{a,b}	0.39±0.04 ^c	1.35±0.06 ^a	0.15±0.01 ^c	1.63±0.02 ^e	4.50±0.08 ^c	64.6±0.1 ^b	Pink	Dark purple

Data were mean ± 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 least significant difference (LSD) test

using a grinder. The mash for each variety was used for subsequent sugar composition analysis.

Sugar composition analysis

A five-gram sample of each sweet potato mash was added to a sealed test tube. Five milliliters of 80 % ethanol was added to each sample and 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 at 15 and 30 min. Fresh 80 % ethanol was then added to bring the total volume to 10 mL. The mixture was filtered using a Whatman No. 4 filtering paper. The filtrate was collected, filtered through a 0.45 µm membrane filter, and injected into a high performance liquid chromatograph (HPLC).

Sugar content was determined using a modified method provided by Picha (1985). Sugars were analyzed using HPLC (Pump model No. LC1150: GBC Scientific Equipment, Dandenong, Australia) equipped 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 column was heated to 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 were used: glucose, fructose, sucrose, and maltose (Sigma Chemical Co., St. Louis, MO, USA). Each sugar standard was prepared by dissolving 0.01 g of sugar in 1 mL of distilled water.

Sensory evaluation

For each variety, ten baked sweet potato tubers were peeled and cut into small cubes. The sample size was approximately 2×2×2 cm. Sensory evaluation was held at Chang Gung University of Science and Technology. Trained panelists were required to precisely evaluate specific sensory parameters such as texture and flavor (Hamann et al. 1980). Untrained panelists were those that have no exposure to specific training in sensory evaluation. In this study, 48 untrained panelists consisting of students and staff of the nursing department were selected to evaluate the seven baked sweet potato samples in the nutrition and sensory laboratory. All of these panelists had previously served on other sensory panels. These untrained panelists were chosen to represent the general consumers for determining the overall acceptability of markets. The panelists included 10 males (20.8 %) and 38 females (79.2 %). Forty-two (87.5 %) panelists liked eating baked sweet potatoes and 6 (12.5 %) did not. The average frequency of eating baked sweet potatoes was three times every 6 months. In general, more than 75 % of the panelists who like eating baked sweet potatoes considered that the major factors determining the overall

acceptability of baked sweet potatoes were odor and sweetness (Table 2).

Samples were evaluated on a 7-point hedonic scale ranging from 1 = dislike extremely to 7 = like extremely (Sulaeman et al. 2003; Truong and Walter 1994). The panelists sat in individual booths and received one coded sample at a time in a random order. Panelists were instructed before testing in regards to how to handle samples, how to mark their responses, and what information is gained from the testing. The samples were evaluated for acceptability on the basis of sensory attributes, including appearance, odor, color, sweetness, chewiness, ease of swallowing, moisture, hardness, and bitterness.

Statistical analysis

Sugar composition analysis were performed in triplicates, and the significance level was set at 0.05 ($\alpha=0.05$). A difference was considered statistically significant when $*p<0.05$. Sugar content values were reported as mean $\pm$ SD. Sensory data were analyzed by descriptive statistics, correlation analysis, and analysis of variance (ANOVA). SPSS statistical software (version 14.0: IBM, Somers, New York, USA) was used to evaluate the results of sugar composition analysis and sensory evaluation.

Results and discussion

Sugar composition analysis of fresh sweet potato tubers

The moisture content of the fresh sweet potato tubers was approximately 70 %, and this result was similar to the results reported by Rumbaoa et al. (2009). After baking, each tuber lost approximately 10.5 % of its weight because of moisture evaporation. The results of sugar composition analysis of the seven sweet potato varieties are shown in Table 1. Total sugar content values for the fresh tubers were

Table 2 Frequency of reasons for panelists enjoying baked sweet potatoes

Reasons of like	Percent (%) ^a	Rank
Attractive appearance	23.8	7
Odor	85.7	1
Attractive texture	33.3	4
Sweetness	78.6	2
Ease-of-chewiness	23.8	7
Ease-of-swallow	21.4	6
Moisture	28.6	5
Hardness	35.7	3
Others	7.1	8

^aMultiple choice results were provided by 42 panelists who like eating baked sweet potatoes

Table 3 Correlation analysis of the results of sensory evaluations of baked sweet potatoes

	Appearance	Odor	Color	Sweetness	Chewiness	Ease of swallow	Moisture	Hardness	Bitterness	Overall
Appearance	1.00									
Odor	0.50**	1.00								
Color	0.57**	0.62**	1.00							
Sweetness	0.38**	0.62**	0.53**	1.00						
Chewiness	0.28**	0.42**	0.44**	0.52**	1.00					
Ease of swallow	0.25**	0.38**	0.41**	0.44**	0.52**	1.00				
Moisture	0.30**	0.40**	0.43**	0.48**	0.52**	0.60**	1.00			
Hardness	0.34**	0.38**	0.42**	0.38**	0.58**	0.63**	0.65**	1.00		
Bitterness	0.03	0.14*	0.17**	0.20**	0.15**	0.08	0.14**	0.01	1.00	
Overall	0.39**	0.58**	0.57**	0.69**	0.60**	0.59**	0.64**	0.59**	0.23**	1.00

* $p < 0.05$, ** $p < 0.01$

between 1 % and 2.5 %. CYY95-26 had higher total sugar content and TNG73 had lower total sugar content. Sucrose was the major sugar component of fresh sweet potatoes and almost no maltose was detected. Fructose and glucose contents were less than sucrose content. Zhang et al. (2002) concluded that glucose was the major sugar component of fresh sweet potatoes, and fructose content was similar to sucrose content. The results of sugar composition analysis obtained in this study differed from those reported by Zhang et al.

Sugar composition analysis of baked sweet potato tubers

Total sugar content, including fructose, sucrose, maltose, and glucose, was significantly increased after baking (Table 2). Takahata et al. (1992) also reported the increase in total sugar content after thermal treatment. According to this study, the total sugar content of baked sweet potatoes was in the order TNG66 > TNG57 > TNG73 > CYY95-66 > TARI97-01 > TNG64 > CYY95-26. The most noticeable difference was the formation of maltose. The maltose content dramatically increased after baking, and thus, maltose became the major sugar component of baked sweet potatoes. The total sugar content of TNG73 was increased by 386 % mainly because of the formation of maltose. The maltose content of the seven sweet potato varieties was in the order TNG57 > TNG66 > TARI97-01 > CYY95-66 > TNG73 > TNG64 > CYY95-26. On the other hand, fructose and glucose contents were not significantly affected by baking and were relatively lower than sucrose and maltose contents. The sucrose content was slightly reduced by baking, except for in TNG66 and TNG73, and was no longer the major sugar component of baked sweet potatoes. The sucrose content of baked sweet potatoes was in the order CYY95-26 > TNG66 > TNG73 > TNG57 > CYY95-66 > TNG64 > TARI97-01. Vanhal and Blond (1999) and Simkovic et al. (2003) reported that the baking temperature had significantly impacted sucrose degradation.

Caramelization of sucrose not only changed the color but also converted sucrose to form oligomers and polymers. Thus, a reduction in sucrose content was expected. However, the sucrose content increased in TNG66 and TNG73 after baking. Because the change in sugar composition could significantly affect the sensory attributes of baked sweet potatoes, more studies should be conducted to understand the mechanism of maltose formation and sucrose degradation.

Sensory evaluation of baked sweet potatoes

Correlation analysis results of the sensory attributes of baked sweet potatoes are shown in Table 3. Correlation analysis was used to justify if there was a linear relation between two selected sensory parameters. All relations were initially assumed to be linear then run the correlation analysis. When the correlation number was close to 1, the relation between selected sensory parameters was linear. Otherwise, the relation was non-linear. All sensory attributes except bitterness were positively correlated with each other. Overall acceptability was positively correlated with every sensory property. Because the correlation between overall acceptability and sweetness was the highest ($r = 0.69$, $p < 0.01$), sweetness was determined as the most important factor determining the overall acceptability of baked

Table 4 The overall acceptability of seven baked sweet potato cultivars

Sweet potato cultivars	Overall acceptability
CYY95-26	5.60 ^a
CYY95-66	3.89 ^c
TARI97-01	4.52 ^b
TNG57	4.85 ^b
TNG64	4.59 ^b
TNG66	5.67 ^a
TNG73	4.76 ^b

Data followed by the same letter are not significantly different at 5 % level by Fisher's protected least significant difference (LSD) test

sweet potatoes. Because sweetness was the major factor, the results of sugar composition analysis have the potential to predict the overall acceptability of baked sweet potatoes. Meanwhile, the correlation between overall acceptability and moisture was 0.64 ($p < 0.01$). Similar to sweetness, moisture was also an important factor determining the overall acceptability of baked sweet potatoes. In addition, chewiness, ease of swallowing, hardness, odor, and color were positively correlated with overall acceptability ($r > 0.57$, $p < 0.01$). Based on sensory evaluation results, sweetness and moisture were considered as the major factors determining overall acceptability. Odor was also a factor but not as important as sweetness and moisture.

The overall acceptability of seven baked sweet potatoes is shown in Table 4. CYY95-26 and TNG66 had higher overall acceptability, while CYY95-66 had lower overall acceptability. No significant difference was observed between TARI97-01, TNG57, TNG64, and TNG73. Overall acceptability results showed that the panelists preferred baked CYY95-26 and TNG66 over the other baked varieties.

The effect of sugar composition on sensory attributes

Because overall acceptability and sweetness had the highest correlation, baked sweet potatoes with higher sugar content are assumed to have better overall acceptability. Corrigan et al. (2000) reported that sweetness could be predicted by sucrose content. After performing correlation analysis for sugar composition and overall acceptability, sucrose was found to be highly correlated with the overall acceptability of baked sweet potatoes ($r = 0.77$). The rest of sugars were not positively correlated with the overall acceptability. Since CYY95-26 and TNG66 had higher sucrose content, they had better overall acceptability. On the other hand, CYY95-66, TNG64, and TARI97-01 had lower sucrose content; therefore, they had the lowest overall acceptability. Thus, the sucrose content was considered a good indicator predicting the overall acceptability of baked sweet potatoes. Although sugar composition changed on baking, the overall acceptability of baked sweet potatoes was mainly determined by the sucrose content. Thus, it is better to select the sweet potato variety with higher sucrose content.

Conclusions

Total sugar content of sweet potatoes was significantly increased after baking. Baking treatment significantly changed the sugar composition of sweet potatoes, and caused maltose to become the major sugar component. More studies should be conducted to understand the mechanism of maltose formation and sucrose degradation caused

by baking. The overall acceptability of baked sweet potatoes was highly associated with sweetness. Although sugar composition changed on baking, the overall acceptability of baked sweet potatoes was mainly determined by the sucrose content. As a result, CYY95-26 and TNG66 had better overall acceptability than CYY95-66, TNG64, and TARI97-01. It is better to select the sweet potato variety with higher sucrose content. Results of this study will aid breeders and manufacturers select proper sweet potato varieties for the baked sweet potato market.

Acknowledgment This research was funded by the National Science Council of Taiwan, No. NSC 101-2221-E-255-001.

References

- Ahmed M, Akter MS, Eun JB (2010) Peeling, drying temperatures, and sulphite-treatment affect physicochemical properties and nutritional quality of sweet potato flour. *Food Chem* 121:112–118
- Ahromrit A, Nema PK (2010) Heat and mass transfer in deep-frying of pumpkin, sweet potato and taro. *J Food Sci Technol* 47:632–637
- Aina AJ, Falade KO, Akingbala JO, Titus P (2009) Physicochemical properties of twenty-one Caribbean sweet potato cultivars. *Int J Food Sci Technol* 44:1696–1704
- Bradbury JH, Singh U (1986) Ascorbic acid and dehydroascorbic acid content of tropical root crops from the south pacific. *J Food Sci* 51:975–978
- Claude J, Ubbink J (2006) Thermal degradation of carbohydrate polymers in amorphous states: a physical study including colorimetry. *Food Chem* 96:402–410
- Collins JL, Liao JY, Penfield MP (1995) Chemical, physical and sensory attributes of formed and frozen, baked sweetpotato. *J Food Sci* 60:465–467
- Corrigan VK, Irving DE, Potter JF (2000) Sugars and sweetness in buttercup squash. *Food Qual Prefer* 11:313–322
- Hamann DD, Miller NC, Purcell AE (1980) Effects of curing on the flavor and texture of baked sweet potatoes. *J Food Sci* 45: 992–994
- Koehler PE, Kays SJ (1991) Sweet potato flavor: quantitative and qualitative assessment of optimum sweetness. *J Food Qual* 14:241–249
- Lai YC, Huang CL, Chan CF, Lien CY, Liao WC (2011) Studies of sugar composition and starch morphology of baked sweet potatoes (*Ipomoea batatas* (L.) Lam). *J Food Sci Technol*. doi:10.1007/s13197-011-0453-6
- Lien CY, Chan CF, Huang CL, Lai YC, Liao WC (2012) Studies of carotene extraction from sweet potato variety CYY95-26, *Ipomoea batatas*, L. *Int J Food Eng*. doi:10.1515/1556-3758.2490
- Losh JM, Phillips JA, Axelson JM, Schulman RS (1981) Sweet potato quality after baking. *J Food Sci* 46:283–290
- Picha DH (1985) HPLC determination of sugars in raw and baked sweet potatoes. *J Food Sci* 50:1189–1190
- Picha DH (1986) Sugar content of baked sweet potatoes from different cultivars and lengths of storage. *J Food Sci* 51:845–846
- Purcell AE, Water WM Jr (1988) Comparison of carbohydrate components in sweet potatoes baked by convection heating and microwave heating. *J Agric Food Chem* 36:360–362
- Purcell AE, Later DW, Lee ML (1980) Analysis of the volatile constituents of baked, “Jewel” sweet potatoes. *J Agric Food Chem* 28:939–941

- Rumbaoa RGO, Cornago DF, Geronimo IM (2009) Phenolic content and antioxidant capacity of Philippine sweet potato (*Ipomoea batatas*) varieties. *Food Chem* 113:1133–1138
- Saxena TM, Raju PS, Bawa AS (2011) Evaluation of sensory acceptability and storage stability of frozen carrot based dessert. *J Food Sci Technol*. doi:10.1007/s13197-011-0605-8
- Simkovic I, Surina I, Vrican M (2003) Primary reactions of sucrose thermal degradation. *J Anal Appl Pyrol* 70:493–504
- Sulaeman A, Keeler L, Giraud DW, Taylor SL, Driskell JA (2003) Changes in carotenoid, physicochemical and sensory values of deep-fried carrot chips during storage. *Int J Food Sci Technol* 38:603–613
- Takahata Y, Noda T, Nagata T (1992) Varietal diversity of free sugar composition in storage root of sweet potato. *Jpn J Breed* 42:515–521
- Tiu CS, Purcell AE, Collins WW (1985) Contribution of some volatile compounds to sweet potato aroma. *J Agric Food Chem* 33:223–226
- Truong VD, Walter WM Jr (1994) Physical and sensory properties of sweetpotato puree texturized with cellulose derivatives. *J Food Sci* 59:1175–1180
- Vanhal I, Blond G (1999) Impact of melting conditions of sucrose on its glass transition temperature. *J Agric Food Chem* 47:4285–4290
- Vimala B, Nambisan B, Hariprakash B (2011) Retention of carotenoids in orange-fleshed sweet potato during processing. *J Food Sci Technol* 48:520–524
- Zhang Z, Wheatley CC, Corke H (2002) Biochemical changes during storage of sweet potato roots differing in dry matter content. *Postharvest Biol Technol* 24:317–325