Effect of Low Oxygen Treatment on Chilling Injury Symptom of Jicama (*Pachyrhizus erosus* (L.) Urban) Tuberous Root after Storage at Low Temperature

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Key words: jicama tuberous root, chilling injury, low oxygen treatment

Summary

The effect of low oxygen treatment on the chilling injury symptoms of jicama tuberous root after storing at low-temperature was investigated. The experiment was a completely randomized design (CRD) with 4 treatments; 1) air control of approximately 21% O_2, 2) 10% O_2, 3) 5% O_2, and 4) 100% N_2 (0% O_2). Jicama tuberous root was stored at 6℃ either 9 or 18 days then transferred to ambient temperature with low oxygen treatment, for another 3 days. Results showed that the low O2 treatments can reduce browning discoloration, maintaining lightness value, and delaying weight loss of jicama tuberous root. Additionally, low oxygen treatments did not affect the root firmness. The best browning prevention was found in root treated with 0% O_2 (100% N_2) while the high decay was also found in this treatment. Moreover, 0% O_2 (100% N_2) treatment damaged the root cell membranes, which give the rise of ion leakage percentage and decay.

Introduction

Jicama tuberous root (*Pachyrhizus erosus* (L.) Urban), also called yam bean, is a tropical leguminous root crop and eaten as a vegetable. It is native to Mexico and Central America, and grows well in the tropical and subtropical regions. The plant has a high capacity to fix nitrogen, and

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the yields can be high. The root has a good compositional balance between carbohydrates and protein (Stamford *et al*., 2002; Kay, 1973; Sørensen, 1996). The jicama tuberous root contains about 85% water, <1% fiber, <1.5% protein, <0.5% ash and about 10% carbohydrate (Paull and Chen, 1988). The root is composed of a white, crisp, succulent and sweet-starchy pulp and a light or dark brown periderm. It is usually consumed as raw vegetable with lemon juice and chili in salads, or cooked vegetable in soups, stir-fried and pickled in vinegar. Jicama tuberous root is also used as a substitute for the water chestnut in Chinese food (Cadiz *et al*., 2000; Juárez and Paredes-López, 1994; Sørensen, 1996).

Non-damaged jicama tuberous root can be stored for long time, up to 6 months. However, jicama tuberous root very sensitive to chilling injury when storage at nonfreezing low temperature (below 10℃) and the severe symptom was observed after removal the root from storage condition (Bergsma and Brecht, 1992; Cantwell *et al*., 1992; Mercado-Silva and Cantwell, 1998; Paull and Chen, 1988). It has been reported that the major symptoms of chilling injury in jicama tuberous root are increased external decay, internal browning, loss of whiteness and crispness (Cantwell *et al*., 1992).

Low-oxygen modified atmospheres packaging has been used to extend the shelf-life of fresh-cut fruits and vegetables, helping to reduce respiration and ethylene production, inhibiting or delaying enzymatic reactions and preserving the product from quality losses. Treatment with reduced oxygen prior to storage delays fruit ripening in bananas (Wills *et al*., 1990), tomatoes (Kelly and Saltveit, 1988), peaches and nectarines (Lurie and Pesis, 1992), mangoes (Burdon *et al*., 1994) and avocados (Pesis *et al*., 1994). In addition, atmosphere modification can substantially delay the growth of most aerobic spoilage microorganisms (Soliva-Fortuny and Martin-Belloso, 2003).

There are less published data on the effects of low oxygen atmospheres on the quality and chilling injury of jicama tuberous root. Thus, objective of the present study was mainly to investigate the effects of different concentrations of oxygen on color, weight loss, firmness, decay, browning, and ion leakage (%) of jicama tuberous root after storage at low temperature.

Materials and methods

1. Plans materials

Small sizes (250-400g) of jicama tuberous root were obtained from a local market (Pingtung Country, Taiwan) and transported by car under ambient conditions to postharvest laboratory, Department of Horticulture, National Chung Hsing University, Taichung city, Taiwan. Jicama tuberous roots free of mechanical damage or decay were selected and cleaned with tap water to remove the surface dirt and dried at room temperature. Roots were stored at 15℃ until use.

2. Experiment

This experiment on the effect of low oxygen treatment applied after remove the root from low temperature storage. Thirty two roots were put into 40 L container {the container was set up with air flow humidifier (>90%RH)} and stored at 6℃ for either 9 or 18 days then transferred to ambient temperature. Sixteen roots were divided into 4 groups and treated with different concentration of oxygen. Atmospheric conditions were set up using a flow system with air (about 21% oxygen, control), 10% and 5% oxygen, and 100% nitrogen (0% oxygen) in compressed tanks. Three days after treatments, weight loss, decay, browning, color, firmness, and ion leakage were investigated. The experiment has 4 replications per treatment and repeated for 2 times.

3. Weight loss (%)

The weight of jicama root was determined before and after treatments. The measurements were repeated three times per treatments. The weight loss (%) was calculated as:

$$\text{Weight loss (\%)} = (\text{Initial Weight} - \text{Final Weight}) \div \text{Initial Weight} \times 100\%$$

4. Firmness

Exterior tissue skin of the jicama tuberous root was removed with a sharp knife and the pulp next the external tissue was used for firmness penetration. Root firmness was measured at the middle of two opposite sides of each root using a penetrometer (Effegi, FT 327, Wilson, Italy) with an 8 mm diameter. The mean values for maximum force are reported in Newtons (N).

5. Color measurement

Exterior and interior tissue color of jicama tuberous root was measured from the middle of the root on two opposite sides of each root by a Hunter Lab Scan colorimeter (MiniScan XE Plus, MSXP-4500S, USA). The values of L* (lightness), a (redness to greenness), b (yellowness to blueness), C (Chroma), and Hº (Hue angle) were recorded for each sample.

6. Decay and browning assessment

Decay were evaluated on a score of 0–4 (Fig. 1A), where 0=none, 1=slight (up to 5% surface affected), 2=moderate (>5–20% surface affected), 3=moderately severe (>20–50%), and 4=extremely severe (>50% surface affected). Browning was evaluated on a score of 0-4 (Fig. 1B),

where 0=none, 1=slight, 2=moderate, 3=severe, and 4=extreme. These scores were applied as previously reported by some modification (Cantwell *et al*., 1992; Mercado-Silva *et al*., 1998b). The decay and browning index were defined and calculated as:

Decay =Σ (number of roots in given score × score value) ÷ total number of root evaluated.

Browning =Σ (number of roots in given score × score value) ÷ total number of root evaluated.

7. Measurement of electrolyte conductivity,

Electrolyte conductivity was measured following the method described by Cantwell *et al*., (1992). Eight discs were prepared from interior tissue near the epidermis taken with a cork bore at the equator of each root 2 cm from the surface (5 mm think and 1 cm in diameter). Individual discs were agitated at 20℃ in 10 mL deionized water for 30 min and measured with a conductivity meter, then frozen for 1 day to disrupt membranes, and conductivity of the thawed solution was again measured after agitation for 4.5 hours. The electrolyte conductivity (%) was calculated as:

ion leakage (%) = (initial conductance ÷ final conductance) × 100%.

8. Statistical analysis

The data of the experiment were statistically analyzed by SAS 9.4 (Institute Inc, 2002-2012) and subjected to one-way analysis of variance (ANOVA) for a completely randomized design (CRD) statistical model. Mean values among treatments were compared by t-Test (LSD) at 5% level of significance ($\rho \leq 0.05$).

Results

The effects of low oxygen (O_2) treatments on weight loss percentage in jicama tuberous roots after storing at 6℃ for 9 or 18 days and then transferred to ambient temperature with different concentrations of O_2 for another 3 days were presented in Fig. 2. Weight loss percentage of root stored at 6℃ for 9 days was not significantly different between treatments. The weight loss percentage slightly increased as time increased. Highest percentage (2.91%) was observed in root stored at 6℃ for 18 days and then treated with air for another 3 days while weight loss percentage of root treated with low O_2 was significantly lower than that treated with air. Lowest percentage of weight loss (1.96%) was observed in root stored at 6℃ for 18 days and treated with 0% O_2 for another 3 days.

As showed in Fig. 3, firmness had a slightly decreased after stored and treated with different

concentration of O_2 for another 3 days. But firmness of low O_2 treatments showed not significantly different as compared to the air control. The results of ion leakage percentage showed in Fig. 4. The initial ion leakage percentage in the internal tissue of root was 27.89%. The ion leakage percentage had an increased with time increased. Nine days after stored and treated with low O_2 for another 3 days, highest ion leakage percentage was observed in 0% O_2 treatment (63.61%) while ion leakage percentage of air control (21% O_2), and 10% O_2 treatment were significantly lower than 0% O_2 treatment. These behaviors were also observed in root stored for 18 days and treated with the same conditioning.

At the first 9 days of storage, decay index of root stored at 6℃ and treated with different concentration of oxygen for another 3 days was lower than root stored at 6℃ of 18 days. Highest of decay was observed in the root treated with 0% O_2 treatment in both two time surveys (Fig. 5, and Fig. 7). In addition, browning of root was observed in the root stored for 9 days and treated with different concentration of O_2 for another 3 days, but data showed not significantly different between treatments. Severe of browning was observed in root stored at 6℃ for 18 days and treated with the higher concentration of O_2 (Fig. 6, and Fig. 7). At the first 9 days of storage, the lightness values were not significantly different in both external and internal tissue of root while the internal tissue of root stored at 6℃ for 18 days and treated with air (21% O_2) was significantly lower than other treatments (Table 1). This indicates that low O_2 treatments can maintain white color of interior tissue of jicama tuberous root.

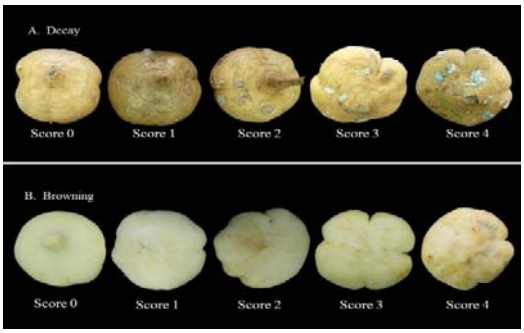

Fig. 1. Scale for (A) decay and (B) browning index of jicama tuberous root.

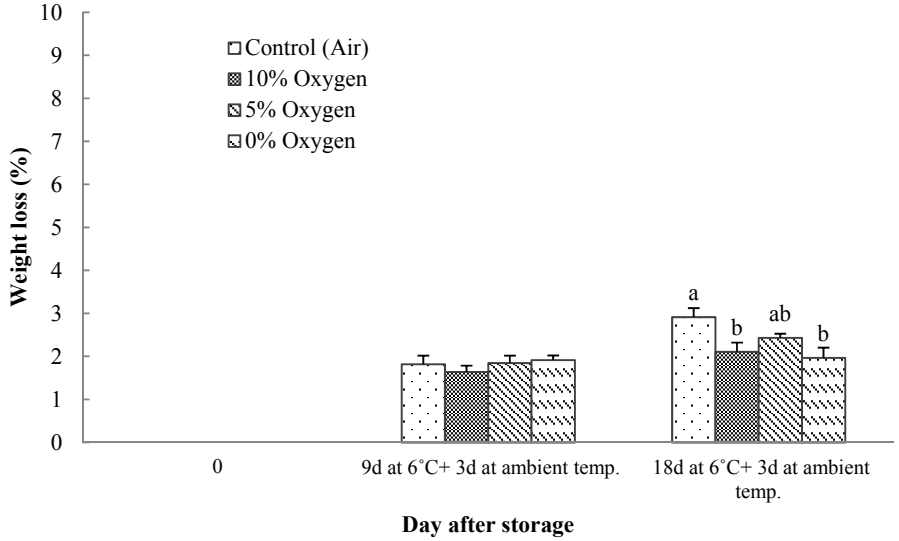

Fig. 2. Weight loss (%) of jicama tuberous root after storage at 6℃ for 9 or 18 days then transferred to ambient temperature with O_2 treatment, for another 3 days.

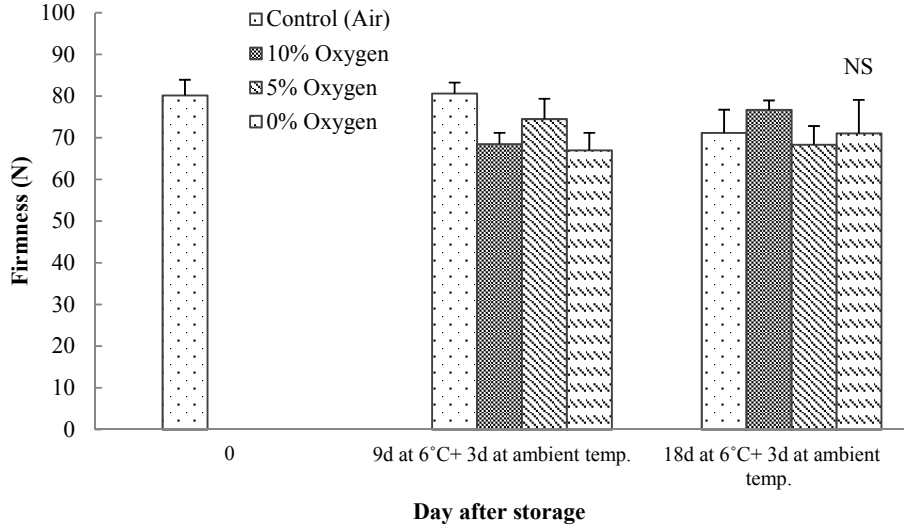

Fig. 3. Firmness (N) of jicama tuberous root after storage at 6℃ for 9 or 18 days then transferred to ambient temperature with O_2 treatment, for another 3 days.

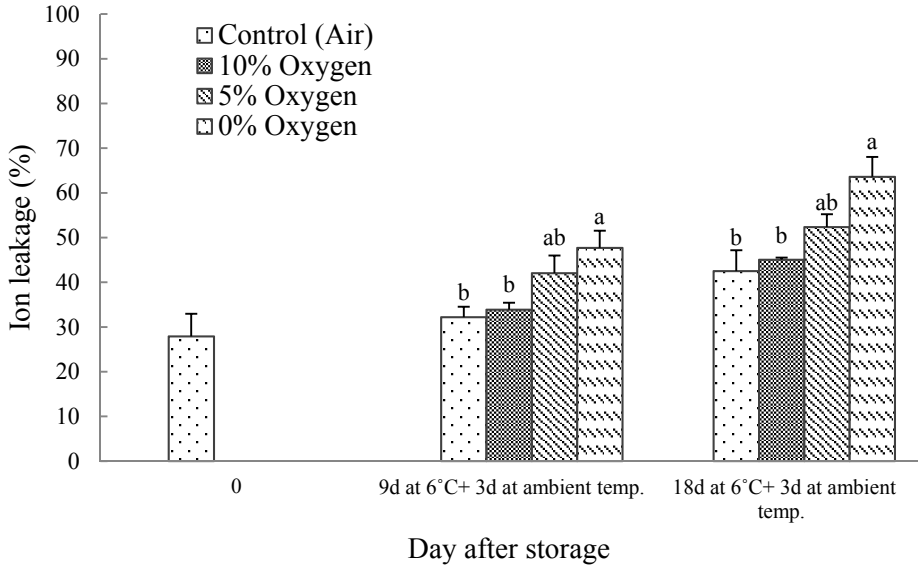

Fig. 4. Ion leakage (%) of jicama tuberous root after storage at 6℃ for 9 or 18 days then transferred to ambient temperature with O_2 treatment, for another 3 days.

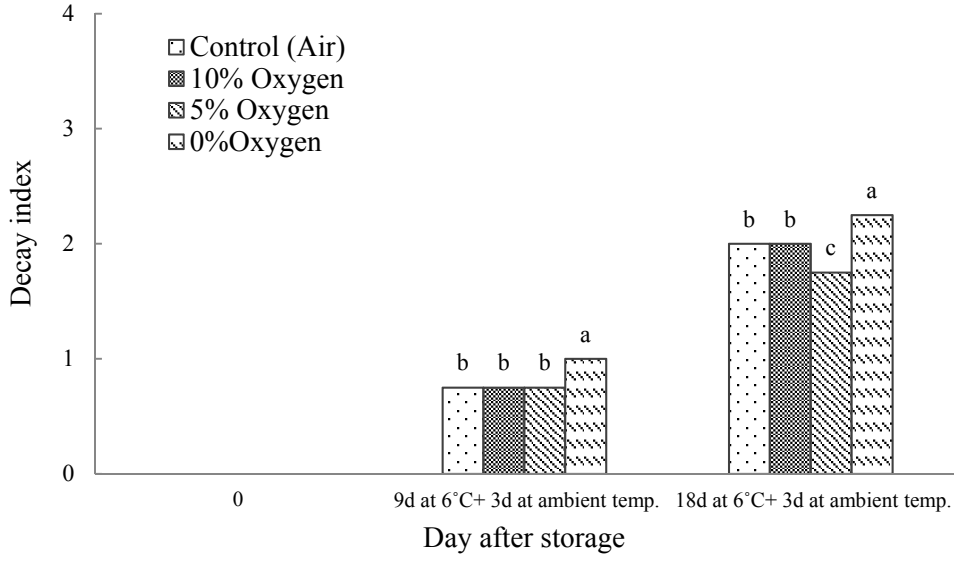

Fig. 5. Decay index of jicama tuberous root after storage at 6℃ for 9 or 18 days then transferred to ambient temperature with O_2 treatment, for another 3 days.

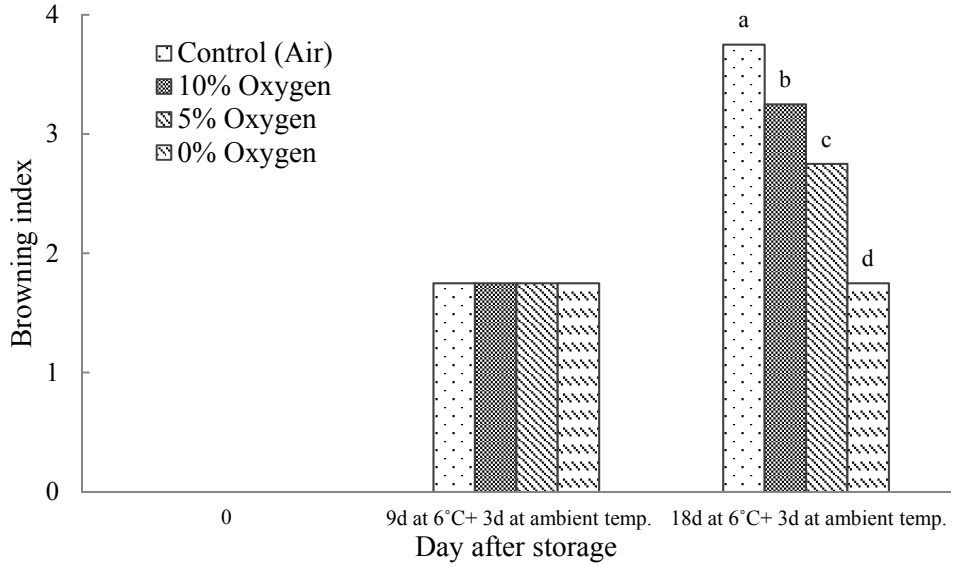

Fig. 6. Browning index of jicama tuberous root after storage at 6℃ for 9 or 18 days then transferred to ambient temperature with O_2 treatment, for another 3 days.

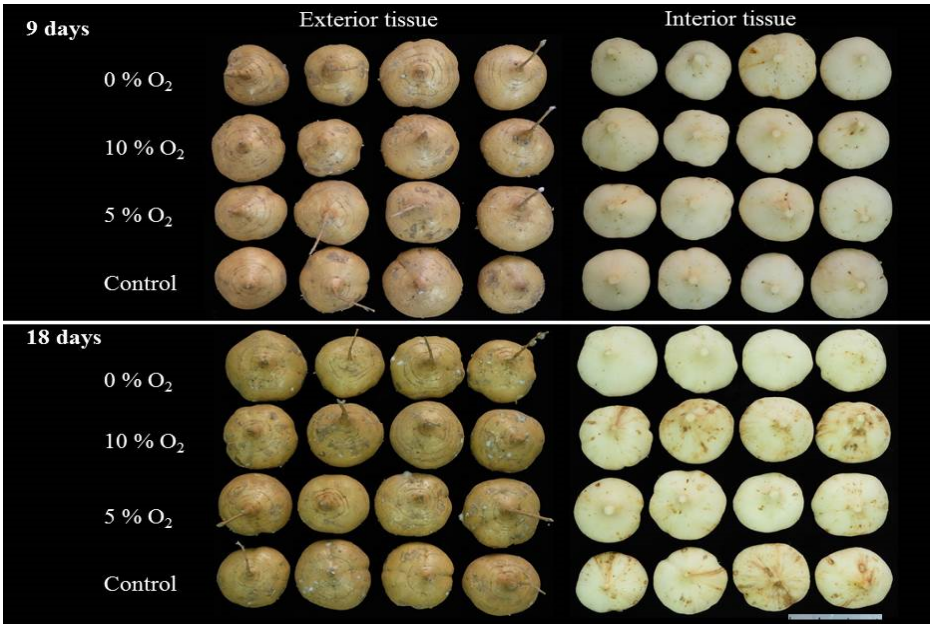

Fig. 7. Appearance of exterior and interior tissue of jicama tuberous root after storage at 6℃, either 9 or 18 days, then transferred to ambient temperature with O_2 treatment, for another 3 days.

Table 1. Change in the lightness (L*) of jicama tuberous root after storage at 6℃ for 9 or 18 days, then transferred to ambient temperature with O_2 treatment, for another 3 days.

Treatment	Lightness value	
	Exterior tissue	Interior tissue
Day 0		
Control (Air)	58.6 ± 1.7 a[x]	72.5 ± 2.1 [y] a
10% Oxygen	58.0 ± 3.0 a	72.9 ± 0.1 a
5% Oxygen	59.5 ± 1.5 a	70.6 ± 1.8 a
0% Oxygen	60.1 ± 2.2 a	70.4 ± 3.0 a
9 days after storage		
Control (Air)	58.3 ± 1.1 a	70.6 ± 2.0 a
10% Oxygen	57.0 ± 1.2 a	71.8 ± 1.0 a
5% Oxygen	59.9 ± 0.9 a	69.3 ± 1.2 a
0% Oxygen	58.6 ± 1.2 a	72.0 ± 0.9 a
18 days after storage		
Control (Air)	55.1 ± 1.3 a	61.9 ± 1.7 b
10% Oxygen	57.1 ± 0.8 a	66.4 ± 1.7 ab
5% Oxygen	55.8 ± 0.8 a	69.8 ± 1.2 a
0% Oxygen	55.5 ± 2.5 a	69.1 ± 1.3 a

[y] Values represent mean ± standard error.

[x] Mean separation within columns was by Least Significant Different test (LSD) at 5% level.

Discussion

Soliva-Fortuny and Martin-Belloso (2003) reported that atmosphere modification can substantially delay the growth of most aerobic spoilage microorganisms. However, under certain conditions, the growth of some anaerobic psychotrophic pathogens might be allowed or even stimulated, and excessively low O_2 levels are often detrimental to the fruits and vegetables shelf-life because anaerobic respiration is induced, leading to fermentation processes, and the subsequent production of undesirable metabolites. Aquino-Bolaños *et al*., (2000) described that reduction in the rate of browning of jicama tuberous root can be explained by modifications in the synthesis and/or degradation of phenolic compounds due to reduced oxygen concentrations or low temperatures.

As a result, jicama tuberous root after stored at 6℃ for 18 days and treated with different

concentrations of O_2 for another 3 days showed that browning of jicama tuberous root was significantly lower in low O_2 treated root. The best control of browning was observed in root treated with 0% O_2, whereas high decay was occurred in this treatment. Therefore, it is possible that reduced O_2 concentrations can reduce the rate of browning but under excessively low O_2 levels are often detrimental to the root because anaerobic respiration is induced, leading to fermentation processes, which cause decomposition of the jicama tuberous root. In addition, enzymatic browning is one of the most important reactions that occur in chilling injury of jicama tuberous root and resulting in negative effects on color such as internal browning. The reaction is a consequence of phenolic compounds' oxidation by PPO, which triggers the generation of dark pigments (Aquino-Bolaños *et al*., 2000; Aquino-Bolaños and Mercado-Silva, 2004). Thus, the reduction of internal browning in this study probably associated with PPO activity inhibited under low O_2 conditions.

Ion leakage percentage of low O_2 treated root was significantly higher than air control in both two observation times. This suggested that loss of membrane integrity not directly associated with browning discoloration of jicama tissue, but maybe associated with decay of jicama tuberous root. Low O_2 treatments also maintain root firmness, lightness values and delay weight loss of jicama tuberous root after storage. However, low O_2 atmospheres resulted in a loss of visual quality due to discoloration and decay in jicama tuberous root was found in the reported of Aquino-Bolaños *et al.*, (2000). Thus, suitability of O_2 levels is an important in treatments, which excessively low oxygen levels are often detrimental to the horticultural product. This result suggests that treatment with 5% O_2 is the best prevention the root from chilling injury symptoms.

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低氧處理對低溫貯藏後豆薯塊根低溫貯藏寒害症狀的影響

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關鍵字：豆薯塊根、寒害、低氧處理

摘要：豆薯塊根低溫貯藏後再以低氧處理評估減輕寒害之效果。實驗共四個氧氣濃度處理為完全逢機設計；對照組為空氣(氧氣濃度約為 21%，處理組的氧氣濃度為 10%、5%及 0% (100%氮氣)。豆薯塊根先貯藏於 6℃下 9 及 18 天後再移置室溫以低氧處理 3 天。結果顯示，豆薯塊根低氧處理後可減輕褐化及失重率，並維持明度，但不影響硬度。其中以 0%低氧處理防止褐化的效果最佳，但腐損程度嚴重，過度低氧處理(0%、100%氮氣)可能造成塊根細胞膜損傷，提高了離子滲漏及腐損率。

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