Storage performance of Taiwanese sweet potato cultivars

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Abstract Three sweet potato cultivars (TNG57, TNG66, and TNG73), provided by the Taiwanese Agricultural Research Institute (TARI), were stored at either 15 °C or under ambient conditions (23.8~28.4 °C and 77.1~81.0 % of relative humidity). Sweet potato roots were randomly chosen from each replicate and evaluated for measurement of weight loss, sugar content analysis, and sprouting after 0, 14, 24, 48, 56, 70, 84, and 98 days of storage. Fresh sweet potato roots were baked at 200 °C for 60 min then samples were taken for sugar analysis. After 14 days of ambient condition storage, the sprouting percentages for TNG57, TNG66, and TNG73 were 100, 85, and 95 % respectively. When sweet potatoes were stored at 15 °C, the weight loss became less and no sweet potato root sprouted after 14 days of storage. Because manufacturers can store sweet potatoes at 15 °C for almost 2 month without other treatments, the supply capacity shortage in July and September can be reduced. The total sugar content slowly increased along with increasing the storage time. After baking, the total sugar content of sweet potatoes significantly increased due to the formation of maltose. Maltose became the major sugar of baked sweet potatoes. Raw sweet potatoes stored at 15 °C had higher total sugar contents after

baking than those stored under ambient conditions. Raw sweet potatoes were recommended to be stored at 15 °C before baking.

Keywords Sweet potatoes · Storage · Baking · Sugars

Introduction

Sweet potatoes (*Ipomoea batatas* (L.) Lam) are an important crop in the world. Because, sweet potatoes contain substantial amount of nutrients, they are a good food source in developing countries. Traditional sweet potato breeding programs have tended to focus on yield improvement and pest resistance. Although sweet potatoes can be planted all year round in Taiwan, two thirds of sweet potatoes are planted in fall to avoid the rain season. Thus, the supply capacity of fresh sweet potatoes will be excessive from December to next year's May. The price of fresh sweet potato will be reduced. On the other hand, the supply capacity will become shortage between July and September. Therefore, the price of fresh sweet potatoes will be increased. The price variation of fresh sweet potatoes is a disadvantage for manufacturers. If the storage-life of sweet potatoes could be lasted for another 2 months, it would have provided a huge economical advantage for the sweet potato manufacturers (Cohen 2005; McConnell et al. 2005; Ramesh Yadav et al. 2007).

Post-harvest handlings are very important for quality (Doymaz 2011; Haseena et al. 2010; Rezaee et al. 2011). Fresh sweet potatoes are usually stored in a cool room to prevent sprouting. During the storage period, physicochemical properties of sweet potatoes may have been changed (McArdle and Bouwkamp 1986; Picha 1985, 1986a; Rees et al. 2003; Takahata et al. 1994, 1995; Zhang et al. 2002). The most noticeable change is the weight loss which has significant influence on the quality of sweet potatoes (Ezekiel et al. 2010; Kaur et al. 2011). In addition, the change of sugar

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composition will affect the sensory characteristic of sweet potatoes (Chan et al. 2012; Koehler and Kays 1991).

Active ingredients, such as anthocyanins and β -carotenes, have been successfully extracted from raw sweet potatoes (Huang et al. 2012; Lien et al. 2010, 2012a, b; Vimala et al. 2011). Data correlating sugar composition and sensory characteristics will assist manufacturers in producing sweet potatoes with better quality (Chan et al. 2012). The total sugar content of sweet potatoes is mainly calculated by the sum of glucose, fructose, and sucrose (Shahba et al. 2007). Zhang et al. (2002) reported that the total sugar content of several fresh sweet potato cultivars was approximately less than 12 % on a dry weight basis. Fresh sweet potatoes usually do not contain maltose, but maltose may be formed by either the activity of amylases or thermal treatments (Kaplan et al. 2006). Both α and β amylases can degrade sweet potato starch to form maltose (Dziedzoave et al. 2010; Kaplan et al. 2006). In addition, the cooking process will also induce the maltose formation (Gore 1923; Van Den et al. 1986). As a result, maltose should be evaluated and included for calculating the total sugar content.

Consumers enjoy baked sweet potatoes because baked sweet potatoes have a pleasant taste. Raw sweet potatoes are usually baked at 180–220 °C for 60–90 min depending on the root size (Bradbury and Singh 1986; Losh et al. 1981). After baking, the texture of sweet potatoes becomes soft and the color becomes yellowish or brownish. The change of total sugar content is a key factor for determining the sensory characteristic of baked sweet potatoes (Chan et al. 2012; Koehler and Kays 1991). However, few research papers discuss the influence of baking treatment on the total sugar content of baked sweet potatoes (Picha 1985, 1986a; Lai et al. 2011).

The production yield of sweet potatoes in Taiwan was 209,191 tons in 2010. Nearly half of these sweet potatoes were processed to become baked sweet potatoes. TNG57, TNG66, and TNG73 are the most popular cultivars for making baked sweet potatoes. The root of TNG57 has brownish yellow skin and orange flesh. The average yield of TNG57 is approximately 43.0±1.52 ton/ha. The moisture content of TNG57 is 70.1±0.65 %. The root of TNG66 has brownish red skin and reddish orange flesh. The average yield of TNG66 is approximately 48.0±1.75 ton/ha. The moisture content of TNG66 is 73.1±1.11 %. TNG73 is the first sweet potato variety developed by Taiwanese breeders with high anthocyanin content. The root of TNG73 has pink skin and dark purple flesh. The average yield of TNG73 is approximately 30.0±2.64 ton/ha. The moisture content of TNG73 is 64.6±1.06 %.

Three sweet potato cultivars (TNG57, TNG66, and TNG73) which were provided by the Taiwanese Agricultural

Research Institute (TARI) and stored at either 15 °C or under ambient conditions (23.8~28.4 °C and 77.1~81.0 % of relative humidity) were used to study the effect of baking on total sugar contents. The weight loss and sprouting of these sweet potatoes during 98 days of storage were evaluated. Results are valuable for further breeding programs to select new sweet potato cultivars for making high quality baked sweet potatoes.

Materials and methods

Three fresh sweet potato cultivars (TNG57, TNG66, and TNG73) were provided by TARI. All cultivars were planted in a field at TARI in November 2009 and harvested in March 2010. A total of 240 roots per cultivar each weighing between 150 and 200 g were randomly selected from the field of TARI. Sweet potato roots were held for 5 days at 30 °C and 92 % of relative humidity to cure. Half of the roots were stored under ambient conditions while the other half were stored at 15 °C with 90 % of relative humidity (Picha 1986b). Monthly ambient conditions averaged between 23.8 and 28.4 °C and the relative humidity was between 77.1 and 81.0 %. The 120 roots held under each condition were further divided into three replicates of 40 roots each. Five roots were randomly chosen from each replicate and evaluated for measurement of weight loss, sugar content analysis, and sprouting after 0, 14, 24, 48, 56, 70, 84, and 98 days of storage.

Sweet potato quality evaluations

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.

Raw sweet potato roots were weighted to calculate the weight loss (Eq. 1).

$$\text{Weight loss(\%)} = \frac{W_o - W_i}{W_o} \times 100\% \quad (1)$$

Where W_o is the weight (g) of raw sweet potato root at day 0. W_i is the weight (g) of raw sweet potato root after a particular storage time.

The average sprouting number was defined as the average number of observed sprouts per sweet potato root. The sprouting percentage was the ratio of the number of sprouted roots to the number of total roots.

Baking treatment

For each storage condition, five raw sweet potato roots were randomly selected after 0, 14, 24, 48, 56, 70, 84, and 98 days

of storage, washed with tap water, wrapped with aluminum foil, placed on a stainless steel tray, and then baked using an electrical convection oven (Model No. SO-1000, 600 W, Sunpentown International Inc., Taiwan). The oven was preheated and the baking temperature was set at 200 °C. After 60 min, baked sweet potatoes were removed from the oven and placed on a stainless steel plate. After removing the sweet potato's skin, 5 baked sweet potatoes were mashed together with the use of a grinder. The mixture was saved for sugar extraction.

Sugars extraction

Five grams of mashed sweet potato were put into a sealed test tube. Five milliliters of 80 % of ethanol were added and mixed. The test tube was placed in a water-bath at 80 °C for 15 min. Subsequently, 2.5 mL of 80 % of ethanol was added at 15 and 30 min. Fresh 80 % of ethanol was added to make-up the total volume to 10 mL. The mixture was filtered using Whatman No. 4 filtering paper. The filtrate was collected, and filtered through a 0.45 µm membrane filter before injecting into the high performance liquid chromatograph (HPLC).

HPLC analysis of sugars

The sugar content determination was based on a modified method provided by Picha (1985). Sugars were analyzed 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 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. Glucose, fructose, sucrose, and maltose standards were purchased from Sigma Chemical Co. (St. Louis, MO, USA). Each sugar standard was prepared by dissolving 0.01 g of sugar into 1 mL of distilled water.

Statistical analysis

The experiment design was completely random design. Data were analyzed by using analysis of variance (ANOVA) with SAS^R (version 9.0, SAS institute Inc., USA). Mean comparisons were performed by using the least significance difference at $*p < 0.05$ level. The sugar content analysis of each sample was carried out in duplicated tests. Because each sample had three replicates, total six tests were performed for sugar content analysis of each sample. The mean value of six tests was used to represent the result of sugar content analysis.

Results and discussion

During 98 days of storage, weight loss (%) and sprouting of three sweet potato cultivars are shown in Table 1. When sweet potatoes were stored at ambient condition, the weight loss after 56 days of storage was significantly higher than the weight loss before 56 days of storage. TNG66 had greater weight loss than TNG57 and TNG73. The weight loss was mainly caused by the moisture evaporation. When water evaporates through the sweet potato's skin, shrinkage occurs (Picha 1986b). Rees et al. (2003) have shown that root shriveling is due to weight loss and rotting. Weight loss is a good indicator for determining the storage-life of raw sweet potatoes. After 14 days of ambient condition storage, the sprouting percentages for TNG57, TNG66, and TNG73 were 100, 85, and 95 % respectively (Table 1). Almost every sweet potato root sprouted. The average sprouting number per sweet potato root also increased. For TNG57 and TNG73, there was slight difference and/or no significant difference between storage time and sprouting percentage or average sprouting number. On the other hand, the sprouting and average sprouting number of TNG66 significantly increased while stored more than 56 days. Because TNG57 had greater average sprouting number, raw TNG57 roots had higher tendency of sprouting. In addition, these sweet potato roots became unacceptable for making baked sweet potatoes after 14 days of ambient condition storage. The color became unpleasant and the texture became softer. These results indicated that the storage-life of TNG57, TNG66, and TNG73 is generally less than 2 weeks when stored under ambient conditions.

When sweet potatoes were stored at 15 °C, the weight loss became less and no sweet potato root sprouted. Therefore, these sweet potatoes had a longer storage-life and better quality. Picha (1986b) reported that after curing, sweet potato roots could be stored at 15.6 °C for up to 1 year without sprouting. Therefore, the 15 °C cooling treatment is an effective method to extend the storage-life of raw TNG57, TNG66, and TNG73 sweet potatoes. After 56 days of storage at 15 °C, the weight loss of TNG57, TNG66, and TNG73 were 17.9, 13.4, and 14.5 % respectively. When sweet potatoes were stored at 15 °C, the weight loss after 56 days of storage was also significantly higher than the weight loss before 56 days of storage. Although no sprouting was observed, the quality of some sweet potato roots became unacceptable for making baked sweet potatoes. After 98 days of 15 °C storage, the appearance of most roots became bad and not-marketable. Because manufacturers can store sweet potatoes at 15 °C for almost 2 month without other treatments, the supply capacity shortage in July and September can be reduced.

Based on previous studies, raw sweet potato roots didn't contain maltose. The total sugar content of raw sweet potato

Table 1 Weight loss (%) and sprouting of three sweet potato cultivars during storage at ambient conditions and at 15 °C and 90 % of relative humidity

Table 1 Weight loss (%) and sprouting of three sweet potato cultivars during storage at ambient conditions and at 15 °C and 90 % of relative humidity	Storage time (days)	Weight loss (%)		Sprouting (%)	Average sprouting number (per root)
		AC	15 °C	AC	AC
Each observation is a mean±SD of 15 replicate experiments (n=15)	TNG57				
	14	8.5±1.78 ^c	4.2±1.62 ^c	100.0±0.00 ^a	8.1±1.20 ^a
	28	13.2±2.68 ^{ab}	8.6±1.82 ^d	100.0±0.00 ^a	8.1±1.70 ^a
	42	15.6±2.48 ^{ab}	11.6±2.72 ^c	100.0±0.00 ^a	9.0±1.27 ^a
	56	17.9±2.08 ^a	17.9±2.52 ^b	100.0±0.00 ^a	8.9±0.68 ^a
	70	17.5±2.78 ^a	21.6±2.32 ^a	100.0±0.00 ^a	8.8±0.46 ^a
	84	17.8±2.18 ^a	23.1±2.96 ^a	100.0±0.00 ^a	8.9±1.54 ^a
	98	17.5±2.96 ^a	26.7±3.77 ^a	100.0±0.00 ^a	8.9±1.07 ^a
	TNG66				
	14	10.2±1.50 ^d	5.9±0.72 ^d	85.0±5.00 ^b	2.0±0.24 ^c
AC ambient condition (23.8~28.4 °C and 77.1~81.0 % of relative humidity)	28	14.5±2.00 ^c	7.9±1.32 ^c	88.3±2.90 ^b	2.1±0.26 ^c
	42	18.3±1.60 ^b	9.2±1.62 ^b	91.7±2.90 ^b	3.1±0.29 ^b
	56	19.9±1.20 ^b	13.4±2.62 ^a	96.7±2.90 ^a	3.4±0.34 ^b
	70	30.4±1.44 ^a	13.2±2.62 ^a	98.3±2.90 ^a	4.1±0.39 ^a
	84	32.4±2.84 ^a	14.6±1.71 ^a	100.0±0.00 ^a	4.2±1.64 ^a
	98	32.9±3.17 ^a	13.4±1.62 ^a	100.0±0.00 ^a	4.6±0.89 ^a
	TNG73				
	14	8.5±1.71 ^{cd}	6.4±1.74 ^c	95.0±5.00 ^{ab}	4.1±0.46 ^b
	28	12.1±1.51 ^c	9.0±1.64 ^d	100.0±0.00 ^a	4.3±0.46 ^b
	The sprouting (%) and average sprouting number (per root) for each sweet potato cultivar stored at 15 °C were all zero	42	16.6±0.51 ^b	11.6±1.94 ^{cd}	100.0±0.00 ^a
56		19.1±2.51 ^{ab}	14.5±2.04 ^c	100.0±0.00 ^a	5.8±0.48 ^a
70		24.8±2.62 ^a	19.4±0.74 ^b	100.0±0.00 ^a	5.8±0.39 ^a
84		24.8±2.16 ^a	22.9±2.55 ^b	100.0±0.00 ^a	5.5±1.29 ^a
98		24.5±2.97 ^a	28.5±1.87 ^a	100.0±0.00 ^a	5.9±1.77 ^a
Means within each column followed by the same letter are not significantly different at 5 % level by Fisher's protected LSD test					

Each observation is a mean±SD of 15 replicate experiments ($n=15$)

AC ambient condition (23.8~28.4 °C and 77.1~81.0 % of relative humidity)

The sprouting (%) and average sprouting number (per root) for each sweet potato cultivar stored at 15 °C were all zero

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

roots was calculated by adding glucose, fructose, and sucrose together (Picha 1985; Shahba et al. 2007; Zhang et al. 2002). However, the present study shows that raw TNG57, TNG66, and TNG73 sweet potatoes contained maltose (Fig. 1). Thus, the calculation of the total sugar content must include maltose. The total sugar content became the summation of fructose, glucose, sucrose, and maltose. Because the amount of fructose and the amount of glucose were very close, their graphic markers were almost completely overlapped in figures.

For raw TNG57 sweet potatoes, the total sugar content was not significantly affected by the storage condition. The total sugar content slowly increased after 28 days of storage, then remained at approximate 1.8 % (on fresh basis) (Fig. 1a, b). Sucrose was the major sugar and it also slowly increased along with increasing storage time. Fructose, glucose, and maltose all remained at a very low level. The influence of baking on the sugar composition of TNG57 was significant (Fig. 1c, d). The total sugar content increased due to the formation of maltose. Maltose content dramatically increased then became the major sugar of baked TNG57 sweet potatoes. Even for fresh sweet potato roots, maltose increased from almost 0 to 1.9 % after

baking treatment. However, the baking treatment did not have significant impact on sucrose, fructose, and glucose (comparing Figures a with c, b with d). When TNG57 sweet potatoes were stored at ambient condition, the total sugar content of baked sweet potatoes increased along with increasing the storage time. After 42 days of storage, the total sugar content basically remained at approximately 7.5 %. The change of total sugar content was mainly caused by the formation of maltose. After 70 days of storage, the sugar content increased again because of the excessive loss of moisture. When TNG57 sweet potatoes were stored at 15 °C, the total sugar content increased after 14 and 28 days of storage. The total sugar content was 6.8 % at 28 days of storage. After 28 days of storage, the total sugar content began to decrease. The total sugar content was 5.2 % at 56 days of storage. After 56 days of storage, the total sugar content increased again because of the excessive loss of moisture. After 28 days of storage, the total sugar contents of baked TNG57 sweet potatoes stored at ambient condition and 15 °C were 6 and 6.8 % respectively. Meanwhile, TNG57 roots stored at 15 °C did not sprout after 28 days of storage. Thus, it was recommended to store TNG57 sweet potatoes at 15 °C before baking.

Fig. 1 Sugar contents (% on fresh basis) of raw and baked TNG57, TNG66, and TNG73 sweet potatoes (black circle: fructose; white circle: glucose; black down pointing triangle: sucrose; white triangle: maltose; black square: F+G+S+M; Markers of fructose and glucose were overlapped. Vertical bars represented the SD, and when absent, they fell within the area of the symbol.). For each sweet potato cultivar, **a** and **c** represented the ambient storage condition (23.8~28.4 °C and 77.1~81.0 % of relative humidity), and **b** and **d** represented the 15 °C storage condition. Each observation was a mean of 6 replicate experiments ($n=6$)

For raw TNG66 sweet potatoes, the total sugar content slowly increased along with increasing the storage time (Fig. 1a, b). The total sugar content reached approximately 1.8 % for both storage conditions. Sucrose was the major sugar. Fructose, glucose, and maltose basically remained unchanged with increasing the storage time (Fig. 1a, b). Similar to TNG57, the baking treatment also had significant influence on the maltose content of baked TNG66 sweet potatoes (Fig. 1c, d). Maltose became the major sugar of baked TNG66 sweet potatoes. The rest of sugars changed a little after baking treatment. When TNG66 sweet potatoes were stored at ambient condition, the total sugar content of baked sweet potatoes basically remained at approximately 6 %. After 70 days of storage, the change of total sugar content was caused by the excessive loss of moisture. When TNG66 sweet potatoes were stored at 15 °C, the total sugar content increased to 6 % at 28 days of storage. After 28 days of storage, the total sugar content decreased to 5.7 %. The total sugar content increased again after 56 days of storage because of the excessive loss of moisture. After 28 days of storage, the total sugar contents of baked TNG66 sweet potatoes stored at ambient condition and 15 °C were 4.0 and 6.0 % respectively. Although there was no significant difference of the total sugar content after 56 days of storage, it was strongly suggested to store TNG66 at 15 °C to maintain the quality of raw TNG66 sweet potatoes.

Unlike TNG57 and TNG66, the storage condition of TNG73 sweet potatoes had significant influence on the total sugar content after 14 days of storage (Fig. 1a, b). Along with increasing the storage time, the total sugar content reached approximately 2 % for both storage conditions. Sucrose was also the major sugar of raw sweet potatoes. The influence of baking treatment on the sugar composition of baked TNG73 is shown in Fig. 1c, d. When TNG73 sweet potatoes were stored at ambient condition, the total sugar content of baked sweet potatoes basically increased along with increasing the storage time. After 70 days of storage, the excessive loss of moisture caused the change of the total sugar content. When TNG73 sweet potatoes were stored at 15 °C, the total sugar content increased after 14, 28, and 42 days of storage. The total sugar content remained at approximately 7.8 % after 42 days of storage. After 84 days of storage, the total sugar content began to decrease. Raw TNG73 stored at 15 °C had higher total sugar content after baking treatment than those stored under ambient conditions after 56 days of storage. The cooling treatment prevented TNG73 from sprouting and achieved a higher total sugar content of baked sweet potatoes. Same as TNG57 and TNG66, maltose became the major sugar of baked TNG73 sweet potatoes. As a result, it was also recommended to store TNG73 at 15 °C before baking.

Conclusions

The results of this study provided valuable information for manufacturers to store and make baked sweet potatoes. Sweet potatoes stored at 15 °C had less weight loss than those stored under ambient conditions (23.8~28.4 °C and 77.1~81.0 % of relative humidity). Because manufacturers can store sweet potatoes at 15 °C for almost 2 month without other treatments, the supply capacity shortage in July and September can be reduced. The total sugar content was significantly increased after baking treatment due to the formation of maltose. Raw sweet potatoes stored at 15 °C had higher total sugar content after baking treatment. Therefore, it was strongly recommended to store raw sweet potatoes at 15 °C before baking.

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