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Hu, Wenzhong
Laboratory of Postharvest Science, Division of Bioproduction System Science, Department of Bioproduction Environmental Sciences, Faculty of Agriculture, Kyushu University

Tanaka, Shun-ichiro
Laboratory of Postharvest Science, Division of Bioproduction System Science, Department of Bioproduction Environmental Sciences, Faculty of Agriculture, Kyushu University

Hori, Yoshiaki
Laboratory of Postharvest Science, Division of Bioproduction System Science, Department of Bioproduction Environmental Sciences, Faculty of Agriculture, Kyushu University

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Effect of Heat Treatment on Quality of Sweet Potato in Wrapper Type Cold Store during Long–term Storage

Wenzhong HU*, Shun–ichiro TANAKA and Yoshiaki HORI

Laboratory of Postharvest Science, Division of Bioproduction System Science, Department of Bioproduction Environmental Sciences, Faculty of Agriculture, Kyushu University, Fukuoka 812–8581, Japan
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The effects of hot water treatment on the sprouting inhibition and spoilage of sweet potato roots were evaluated in Wrapper Type Cold Store (WTCS) during long–term storage. The changes in quality attribute were also determined. The results indicated that hot water treatment significantly inhibited sprouting and decay of sweet potato for the storage period. It also showed that there were no significant differences in starch properties in terms of pasting properties, enthalpy and temperatures onset (T_O), peak (T_P) and endset (T_E) of gelatinization of potato starches among all the treatments, especially between heat–treated and untreated samples. Hot water treatment had also no significant impact on the internal components' quality of the roots. Only less than 4% of the year long stored roots were discarded due to spoilage. It was considered that thermal treatment supplied a lethal dose of heat to surface pathogens and cauterized eye without damaging the nutritional and processing qualities of sweet potato. The success of storage experiments in prolonging sweet potato by means of WTCS was obtained in the decrease in weight loss and demand the for grower and consumer. This new technique opens a new avenue to prolonging the storage life of sweet potato with good quality and minimal waste.

INTRODUCTION

Sweet potato (*Ipomoea batatas* (L.) Lam) is a main roots crop grown around the world. It is available for several months from storage after harvest in November or December in Japan. Proper postharvest handling of sweet potato is an important link in the chain from producer to consumer or manufacturing industry. However, storage life of sweet potato is affected by several forms of deteriorations: weight loss resulting in shriveling, decay, sprouting and sensory properties (taste and texture). The relative important problem is the postharvest weight loss. Although curing can heal the skin abrasions and wounds inflicted during harvest and handling, reduce moisture loss during storage and minimize microbial decay, deterioration of sweet potato was occurred by some microbial during storage and marketing. The decrease in quality was also affected by sprouting. The spoilage of roots due to invasion by fungi often also occurred and resulted in decreasing quality and large loss during storage.

Heat treatments have been used as a non–chemical means to modify the postharvest quality and reduce pathogen levels and disease development of a wide variety of horticultural products (Lurie, 1998; Cantwell and Nie, 1996; Schirra *et al.*, 2000). Postharvest heat treatments can also reduce undesirable postharvest growth and sprouting and

* Corresponding author (E–mail:hu@bpes.kyushu–u.ac.jp)

spoilage (Ranganna *et al.*, 1998; Paull and Chen, 1999, 2000). Prolonged storage of fresh sweet potato roots is important for food and feed availability. But comprehensive studies have not been carried out on the combination of hot water treatment and storage in WTCS on qualities, starch properties and gelatinisation enthalpy of sweet potatoes. The objectives of present study were to investigate the effects of washing with sodium hypochlorite and hot water dipping on the sprouting inhibition and spoilage of sweet potato roots stored in WTCS during long-term storage. The quality attributes were also evaluated.

MATERIALS AND METHODS

Plant Materials

Sweet potato roots (cv. Beniotome) used in this study were harvested from a local grower in Kagoshima Prefecture, Japan. Samples were transported to laboratory on the same day and sorted to exclude those with obvious defects or dissimilar state based primarily on size and appearance.

Postharvest treatments

The sweet potato had undergone wound curing at 29 °C and 90–95% RH for 6 days in WTCS, which can help the preventing the entrance of decay organisms by healing cuts and other injuries received in harvesting and handling. After curing, a part of samples was washed and surface-sterilized in 200 ppm sodium hypochlorite solution for 5 min, rinsed and dried in a well-ventilated room. Other was without washing. And then the half of washed and without washing samples were treated in 50 °C hot water for 30 min. Others were not treated. The treatments in this experiment were: (1) Attached soil: No washing; (2) Attached soil HWT: No washing and hot water treatment; (3) Detached soil: washing with water and sodium hypochlorite solution; (4) Detached soil HWT: Washing and hot water treatment. After treatments, all experiments were conducted in a completely randomized design with three replicates for each treatment. A replicate included 100 kg of roots which were stored in WTCS under 14 °C and 90–95% RH conditions for 12 months. WTCS is a storage system with double chamber to enable separation of product from contacting air from the cooler exit and moisture from humidifier and to keep high humidity in storage room. The high stability in temperature and humidity is also maintained in the storage room. Roots were sampled from storage room at intervals of month for quality evaluation and chemical analysis. Experiments were conducted two times and similar results were obtained each time.

Assessment of overall rotting

All roots in each treatment were assessed for the percentage of surface showing visible rotting every month. Decay was calculated for each treatment based on the over 10% of the surface shows visible rotting of each root. Roots showing extensive rotting (over 50% surface) were removed from the storage room.

Sprout of sweet potatoes

The sprouting rates of sweet potato root were examined after storage. The sprouted root was determined and expressed as the percentage of the numbers of sprouted roots to total root after storage.

Weight loss

Weight loss was determined on all samples that were selected at random from each treatment. The loss in weight of roots was recorded at start of experiment and at monthly intervals due to respiration and transpiration.

Free sugar content

Free sugar content was determined by HPLC equipped with NH2P-50 column (4.6 mm $\phi \times 250$ mm) at 40 °C. The column (Asahipak model, Showa Denko Corp., Tokyo Japan) was packed with SUS 316. The mobile phase was acetonitrile : water = 75 : 25 at a flow rate of 1.0 ml min^{-1}. Detector is RI. 20 g sample of cut sweet potatoes was homogenized with 40 ml of 75% acetonitrile by homogenizer. The homogenate was centrifuged at 3,000 $\times$ g for 15 min. The 20 μl of supernatant was taken as sample to inject onto HPLC through a 0.45 μm PTFE syringe filter to measure the glucose, fructose and sucrose. External standard solutions of glucose, sucrose and fructose (Sigma Chemical Co, St Louis, MO) were used for identification and quantification.

Starch extraction and purification

Sweet potato roots were thoroughly washed, peeled and cut into 2–3 cm cubes. A 500 g batch was macerated by grinder (Foss Tector AB1095 Knifetec, Sweden) with 400 ml distilled water at 5 °C by freezer (Eyela UNI ACE Bath NCB-2200). The mixture was filtered with 4-layer gauge, and then was left to stand for 30 min to the sediment. The liquid was decanted and leaving sediment was further purified. A 400 ml distilled water was added to the sediment and mixed and left to stand to sediment for 30 min. And then liquid was decanted and discarded. Finally, starch sediment was dried in a convection oven at 35 °C. Samples were stored in airtight container at room temperature until use.

Thermal analysis

The gelatinisation characteristics of the starch sample were determined by using a DSC-60 differential scanning calorimetery (DSC) (Shimadzu, TA-60WS, Tokyo, Japan). Starch suspension was prepared by weighing 2.5 g of starch sample and put into 25 ml distilled water. A about 30.0 mg of starch suspension was withdrawn by micro-syringe and was put into an aluminum DSC pan. And then the pan was then hermetically sealed with (SSC-30, Shimadzu, Tokyo, Japan) for DSC analysis. A another aluminum pan filled with α-Al_2O_3 was used as a reference to balance the heat capacity of sample pan. The measurement was carried out in a nitrogen atmosphere with flow rate 100 ml min^{-1}. The sample was heated at a rate of 5 °C min^{-1} from 30 to 95 °C. The onset (T_O), peak (T_P) and endset (T_E) temperatures and gelatinisation enthalpy (J g^{-1}) were determined. Measurements were carried out for each starch sample in triplicate.

Measurement of viscosity

The pasting properties of starch samples of sweet potato were determined using a Rapid Visco-Analyzer 3D (RVA) (Newport Scientific Pty Ltd, Warriewood, Australia). A

25 ml of starch suspension with 2.5 g starch was put into the experiment tube. Then the suspension in the tube was heated on a hot plate under magnetic stirring until the completion of gelatinisation. The peak viscosity, breakdown, setback and final or cool paste viscosity (CPV) were continuously recorded by computer. The unit of viscosity was expressed as rapid viscosity unit (RVU, $1 RVU = 12 \times 10^{-3}$ Pa·s)

RESULTS AND DISCUSSION

Sprout of sweet potatoes

The sweet potato is of tropical origin and is chilled if held at temperatures below about 12.2 °C. Sweet potatoes may develop discoloration of the flesh, internal breakdown, off–flavor and hard–core when cooked, and increased susceptibility to decay when sweet potatoes were stored shorter period at lower temperatures. Temperatures above 15 °C stimulate development of sprouts (especially at high humidity), pithiness and internal cork. In this experiment, percentages of sprouting in detached soil HWT and attached soil HWT were only 0.8 and 1.0%, while it was showed higher sprouting rate of 3.5 and 2.8% in treatments of detached soil and attached soil, respectively (Fig. 1). It indicated that hot water treatment significantly inhibited sprouting of sweet potato for the storage period. It also showed some effects of sodium hypochlorite solution on the sprouting inhibition.

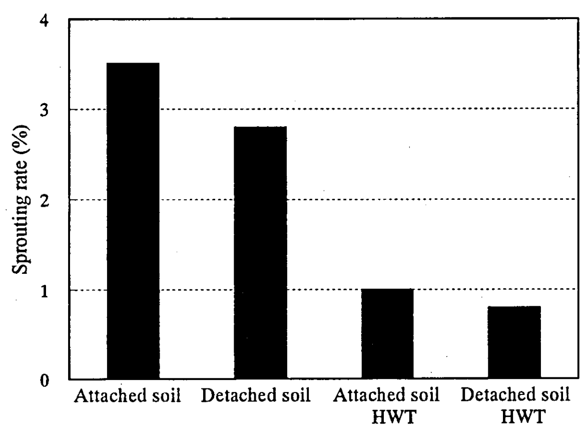

Fig. 1. Percentage of sprouted sweet potato root at different treatments after storage

Weight loss

Weight loss of potato by decay

Decay of sweet potatoes infection by micro–organisms is generally the most serious cause of postharvest loss in sweet potato. Disease incidence can be reduced by the appropriate handling, curing and storage potato systems (Picha, 1986). It was known that sodium hypochlorite solution was widely used in food sterilization. In this experiment, fresh sweet potato roots were treated with sodium hypochlorite solution and hot water to decrease the loss in decay percentage of sweet potato. The results of the present study were showed in Table 1. The decay percentage increased gradually in all treatments during storage. The decay percentage of sweet potato was lower (1.4–2.2%) in treatments of sodium hypochlorite solution than that (2.6–3.2%) of without treatments after storage. Especially in treatment of sodium hypochlorite solution and hot water dipping, percent decay was the lowest among the all treatments. It was considered that thermal treatment supplied a lethal dose of heat to surface pathogens and cauterized eye without damaging the nutritional and processing qualities of sweet potato.

Table 1. Percent decay of sweet potato during 12 months of storage in WTCS

Treatment	Months in storage (%)				
	1	4	7	9	12
Attached soil	0.3	0.4	0.5	1.5	3.2
Detached soil	0.2	0.2	0.4	1.1	2.6
Attached soil HWT	0.0	0.0	0.2	0.6	1.4
Detached soil HWT	0.0	0.0	0.2	0.7	1.6

Weight loss of potato by transpiration

The sweet potato damages were also expressed in increase of weight loss and shrinkage following evaporation of water through the skin and damaged part. The weight loss of sweet potato stored in WTCS was showed in Table 2. It was also showed that the weight loss increased gradually in all treatments during storage. It was found that there was lower weight loss (6.9–7.3%) in treatments of hot water dipping than that (8.0%) in without hot water dipping. It was reasoned that hot water treatment would inactivated the protein and tissue of surface flesh of sweet potato to retard the evaporation of water through the skin and also formed the protection tissue from pathogens. The best control measures are careful handling to minimizes wounding, prompt curing and storage at 12 °C immediately after curing.

Table 2. Weight loss of sweet potato stored in WTCS (expressed as percentage of initial fresh weight)

Treatment	Months in storage (%)				
	1	4	7	9	12
Attached soil	1.2	2.7	5.3	6.7	8.0
Detached soil	0.6	1.3	5.3	5.9	8.0
Attached soil HWT	0.4	1.2	4.2	5.1	6.9
Detached soil HWT	0.5	1.3	4.4	5.5	7.3

Thermal properties

The enthalpy and temperatures onset (T_O), peak (T_P) and endset (T_E) of gelatinization of potato starches were determined by differential scanning calorimetry (DSC) and the data were given in Table 3. T_P, T_O and T_E remained relatively constant in first 4 months of storage, followed by increased gradually from 4 to 6 months of storage and then the changes in T_P, T_O and T_E decreased gradually in treatment of attached soil. In detached soil treatment, it showed the similar result as that in treatment of attached soil. In treatments of attached soil HWT and detached soil HWT, it was showed that changes in T_P, T_O and T_E was not significant and fluctuated 72.8 to 75.3 °C, 67.3 to 70.4 °C and 78.4 to 81.6 °C, respectively. The T_P of sweet potato starches ranged from 71.2 to 74.6 °C in treatment of attached soil, 71.3 to 74.0 °C in treatment of detached soil and 72.7 to 75.3 °C in

Table 3. Changes in thermal properties of sweet potato at different treatments during storage

Treatment	Storage time (months)	Peak T_P (°C)	Onset T_O (°C)	Endset T_E (°C)	Enthalpy (J g^{-1})	T_E–T_O* (°C)	T_P–T_O* (°C)
Attached soil	1	71.23	64.52	78.32	–1.23	12.82	6.00
	4	71.49	65.59	78.34	–1.25	12.75	5.90
	5	74.55	69.25	81.83	–0.88	12.58	5.30
	6	73.66	68.26	80.37	–1.20	12.11	5.40
	7	74.09	69.62	80.45	–0.97	10.83	4.47
	8	72.37	67.60	78.58	–1.10	10.98	4.77
	9	72.49	68.11	79.17	–0.80	11.06	4.38
Detached soil	1	71.30	64.80	79.82	–1.02	15.02	6.50
	4	71.52	65.10	79.99	–1.01	14.89	6.42
	5	73.33	68.78	79.32	–0.92	10.54	4.55
	6	73.99	69.18	79.83	–0.92	10.65	4.81
	7	73.33	69.35	79.16	–0.98	9.81	3.98
	8	73.02	68.94	78.56	–1.14	9.62	4.08
	9	72.69	67.73	78.36	–1.08	10.63	4.96
Attached soil HWT	1	74.08	68.72	80.78	–1.05	12.06	5.36
	4	74.07	68.71	80.75	–1.02	12.04	5.36
	5	73.17	67.31	80.47	–1.69	13.16	5.86
	6	72.69	68.34	78.43	–0.94	10.09	4.35
	7	72.98	66.88	80.68	–1.07	13.80	6.10
	8	75.30	70.40	81.73	–1.11	11.33	4.90
	9	75.19	70.65	81.81	–0.89	11.16	4.54
Detached soil HWT	1	72.89	68.45	78.45	–0.82	10.00	4.44
	4	72.91	68.55	78.52	–0.85	9.97	4.36
	5	73.17	68.96	79.19	–0.77	10.23	4.21
	6	72.82	67.64	78.98	–1.15	11.34	5.18
	7	74.56	69.36	81.55	–1.23	12.19	5.20
	8	73.34	68.72	79.02	–0.80	10.30	4.62
	9	73.06	69.00	78.01	–0.70	9.01	4.06

*Gelalinisation range$R = T_E - T_O$; Peak height index: $T_P - T_O$

treatment of attached soil HWT, 72.8 to 74.6 °C in treatment of detached soil HWT, respectively. It showed that there were no significant differences among all the treatments, especially between heat–treated and untreated samples. It also indicated that similar results of T_O and T_E among the all the treatments. The gelatinization temperature range ($T_E - T_O$) of the starches was between 13.8 and 9.1 °C. There were no significant differences in all treatments during storage. The peak height index ($T_P - T_O$) was range from 4.0 to 6.5 °C, and showed similar results among the all treatments during storage. The enthalpy of gelatinization ranged from −1.25 to −0.70 J g^{-1} and there were no significantly differences among the all treatments during storage. The measurements of starch properties in terms of gelatinization and T_P, T_O and T_E, there was no significant differences between heat–treated and untreated samples. It was considered that thermal treatment supplied a lethal dose of heat to surface pathogens and cauterized eye without damaging the nutritional and processing qualities of sweet potato.

Pasting characteristics

One of the main quality attributes of sweet potato is its viscosity. The viscosity of potato is influenced by various factors: variety, storage condition, water–insoluble and water–soluble solids content; particle size distribution and particle shape, and processing variables (Dennis *et al.*, 1994; Ganga and Corke, 1999).

Changes in pasting properties of sweet potato during storage were shown in Table 4. Storage resulted in increased pasting viscosities. Peak viscosity increased gradually in first 4 months and then increased quickly in detached soil and attached soil HWT treatments, which in attached soil treatment, peak viscosity decreased gradually at initial 4 months, and then declined quickly, fluctuated about 301.7 to 315.3. In detached soil HWT, peak viscosity increased gradually in first 7 months, and quickly increased. Peak viscosity indicates the water–binding capacity of the starch, which is often correlated with final quality. In this experiment, no significant differences of peak viscosity between heat–treated and untreated samples during storage. The changes in breakdown and final viscosity were similar results with the changes in peak viscosity. Of the pasting parameters, Peak viscosity, breakdown and final viscosity were affected more than setback and pasting temperature by storage. It was reported that starch is the main component of sweet potato roots, the decrease in starch content during storage would contribute to the reduced pasting viscosities (Zhang *et al.*, 2002). The largest decrease in starch content, showed the greatest reduction in all pasting parameters. However, in this experiment, this changing trend did not occur in all treatments. This indicated that changes of starch content did not contribute to the changes in pasting properties due to the increase sugar content (Fig. 2). Effects of sugars on starch pasting properties have been previously reported. Bean and Yamazaki (1978) showed that sucrose delayed starch gelatinization. Deffenbaugh and Walker (1989) showed that addition of sugar to starch tended to increase peak viscosity. It can be explained on the basis of the reduced plasticizing effectiveness of sugar–water cosolvents containing more sugar and less water. Sweet potato roots contain low levels of fructose, glucose and sucrose at harvest. Thus, freshly, nonchilled roots would have negligible effects on gelatinisation at initial storage period in DSC analysis. Final viscosity is the commonly used parameter to define a particular sample's quality, while setback is correlated with texture of various products. In this experi-

Table 4. Changes in pasting properties of sweet potato at different treatments during storage

Treatment	Storage time (Months)	Peak viscosity (RVU)	Breakdown (RVU)	Final viscosity (RVU)	Setback (RVU)	Pasting temperature (°C)
Attached soil	1	357.3	235.6	208.7	71.0	72.0
	4	337.3	225.6	203.7	72.0	72.0
	5	296.5	155.7	200.8	70.9	74.3
	6	308.2	186.3	186.8	71.8	73.6
	7	301.7	171.8	201.3	71.5	74.3
	8	369.3	229.5	210.5	70.8	72.8
	9	315.3	181.5	203.8	70.0	73.4
Detached soil	1	227.8	132.7	150.4	49.3	72.1
	4	237.8	133.7	154.4	50.3	73.1
	5	265.7	149.1	173.7	57.1	74.1
	6	306.0	184.8	187.3	66.0	73.8
	7	344.0	208.9	205.0	69.9	73.4
	8	359.1	224.5	204.2	69.6	73.1
	9	377.8	238.1	215.4	75.7	72.8
Attached soil HWT	1	209.5	118.2	138.6	48.3	74.7
	4	219.5	123.2	145.6	49.3	74.7
	5	304.6	169.0	196.9	61.3	73.3
	6	324.3	204.4	187.3	67.3	72.8
	7	366.6	224.6	211.6	69.6	73.2
	8	308.0	176.8	199.0	67.8	75.7
	9	299.4	165.5	201.8	67.8	75.4
Detached soil HWT	1	308.9	187.1	179.0	66.2	73.3
	4	318.9	197.1	189.0	67.2	73.3
	5	312.8	181.1	192.9	61.3	73.4
	6	317.3	194.3	192.5	69.4	73.4
	7	320.6	191.5	199.0	69.9	74.0
	8	349.9	214.9	205.9	70.9	73.3
	9	374.3	229.3	216.0	71.1	73.4

ment, measurements of starch properties in terms of final viscosity, setback and pasting temperatures did not show significant differences between heat-treated and untreated samples during storage. In conclusion, hot water treatment had also no significant impact on the internal components' quality of the sweet potato roots.

Sugar content

Changes in carbohydrate contents of sweet potato were shown in Fig. 2. The sugar content was insignificantly affected by hot water treatment under storage for one year. However, there was increase of sucrose and glucose and decrease of fructose in all treatments. Hot water dipping did not have significant difference in sugar levels. The fructose content was relatively low and gradually decreased from 0.21 to 0.10% in detached soil (Fig. 2A), 0.48 to 0.08% in attached soil (Fig. 2B), 0.31 to 0.12% in detached soil HWT

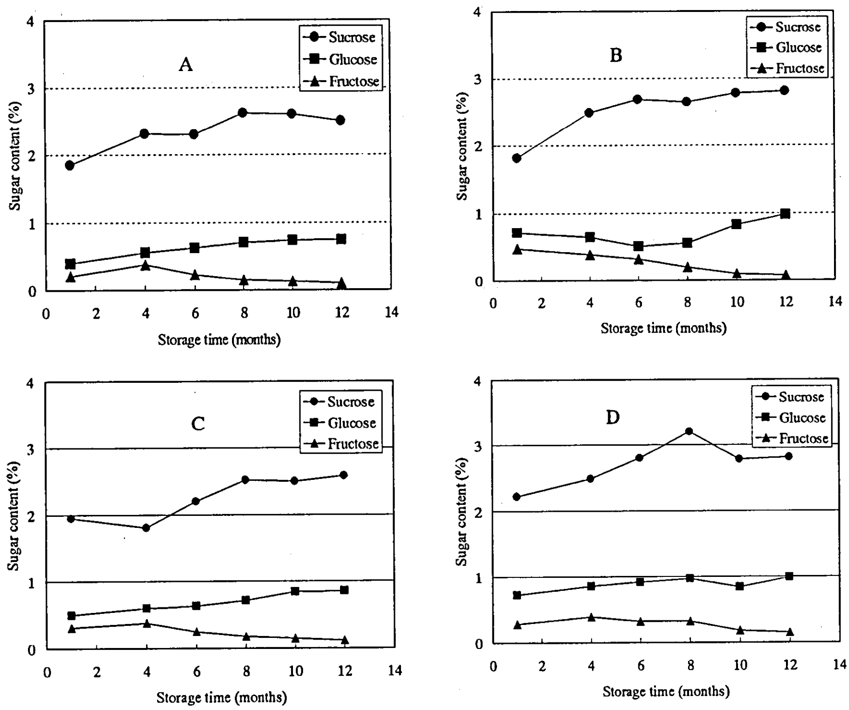

Fig. 2. Changes in sugar content of sweet potato during storage in WTCS (A: Detached soil, B: Attached soil, C: Detached soil HWT, D: Attached soil HWT)

(Fig. 2C) and from 0.28 to 0.15% in attached soil HWT (Fig. 2D) during storage. The glucose content was intermediate level that increased gradually during storage. The fructose and glucose contents were far less than the sucrose content and changed negligibly during storage in all treatments. Sucrose was the major sugar in sweet potato root, which increased greatly by inverting from starch. The sucrose content increased from 1.85 to 2.50% in detached soil (Fig. 2A), 1.82 to 2.81% in attached soil (Fig. 2B), 1.95 to 2.58% in detached soil HWT (Fig. 2C) and from 2.22 to 2.81% in attached soil HWT (Fig. 2D) during storage. It also indicated that hot water treatment did not have significant difference in sucrose levels. It has been reported that α–amylase in sweet potato roots dose play a key role in starch degradation during storage (Takahata *et al.*, 1995; Picha, 1986). Transformation of starch to sugar in sweet potatoes takes place during curing and continues in storage. A characteristic sweet smell was evolved by quality evaluation after storage. The better internal quality of yearlong stored sweet potato was obtained from storage in WTCS.

CONCLUSIONS

Hot water treatment to control sprouting and fungal deceases has good effect and also no significant impact on the internal components' quality of the roots. Only less than 4% of the year long stored roots were discarded due to spoilage. It indicated that thermal treatment supply a lethal dose of heat to surface pathogens and cauterize eye without damaging the nutritional and processing qualities of sweet potato. Hot water treatment had also no significant impact on the internal components' quality of the sweet potato roots. The success of storage experiments in prolonging sweet potato by means of WTCS was obtained from the decrease in the weight loss and demand the for grower and consumer for one year storage. This new technique will open a new avenue to prolonging the storage life of sweet potato with good quality and minimal waste.

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