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Application of Simplified Curing Unit for the Extension of Storage Life and Improvement of Physicochemical Quality of Sweet Potatoes during Long-term Storage

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Abstract. To evaluate the effect of curing treatment using a newly developed simplified curing unit (SCU) on the physicochemical quality of stored sweet potatoes was investigated for six months. The SCU consisting of a heater, an air circulation fan, exhaust fans, and a humidifying duct was installed in a cold storage room where the harvested sweet potatoes were stacked. During the six days of curing treatment, air temperature and relative humidity in the storage room were set at 32°C and 90%, respectively. Physical and chemical properties of sweet potatoes were measured at 1-month intervals from the first day of storage. McKinney index showing the incidence and severity of decay was 0.83% in the curing treatment, while that of untreated control was 5.08% over the same storing period. Firmness, soluble solids content, and dry matter content in the cured sweet potatoes were greater than those of untreated control. Moreover, the changes of skin color in uncured potatoes occurred rapidly than cured one which showed delay of skin discoloration during the long-term storage. Results suggest that the SCU treatment improves the physicochemical quality of stored sweet potatoes and extends their storability. Therefore, the SCU can be effectively used for curing treatment of sweet potatoes with a relatively low cost.

Key words : curing facility, *Ipomoea batatas* Lam., long-term storage, wound healing

Introduction

Sweet potatoes are abundant in vitamins, carbohydrates, proteins, lipids, potassium, phosphate etc. and could be cultivated by environment-friendly farming. Cultivation area of sweet potato in Korea increased to 19,200 ha in 2010 from 12,718 ha in 2001 when its price slumped due to imports of sweet potato in great quantities (KNSO, 2011). Comparing with other Far East Asian countries, Korean farmers tend to harvest sweet potatoes at early stage (normally three to four months after transplanting) because of high consumer acceptance over small size and a concern about frost injuries. And the sweet potatoes just harvested from fields in Korea, and the products usually have an insufficiently developed epiderm (Jung, 2003). Also, sweet potatoes are often cut, skinned, and bruised by the harvesting implements and these mechanical damages are sustained not only during the harvest itself, but also during transporting and marketing (Tomlins et al., 2000; Wagner et al., 1983). To lessen the chance of quality loss after harvest, curing the damaged root surface has been proved to have beneficial effects such as sweetness and palatability on sweet potatoes (Rees et al., 2008; Wang et al., 1998). Lutz (1945) showed that sweet potatoes subjected to a short period of chilling developed more decay when they were not cured. If sweet potatoes were not treated with proper curing methods, they would be infected with microorganisms after going through skinning, wounding, and desiccation which results in substantial postharvest losses (Aidoo, 1993; Booth, 1974).

Process of curing involves desiccation of the surface cell layers, suberization of exposed parenchyma cells, and finally the formation of a wound periderm by cell division (Ray and Ravi, 2005; Sowley and Oduro, 2002). Van Oirschot et al. (2006) reported that continuity of the lignified layer was vital for effective wound-healing, presumably to act as an effective barrier to water loss and pathogen invasion.

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Conditions for effective curing treatment have been reported to be at 29~33°C, and 80~95% relative humidity (RH) for 4~7 days (Blankenship and Boyette, 2002; Picha, 1986; Ray and Ravi, 2005; Wang et al., 1998). Degree of water loss from roots would vary with curing conditions. Appleman et al. (1943) reported that 'Maryland Golden' sweet potatoes lost 5.6% of water while being cured at 30°C with 80~85% RH condition, but only 0.8% of water loss observed when cured 100% RH condition at same temperature. Storage conditions are recommended to sweet potatoes below 90% RH and 14 ± 1°C (Nwinyi, 1987). Relative humidity levels above 95% is not recommended during storage because of discoloration of roots and microbial attack (Ezell et al., 1956).

The recommended curing storage practices are difficult to follow for small-farm owners mainly because of high initial costs for construction of infrastructure (Ray and Ravi, 2005). Not only to reduce initial costs, but also to get the same curing effects on quality of sweet potatoes so that making cumbersome existing curing practices replaced, a novel simplified curing unit (SCU) was developed. In this study we evaluated effect of curing treatment using the SCU on quality of sweet potatoes during the long-term storage.

Materials and Methods

1. Plant materials and conditions for curing treatment

Sweet potato cultivar 'Sinyulmi' grown at Neungseo-myeon, Yeoju-gun, Gyeonggi-do, Korea harvested on October in 2005 were used in this experiment. After harvest, samples were immediately moved to a storage room for the curing treatment using a portable SCU, while control samples were left on the field for three days to dry naturally the root surface. The portable SCU consisting of a heater, an air circulation fan, exhaust fans, and a humidifying duct was installed in a cold storage room (10 × 10 × 5 m) where the samples stacked in nearly 105 tons. Refrigeration unit installed in the storage room was turned off and the heating unit of the SCU was operated until air temperature in the storage room reached up to 32°C. When the heating unit was turned off after reaching at 32°C, humidified air of the storage room was exhausted by operating electronic relay of the SCU that connected to fans installed on the wall. And it was re-operated with simultaneous stop of ventilation when the air temperature became 30°C. During the curing treatment, water was circulated continuously from water reservoir of the humidifying duct and the evaporation cloths vertically installed on the wall, which enabled the passive humidity control in higher RH range with avoiding the direct contact of roots with water during humidification using humidifiers. During six-days of curing treatment, changes in air temperature, root surface temperature, relative humidity in a storage room were measured using T-shaped thermocouples and hygrometers and the data were acquired using a data logger (CR-10X, Campbell Sci., USA) from 14^{th} to 20^{th} October. After the curing treatment, the SCU was removed from the storage room and temperature and relative humidity was maintained at 12~13°C and 40~60% by an air conditioning unit initially installed in the storage room.

2. Quality analysis

Quality analysis was performed for SCU treated or untreated sweet potatoes once in a month during the six-month storage. Ten roots per each of three replicates which were selected randomly from each storage container and marked on the surface for the nondestructive quality attributes such as root fresh weight, disease incidence and severity, and skin color during the six months of storage. Disease severity was recorded using a 4 scale depending on the percentage of the surface damaged: 1 = trace, up to 5% of surface decay; 2 = slight, 5~30%; 3 = moderate, 30~50%; and 4 = severe, over 50%. This scale was used for calculation of McKinney index (MI, McKinney, 1923) that represents the percentage of the total number of infected roots and also the degree of infection. The MI was calculated using the following formula:

$$MI = [\sum df/T_nD] \times 100$$

where d is the degree of disease severity, f its frequency, T_n the total number of the root examined, and D the highest degree of disease intensity (Nigro et al., 2006).

The skin color was quantified using a chromameter (CR-400; Konica Minolta Corp., Japan). Color change can be compared with time which has a decisive effect on external value of the postharvest products. Data were presented as lightness (L*), redness (a*), and yellowness (b*), and were converted to hue angle (h^o) which represent the angular component of the polar representation. Destructive quality examination such as measurements of dry matter, firmness, and soluble solids content were conducted using five samples per replicate. Firmness was measured using a texture analyzer (TA-XT2; Arrow Scientific, Australia), as the force required for an 8 mm probe to penetrate the tissue after a small portion of periderm had been removed, and data were recorded in Newtons (N). To evaluate soluble solids content, 20 g of grated root tissue were squeezed and the extracts were measured using portable refractometer (RA-150; CSC Scientific Co., Inc., USA). Ten roots per each replicate were taken to measure dry matter content by drying for 72 h at 70°C in a fan-assisted oven.

3. Statistics

A randomized complete block experimental design was utilized. For each treatment, they were divided into three replicates with ten roots per replicate. Data within each experiment were subjected to an analysis of variance (ANOVA) using the statistical analysis system (SAS Institute, Inc. 1992, Cary, NC, USA). Differences among means of data were compared by Duncan's Multiple Range Test. Differences at $p \leq 0.05$ were considered significant.

Results and Discussion

1. Decay and water loss

It took about two days to increase the air temperature from 15 to 32°C, an appropriate air temperature for curing (Fig. 1), which was determined by root temperature of sweet potatoes, heating capacity of heating unit, and insulation level of the storage room. Changes in root surface temperature showed similar pattern with that of air temperature except the wider fluctuation in range between 27.9 and 36.5°C. Ventilation using fans installed on the wall after stopping the heating at 32°C decrease both air temperature and root surface temperature. Relative humidity mainly determined by operation of ventilation fans and a heating unit was maintained at around 75 to 80% when the ventilation fans were stopped while

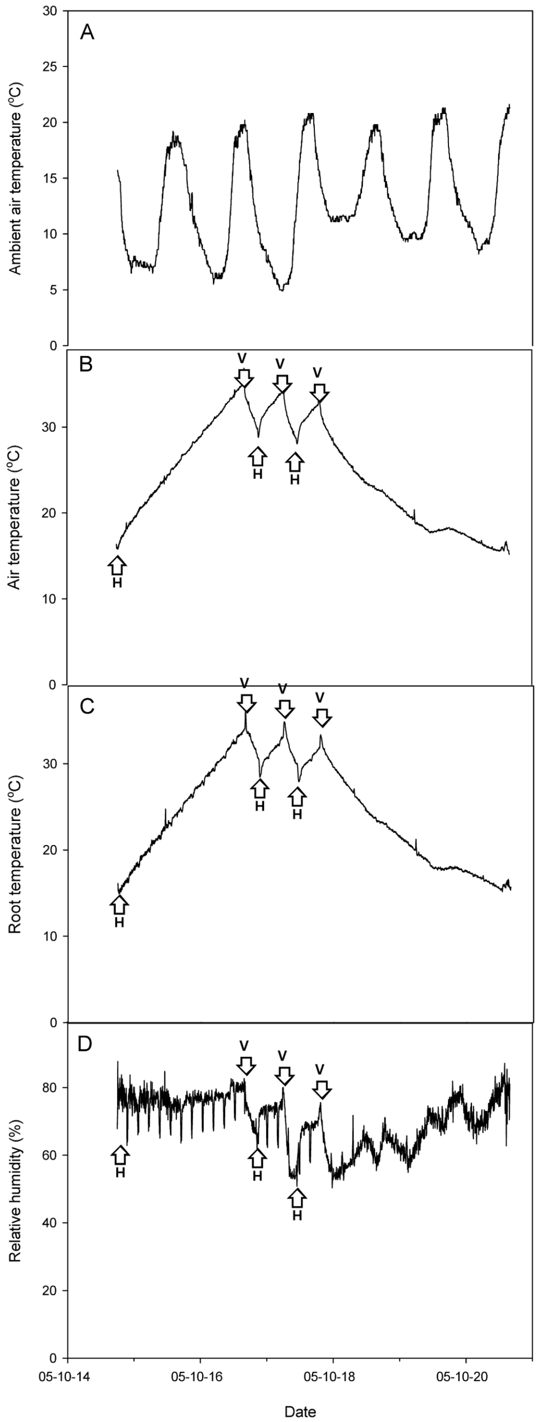

Fig. 1. Changes in ambient air temperature (A), air temperature in the storage room (B), sweet potato temperature (C), and relative humidity in the storage room (D) during the six days of curing treatment as affected by heating (H) and ventilation (V).

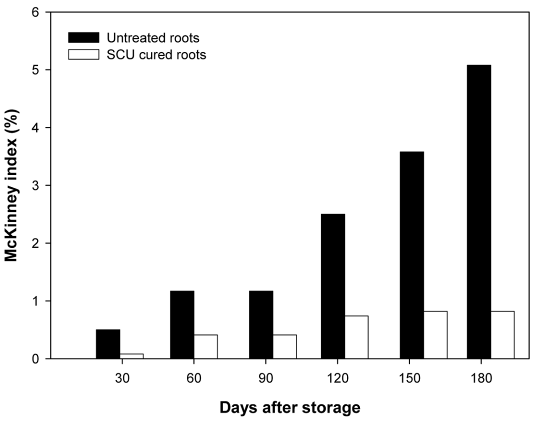

Fig. 2. Decay incidence of sweet potatoes during the long-term storage as affected by curing treatment. McKinney index (MI) was calculated by means of the following formula: $MI = [\sum df/T_nD] \times 100$, where d is the degree of disease severity, f its frequency, T_n the total number of the root examined, and D the highest degree of disease intensity.

the heating unit was operated. The relative humidity lowered after cooling process with ventilation re-increased up to 80% while the air temperature decreased by 15°C at the end of curing processes. The timescale for cooling might be shortened by use of coolers installed in the storage room in combination with the ventilation. In the present study, the cooler unit was not used during the last cooling period.

McKinney index (MI) of untreated sweet potatoes was 5.08 ± 0.50% over the storage, while that of cured roots was 0.83 ± 0.11%, which indicates that the curing treatment significantly decreased the decay of sweet potatoes during a long term storage (Fig. 2). MI of untreated sweet potatoes increased continuously until storage period. Weight loss is primarily due to water loss, and root respiration used to estimate the contribution to weight loss of starch metabolism for an average 14% (Rees et al., 2003a). We found that the untreated sweet potatoes experienced water loss of 15.6 ± 0.6% during the first one-month storage and increased to 50.5 ± 0.6% at the rest of the storage period (Fig. 3). This results can be compared with those of Rees et al. (2003b) report that water losses of 30 kinds of sweet potatoes after two weeks of storage was about 10~25%. In case of untreated sweet potatoes, severe water loss may lead to a condition known as pithiness in which cavities appear within the tissues (Picha,

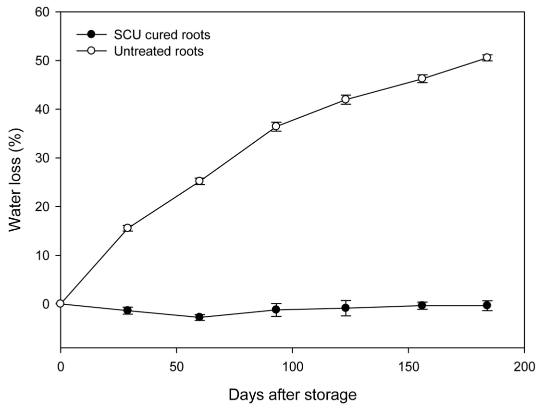

Fig. 3. Change in water loss of sweet potatoes during the long-term storage as affected by curing treatment. Vertical bars represent standard errors of the means.

1986). We could conclude that water loss of untreated sweet potatoes increased continuously, while that of cured one using SCU maintained low level during six months in controlled RH conditions.

2. Firmness

Firmness of SCU cured sweet potatoes was significantly greater than that of untreated one from the first day of storage and this difference became greater as the storage period extended (Fig. 4). Difference of the root firmness in two treatments was thought to be related mainly to the water loss and respiration during curing treatment (Maw and Mullinix, 2005), which resulted in that the

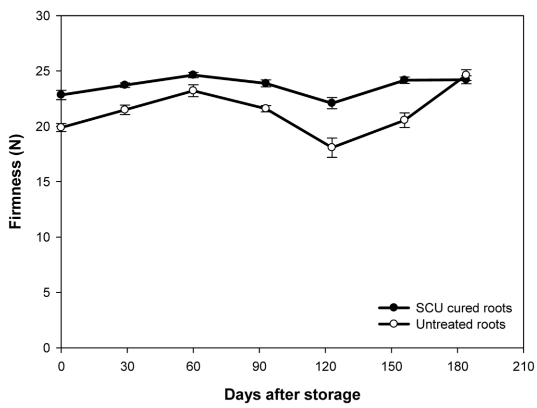

Fig. 4. Change in fimness of sweet potatoes during the long-term storage as affected by curing treatment. Vertical bars represent standard errors of the means.

cured sweet potatoes was harder than uncured roots one during long-term storage, agreed with the results of Rees et al. (2003a). Under high humidity condition, degradation of the middle lamella and disintegration of the primary cell wall were the main factors determining hardness (Deng et al., 2005). Sweet potatoes have a high respiratory rate right after harvest and the resultant heat production soften the texture, however, the respiratory rate decreased during curing due to desiccation of the top cell layers under the wound, and continued to decrease at a slower rate during the first several months of storage (VanOirschot et al., 2006). The facts that curing treatment increases hardness of roots and decreased water loss and respiration rate which results the better storability with minimized weight loss during long term storage was confirmed.

3. Soluble solids content and skin color

Soluble solids in SCU cured sweet potatoes (11.3°Brix) was greater than that of uncured one (8.9°Brix) from the first day of storage (Fig. 5). The cells of sweet potatoes in cured sweet potatoes might turn more starch that makes up the main part of the rest of the dry matter (Woolfe, 1992) to monosaccharide such as sucrose, glucose, fructose, and low levels of maltose comparing to those of untreated control (Rees et al., 2003a). Geigenberger et al. (1999) and Wang et al. (2000) pointed out that the sucrose cycling, a control of the sucrose and starch ratio was an important mechanism and sucrose phosphate synthase activity of sweet potato cells increased to protect against water stress. Mobilization of sugars would provide energy for wound-healing and could be involved in protection against water stress, by which plant tissues can increase their osmotic potential (Rees et al., 2008). Ability to wound-heal is a key factor in determining rates of water loss (Van Oirschot, 2000), however, we could not investigate the relationship of this ability with either dry matter content or soluble solids content in this study. We just observed that surface layers of wounded roots turned flat and white after curing treatment.

Skin color of uncured sweet potatoes changed from red (hue angle of 24-32) to yellow (hue angle of 80-85) rapidly, while that of SCU cured ones changed slowly as shown in Fig. 6. Jung (2003) found that in appropriate curing condition, color change of the roots can be slowed by nearly twice. The oxidation of anthocyanin in the root surface may be the reason of those changes.

Results indicate that curing treatment delays discoloration of sweet potatoes during a long-term storage without any negative effects on soluble solid content, one of major factors that decide the taste of sweet potatoes.

From the results of this study, we found that wound healing by curing treatment was important both to reduce water loss through a wound, and also to prevent entry of pathogens. Using a novel simplified curing unit consisting of a few general appliances, appropriate environmental condition for curing of sweet potatoes before a long-term storage was provided, and we confirmed that the

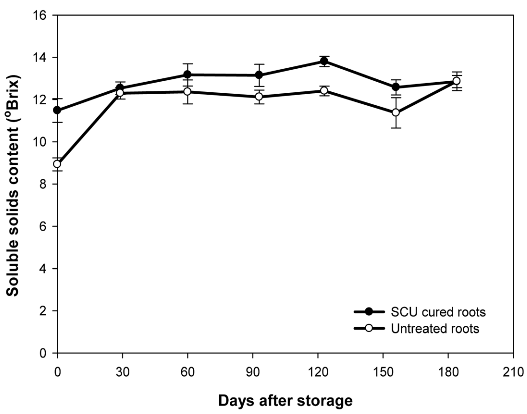

Fig. 5. Change in soluble solids content of sweet potatoes during the long-term storage as affected by curing treatment. Vertical bars represent standard errors of the means.

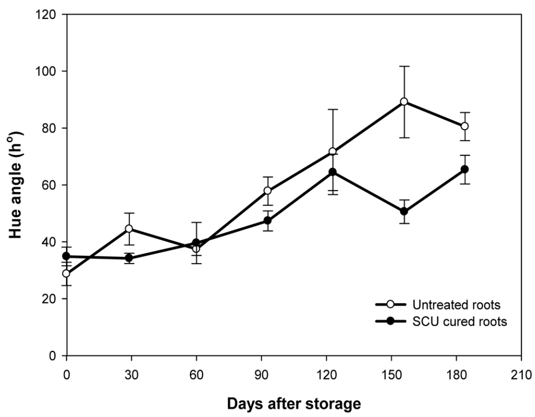

Fig. 6. Change in skin color of sweet potatoes during the long-term storage as affected by curing treatment. Vertical bars represent standard errors of the means.

curing treatment using the SCU improved the physicochemical qualities of stored roots and extended their storage life. Therefore, the developed SCU can be used for curing treatment of long-term stored sweet potatoes, replacing an exclusive curing facility that requires heavy initial investment.

Literature Cited

1. Aidoo, K.E. 1993. Post harvest storage and preservation of tropical crops. Int. Biodeter. Biodegrad. 32:161-173.
2. Appleman, C.O., H.G. Shirk, P.H. Heinze, and R.G. Brown. 1943. The curing and storage of Maryland Golden sweetpotatoes. Maryland Agr. Exp. Sta., Bull. A22.
3. Blankenship, S.M. and M.D. Boyette. 2002. Therdermal adhesion in five sweetpotato cultivars during curing and storage. HortScience 37:374-377.
4. Booth, R.H. 1974. Post-harvest deterioration of tropical root crops: Losses and their control. Trop. Sci. 16:49-63.
5. Deng, Y., Y. Wu, and Y. Li. 2005. Effects of high O_2 levels on post-harvest quality and shelf life of table grapes during long-term storage. Eur. Food Res. Technol. 221:392-397.
6. Ezell, B.D., M.S. Wilcox, and K.D. Demaree. 1956. Physiological and biochemical effects of storage humidity on sweetpotatoes. J. Agric. Food Chem. 4:640-644.
7. Geigenberger, P., R. Reimholz, U. Deiting, U. Sonnewald, and M. Stitt. 1999. Decreased expression of sucrose phosphate synthase strongly inhibits the water stress-induced synthesis of sucrose in growing potato tubers. Plant J. 19:119-129.
8. Jung, M.-C. 2003. Post-harvest treatments and storage technology for extending the freshness of sweet potato. Korea Food Research Institute, Suwon (in Korean).
9. KNSO, 2011. www.kosis.kr. Korea National Statistical Office.
10. Lutz, J.M. 1945. Chilling injury of cured and non-cured Porto Rico sweetpotatoes. U.S. Dept. Agr. Cir. 729.
11. Maw, B.W. and B.G. Mullinix. 2005. Moisture loss of sweet onions during curing. Postharvest Biol. Technol. 35:223-227.
12. McKinney, H.H. 1923. Influence of soil temperature and moisture on infection of wheat seedlings by *Helminthosporium sativum*. J. Agr. Res. 26:195-218.
13. Nigro, F., L. Schena, A. Ligorio, I. Pentimone, A. Ippolito, and M.G. Salerno. 2006. Control of table grape storage rots by pre-harvest applications of salts. Postharvest Biol. Technol. 42:142-149.
14. Nwinyi, S.C.O. 1987. Sweet potato: A potantial industrial and staple food crop of Nigeria. Outlook on Agric. 16:178-181.
15. Picha, D.H. 1986. Weight loss in sweetpotatoes during curing and storage: Contribution of the transpiration and respiration. J. Am. Soc Hort. Sci. 111:889-892.
16. Ray, R.C. and V. Ravi. 2005. Post harvest spoilage of sweetpotato in tropics and control measures. Critic. Rev. Food Sci. Nutr. 45:623-644.
17. Rees, D., Q.E.A. vanOirschot, and J. Aked. 2008. The role of carbohydrates in wound-healing of sweetpotato roots at low humidity. Postharvest Biol. Technol. 50:79-86.
18. Rees, D., Q.E.A. vanOirschot, R. Amour, E. Rwiza, R. Kapinga, and T. Carey. 2003a. Cultivar variation in keeping quality of sweetpotatoes. Postharvest Biol. Technol. 28:313-325.
19. Rees, D., O.E.A. vanOirschoot, R.E. Kapinga. 2003b. Sweetpotato postharvest assessment. Natural Resources Institute, University of Greenwich. London, UK.
20. Sowley, E.N.K. and K.A. Oduro. 2002. Effectiveness of curing in controlling fungal-induced storage rot in sweetpotato in Ghana. Trop. Sci. 42:6-10.
21. Tomlins, K.I., G.T. Ndunguru, E. Rwiza, and A. Westby. 2000. Post harvest handling, transport and quality of sweetpotato in Tanzania. J. Hort. Sci. Biotech. 75:586-590.
22. Van Oirschot, Q.E.A. 2000. Storability of sweet potatoes (*Ipomoea batatas* Lam.) under tropical conditions: physiological and sensory aspects. PhD. Thesis. Cranfield University.
23. Van Oirschot, Q.E.A., D. Rees, J. Aked, and A. Kihurani. 2006. Sweetpotato cultivars differ in efficiency of wound healing. Postharvest Biol. Technol. 42:65-74.
24. Wagner, A.B., E.E. Burns, and D.R. Paterson. 1983. The effect of storage systems on sweetpotato quality. Hort. Sci. 18:336.
25. Wang, H.L., P.D. Lee, W.L. Chen, D.J. Huang, and J.S. Su. 2000. Osmotic stress-induced changes of sucrose metabolism in cultured sweet potato cells. J. Exp. Bot. 51:1991-1999.
26. Wang, Y., R.J. Horvat, R.A. White, and S.J. Kays. 1998. Influence of post harvest curing treatment on the synthesis of the volatile flavor components in sweetpotato. Acta Hort. 64:207-212.
27. Woolfe, J. 1992. Sweetpotato: An untapped food resource. Cambridge University Press, Cambridge, UK.

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간이 큐어링 설비를 이용한 큐어링 처리가 장기간 저장 중 고구마의 품질 개선에 미치는 영향

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적　요. 본 연구는 기존의 농가 보급형 고구마 저장고에 가열기(본체), 환기팬, 배풍구 팬, 습도 조절을 위한 관으로 구성된 간이 큐어링 설비를 부가시킨 후, 그 효과를 검증하기 위하여 수행되었다. 6일간의 큐어링 처리 기간 동안 저장고 내 기온 및 상대습도는 32°C, 90%로 설정되었다. 고구마의 저장 기간(6개월) 동안 1개월에 1회씩 표본을 수집하여 물리화학적 품질을 측정한 결과, 부패율과 부패 정도를 함께 보여주는 McKinney Index는 큐어링 처리구의 경우 0.83%였으며, 큐어링 처리를 하지 않은 대조구의 경우 5.08%였다. 큐어링 처리구의 경도 및 당도, 건물율은 모두 대조구보다 높았으며, 대조구의 표피색이 큐어링 처리구보다 빠르게 변하여 큐어링 처리가 저장기간 동안 고구마의 변색을 지연시켰음을 알 수 있었다. 본 연구를 통하여 간이 큐어링 설비를 이용한 큐어링 처리는 초기 비용이 많이 소모되는 일반 큐어링 설비를 대체하여 고구마의 물리화학적 품질을 증진시킬 수 있으며, 저장 기간을 늘릴 수 있음을 알 수 있었다.

주제어 : 고구마, 상처 치유, 장기간 저장, 큐어링