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Effects of Storage Methods on Quality Characteristics of Carrots Grown Under Organic and Conventional Management

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Abstract. *Based on health benefits, the demand for organic vegetables is sought by consumers in many parts of the world including Canada. Saskatchewan has the potential of producing high-quality organic vegetables cost-effectively and in a sustainable manner. Research is being undertaken at the Canada-Saskatchewan Irrigation Development Centre (CSIDC), Outlook, to develop efficient agronomic practices and storage management for producing high-quality vegetables under irrigation. This paper describes the interactive effects of field production and storage practices for Yaya carrots. Carrots grown under organic (2.5, 5.0, 7.5 cm swine compost, and no compost) and conventional (standard commercial practices) management, Controlled atmosphere (CA) and refrigerated storage were compared. The carrots were stored at a temperature of 4^{o}C and relative humidity of 92% to 94% for CA storage and 79% to 94% for* *refrigerated storage. For the CA storage, the set-points for CO_2 and O_2 were 5% and 3%, respectively. The moisture content, spoilage, total soluble solids, hardness, and color of the stored carrots were examined periodically. The carrot stored under CA conditions had less spoilage and moisture loss compared to the refrigerated carrots. The storage time did not affect total soluble solid content of the carrots stored under CA conditions. However the total soluble solid content of refrigerated carrots increased with storage time. The total soluble solids for the CA stored carrots ranged from 7.7 to 9.2 ^{o}Brix, and for the refrigerated stored carrots the values varied from 8.3 to 28.5 ^{o}Brix. There was no clear trend between storage time and the hardness of the carrots stored under the different conditions. The hardness for CA stored carrots ranged from 203.60 to 263.47 N, and the refrigerated carrots varied from 159.11 to 307.10 N. There was no clear trend on the redness of carrots over time when stored under CA conditions. However, the redness of carrots increased with storage time under refrigerated storage.*

Keywords. Carrots, controlled atmosphere, hardness, storage,

Introduction

Fruits and vegetables are becoming increasingly popular as a healthy diet for the prevention of heart disease, diabetes, obesity and certain cancers (van't Veer et al., 2000). Organic vegetables is one such alternative sought by consumers in many parts of the world including Canada, Organic vegetable sector is the most rapidly expanding sector in the horticultural industry in North America. Saskatchewan is well positioned to compete effectively in the organic vegetable market. Saskatchewan's competitive advantages include low land cost, extensive water resources and irrigable land, less disease incidence due to low relative humidity, and accessibility to North American market.

The crop production season is relatively cool and short in Saskatchewan. Vegetable production generally occurs between May and September. The harvested produce has to be stored appropriately to prolong shelf life and retain quality and nutritive characteristics. It is not known organic vegetables will respond to storage conditions in comparison to conventionally grown vegetables.

Fresh harvested vegetables may be cooled and be stored below zero (frozen) or above zero (chilled) conditions to reduce biochemical, physical and microbial degradation and maintain the quality of the products. Biochemical and physical changes are inevitable and continue after the products have being harvested. Microbial contamination of the product may occur during growing and harvesting, and may be introduced to storage. Biochemical, physical, and microbial activities in the stored product should be minimized in order to prolong the shelf-life during storage. After harvesting the vegetables should be stored to ensure continuous availability until the next harvesting season. Vegetables continue to respire after harvest and this process requires oxygen. Controlling the storage atmosphere by reducing oxygen and increasing carbon dioxide levels may slow down the metabolic rate and thereby reduce biochemical and physical degradation of the product.

Controlled atmosphere (CA) may be used synergistically with chilled storage to extend the shelf-life and maintain the nutritive value of vegetables by further reducing biochemical and microbial activities during storage (Yackel et al., 1971; Harvey, 1978; Ke and Kader, 1992; Paradis et al., 1996; Lopez-Galvez et al., 1996; Sanchez-Mata et al., 2003). In controlled atmosphere storage, the composition of the gases surrounding the product is automatically controlled throughout the storage life of the product (Jayas and Jeyamkondan, 2002). Controlled atmosphere storage studies on vegetables and fruits have been conducted by researchers (Yackel et al., 1971; Robinson et al., 1975; Ke et al., 1990; Carlin et al., 1990; Luo and Mikitzel, 1996; Hurst et al., 1997; Gil et al., 1997). Yackel et al. (1971) studied the effect of CA and air storage on mold growth in fruit. The fruit were stored at 1^{o}C, in a controlled atmosphere of 10.5% CO_2 and 2.0% O_2. They found less mold in the CA storage compared to air storage. Luo and Mikitzel (1996) examined the effect of controlled atmosphere and air storage on decay, weight loss, color and soluble solids content of green bell peppers. They found that after 2 weeks of storage, the air-stored peppers had 33% decay compared to 9% for the CA-stored peppers. CA storage retained color better than air-stored pepper.

The present project, conducted at the Canada-Saskatchewan Irrigation Diversification Centre, is a preliminary investigation designed to study (i) the feasibility of growing vegetables cost effectively and in a sustainable manner using organic management practices, and (ii) develop storage management practices to extend shelf life while maintaining nutritive and quality characteristics.

This paper summarizes the effects of CA and refrigerated storage on quality characteristics (hardness, color, total soluble solids and moisture content) of carrot grown under organic and conventional management.

Material and Methods

Field Production

Carrots (cv. Yaya) grown under organic and conventional management were used in this study. The organic production treatments 2.5 cm, 5.0 cm, and 7.5 cm swine compost and no compost (Control). The conventional treatment included 100 kg N/ha, 100 kg P_2O_5/ha, and 100 kg K_2O/ha of fertilizer applied at planting. The carrots were grown under drip irrigation conditions. Mature carrots were harvested in the fall and went into storage immediately after harvest. The carrots went into storage on October 10, 2008 and the study was terminated on February 23, 2009.

Controlled Atmosphere Equipment

A research-scale controlled atmosphere (CA) storage equipment obtained from Horticultural Research and Development Center, Saint-Jean-sur-Richelieu, Quebec was installed at the Canada-Saskatchewan Irrigation Diversification Centre (CSIDC), Outlook, Saskatchewan. The CA equipment consists of personal computer, data acquisition system, gas analyser, thermocouples, solenoid valves, rigid plastic mini-chambers, expansion bag, CO_2 scrubbers and gas (N_2, CO_2 and compressed air) cylinders. Detailed description of this CA storage equipment is provided by Goyette et al. (2002). Figure 1 shows the carrots in the CA storage chamber at the CSIDC.

Storage Procedure

The mini-chambers were washed and disinfected before placing carrots in storage. A corrugated plastic piece was placed at the bottom of the chamber and a perforated plastic plate was placed on top of the chamber. A ventilating pipe was inserted through a hole in the perforated plate. Carrots were placed on top of the plate. About 500 ml of water was added to the chamber for maintaining humidity. The chamber was covered with a Plexiglas lid and tightened with C-Clamps. Plastic tubes for supplying gases were connected to the cover. Thermocouples were inserted to measure the temperature in the chambers. Water was poured onto of the cover to seal the chamber from the surrounding air.

The set-points for CO_2 and O_2 were 5% and 3%, respectively. Each chamber was manually flushed with pure N_2 for 5 min. followed by injecting CO_2 for 20 s. The control software was started to control the injection of N_2 and compressed air. Excess CO_2 was circulated through the scrubber was absorbed by soda lime. The CA chambers were placed in a refrigerated storage room that was maintained at a temperature of 4^{o}C and relative humidity between 79.2 to 94.0%.

The carrots were thoroughly washed with water before placing them in sampling bags and in CA storage chambers. Carrots were also stored in the same cooler under normal refrigerated conditions. The carrots were weighed before placing them in the chambers and when they were removed from storage. The combined weights of flaccid or spoilt carrots were noted as spoilage. The total soluble solid content, hardness, color and moisture content of the carrots were determined periodically.

Moisture content

The moisture content of the top and the bottom portion of the carrots were determined after drying at 103^{o}C for 24 h in a forced convection oven. Average weight of the two portions is presented as moisture content of the whole carrot.

Total soluble solids content

Total soluble solids of the carrots were determined by using a digital refractometer (Pocket Refractometer PAL-2, ATAGO Company, Limited, Tokyo, Japan). The carrots were ground in a blender and the juice was squeezed onto the refractometer using a garlic press. Three measurements were taken from each sample.

Hardness

The hardness or crispness of the carrots was measured using a texture analyzer (Texture Technologies Corp., Scarsdale, NY). A cylindrical (12.5 mm diameter x 10 mm height) sample was cored from the central portion of a carrot, along the vascular bundle. A test speed of 1 mm/s was used and a sample was compressed to about 50% of its height. The peak force was used as a measure of the hardness of the carrots.

Color parameters

The color of the samples was measured using Hunterlab Color Analyzer (Hunter Associates Laboratory Inc., Reston, VA, U.S.A.). The chromaticity of stored carrots was determined by measuring their respective ‘L’, ‘a’, and ‘b’ coordinates. A carrot was cut into half perpendicular to its length. The color of the cut surface was measured. The ‘L’ values range from minimum ‘L’ which is zero (black) to maximum ‘L’ which is 100 (white). Positive ‘a’ value is red and negative value is green. Also, positive ‘b’ value is yellow and negative ‘b’ is blue. After initial calibration against standard black and white surface plates, four measurements were taken from each sample. Color delta values, ΔL, Δa and Δb, were calculated according to the following equations:

$$\Delta a = a - a_t \quad (1)$$

where ‘L’, ‘a’, and ‘b’ are the measured values of the specimen and L_t, a_t, b_t are values of the target color. The target colors in this experiment are ‘L’, ‘a’, and ‘b’ of the fresh carrots before storage, taken on October 10, 2008 for the CA stored carrots and on November 7, 2008 for refrigerated samples. For the ∆a, a positive value indicates the sample is redder than the target or standard sample and a negative value indicates that the sample is lighter than the target. The total color difference (ΔE) was calculated using the L, a, b color coordinates and as defined by the Equation 4 (Maruyama et al. 2001).

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \qquad (2)$$

Results and Discussion

Moisture content of stored carrots

The moisture content of the carrots during the storage period when stored under CA and refrigerated storage are presented in Table 1. The moisture content of the carrots stored in the CA did not change with time in storage. However, the moisture content of the refrigerated carrots decreased with time of storage. The relative humidity measured inside the CA chambers ranged from 92% to 94%, however the relative humidity under refrigerated conditions varied from 79% to 94%. The low relative humidity under the refrigerated storage might have contributed to the decrease in moisture content of the carrots with time.

The percentage weight change (loss or gain) and the percentage spoilage during the storage of the carrots are presented in Table 2. No appreciable weight change was observed for carrots stored under CA conditions during the storage period. By contrast, significant moisture loss was observed for carrots stored under refrigerated conditions. Carrots treated with swine compost showed less spoilage than the carrots that did not receive any compost, i.e. conventional or control, during the whole storage period. As observed on December 12, the conventional carrots stored under CA conditions had the highest spoilage, whereas, the carrots treated with swine compost and stored under CA did not show any spoilage. On January 19, under refrigerated storage, conventional and control carrots had 100.0% spoilage. Whereas the manure treated carrots were either flaccid and/or spoiled on February 23, 2009. Figure 2 shows the refrigerated and CA stored carrot samples as seen on February 23. Istella et al. (2006) stored different varieties of carrot at temperatures of 4 – 10^{o}C and relative humidity of 85% - 90% in unsealed polyethylene bags. They reported that at the end of 112 days of storage the percentage weight loss ranged from 15% to 35% depending on the carrot variety and the dry matter had increased in all varieties.

Total soluble solids

The total soluble solid contents of the stored carrots are presented in Table 3. The carrot samples stored under CA conditions did not show any significant change in the total soluble content with storage time. Conversely, the total soluble solid content of the refrigerated carrot increased with storage time. The longer the storage time, the increment in the total soluble solid content became higher. The total soluble solids for the CA stored carrots ranged from 7.7 to 9.2 ^{o}Brix, and for the refrigerated stored carrots the values varied from 8.3 to 28.5 ^{o}Brix. Sandhu et al. (1988) reported total soluble solids for carrots ranging from 8.46 to 9.98 ^{o}Brix.

Hardness of the stored carrots

The hardness of the carrot samples with storage time is summarized in Table 4. The hardness for CA stored carrots ranged from 203.60 to 263.47 N, and the refrigerated stored carrots varied from 159.11 to 307.10 N. Bourne and Comstock (1981) determined the hardness of raw carrots and reported a hardness value of about 212.5 N for a sample size of 10.0 mm cube for a 50% degree of compression. Budrewicz et al. (2005) also reported the hardness of different varieties of carrot which ranged from 146.83 to 304.75 N for 10.0 mm cubes with 50% degree of compression.

The hardness of the stored carrots did not show any clear trend with storage time and this may probably due to the fact that the core samples used in these tests consisted of vascular bundles which are mainly fibrous strands. The fibrous vascular bundle probably did not degrade with storage time producing no consistent change in hardness with time.

Color characteristics of the stored carrots

The change in color of the stored carrots with time is presented in Table 5. The color change for some of the CA stored or refrigerated carrots did not show any consistent trend with time of storage, except with 7.5 cm manure, where the redness decreased with time under CA storage and the redness increased with time under refrigerated storage.

Conclusions

1. The carrots stored under CA conditions had less spoilage and moisture loss compared to the refrigerated carrots.
2. The storage time did not affect the total soluble solid content of the carrots stored under CA conditions. However the total soluble solid content of refrigerated carrots increased with storage time. The total soluble solids ranged from 7.7 to 9.2 ^{o}Brix for CA stored carrots, and from 8.3 to 28.5 ^{o}Brix for the refrigerated carrots.
3. There was no clear trend between storage time and the hardness of the carrots stored under different conditions. The hardness for CA stored carrots ranged from 203.60 to 263.47 N, and the refrigerated stored carrots varied from 159.11 to 307.10 N.
4. There was no clear trend between color change and time of storage carrots stored under CA conditions. The redness of carrots increased with storage time for refrigerated carrots.

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Figure 1. Controlled atmosphere storage of carrots.

(a) Refrigerated stored carrots

(b) CA stored carrots

Figure 2. Refrigerated and CA stored carrots: February 23, 2009.

Table 1. Average moisture content of carrot during storage as influenced by growing methods and storage type

Storage type	Growing condition	Moisture content (%, wet basis)				
		Oct 10, 2008	Nov 7, 2008	Dec 12, 2008	Jan 19, 2009	Feb 23, 2009
CA	Conventional	88.70 (1.33)	88.87 (1.65)	88.76 (1.13)	89.90 (1.34)	89.77 (1.15)
CA	Control	89.33 (1.57)	89.25 (1.22)	89.87 (0.77)	90.02 (0.90)	89.76 (0.75)
CA	2.5 cm manure	89.61 (1.16)	89.29 (1.46)	88.25 (1.99)	90.18 (0.86)	89.90 (1.13)
CA	5.0 cm manure	89.20 (2.10)	89.18 (1.63)	88.25 (1.35)	90.10 (1.02)	89.93 (1.20)
CA	7.5 cm manure	89.28 (1.71)	89.71 (1.71)	89.70 (1.15)	90.51 (1.09)	89.35 (0.90)
Refrigerated	Conventional	-	88.83 (1.19)	86.09 (1.62)	83.03 (2.08)	-
Refrigerated	Control	-	89.73 (1.36)	86.54 (1.69)	82.84 (0.74)	-
Refrigerated	2.5 cm manure	-	89.04 (1.73)	87.26 (1.13)	86.55 (1.12)	69.39 (2.01)
Refrigerated	5.0 cm manure	-	88.98 (1.24)	88.12 (1.11)	86.26 (0.70)	66.53 (3.51)
Refrigerated	7.5 cm manure	-	89.58 (1.25)	87.36 (1.36)	86.04 (1.91)	72.72 (1.75)

Values within parentheses are standard deviation.

Table 2. Percentage weight change and spoilage of carrot during storage as influenced by growing methods and storage type

Storage type	Growing condition	Percentage weight change (%)				Percentage spoilage (%)		
		Nov 7	Dec 12	Jan 19	Feb 23	Dec 12	Jan 19	Feb 23
CA	Conventional	0.14	-0.29	2.62	-0.85	8.82	34.72	27.65
CA	Control	6.27	0.00	1.42	-1.19	3.90	1.60	1.69
CA	2.5 cm manure	1.99	0.21	2.06	-2.07	0.00	0.60	1.40
CA	5.0 cm manure	3.48	0.09	2.19	-1.81	0.00	0.00	0.00
CA	7.5 cm manure	1.70	0.08	2.07	-2.55	0.00	0.00	2.84
Refrigerated	Conventional		27.18	49.34		8.75	100.00	
Refrigerated	Control		29.83	54.08		5.11	100.00	
Refrigerated	2.5 cm manure		17.91	37.90	54.68	0.60	72.39	100.00
Refrigerated	5.0 cm manure		14.64	34.24	56.63	0.43	66.18	100.00
Refrigerated	7.5 cm manure		15.12	30.57	52.55	1.78	56.41	100.00

- Sign indicates weight gain.

Table 3. Average total soluble solids of carrot during storage as influenced by growing methods and storage type

Storage type	Growing condition	Total soluble solids (^oBrix)				
		Oct 10, 2008	Nov 7, 2008	Dec 12, 2008	Jan 19, 2009	Feb 23, 2009
CA	Conventional	8.8 (0.3)	9.1 (0.4)	8.8 (0.3)	9.3 (0.7)	8.5 (0.8)
CA	Control	7.7 (0.7)	8.8 (0.3)	7.9 (0.3)	9.0 (0.3)	8.3 (0.4)
CA	2.5 cm manure	8.0 (0.4)	8.6 (0.6)	9.4 (1.4)	8.8 (0.3)	8.4 (0.6)
CA	5.0 cm manure	8.0 (0.6)	8.9 (1.2)	9.2 (0.6)	8.9 (0.6)	8.2 (0.7)
CA	7.5 cm manure	8.0 (0.1)	8.4 (0.5)	7.9 (0.5)	8.6 (0.2)	8.3 (0.4)
Refrigerated	Conventional	-	9.4 (0.6)	11.2 (1.4)	17.0 (2.0)	-
Refrigerated	Control	-	8.5 (0.7)	11.1 (2.0)	16.7 (0.6)	-
Refrigerated	2.5 cm manure	-	9.3 (1.6)	10.3 (1.9)	13.2 (0.2)	25.9 (2.7)
Refrigerated	5.0 cm manure	-	9.2 (0.9)	10.2 (0.9)	13.9 (0.4)	28.5 (2.4)
Refrigerated	7.5 cm manure	-	8.3 (0.5)	9.9 (0.5)	13.9 (2.5)	23.7 (0.6)

Values within parentheses are standard deviation.

Table 4. Average hardness of carrot during storage as influenced by growing methods and storage type

Storage type	Growing condition	Hardness (N)			
		Nov 7, 2008	Dec 12, 2008	Jan 19, 2009	Feb 23, 2009
CA	Conventional	243.93 (30.47)	248.46 (28.57)	226.32 (35.58)	259.55 (37.48)
CA	Control	243.94 (60.70)	211.24 (29.23)	219.28 (75.94)	238.10 (46.58)
CA	2.5 cm manure	219.04 (31.54)	263.47 (17.02)	203.60 (42.89)	204.97 (23.88)
CA	5.0 cm manure	227.34 (36.18)	256.21 (22.34)	206.51 (25.94)	216.28 (15.76)
CA	7.5 cm manure	231.44 (30.53)	234.01 (42.59)	226.93 (31.74)	216.26 (68.79)
Refrigerated	Conventional	256.93 (75.59)	247.69 (69.64)	264.72 (46.05)	-
Refrigerated	Control	237.46 (47.56)	232.68 (23.57)	294.70 (31.56)	-
Refrigerated	2.5 cm manure	243.40 (27.81)	272.84 (27.12)	280.61 (43.26)	159.11 (65.52)
Refrigerated	5.0 cm manure	255.05 (31.48)	257.73 (35.81)	284.91 (54.44)	301.10 (90.09)
Refrigerated	7.5 cm manure	245.52 (30.02)	272.01 (25.12)	201.22 (104.12)	243.30 (58.16

Values within parentheses are standard deviation.

Table 5. Color change of carrot during storage as influenced by growing methods and storage type

Storage type	Carrot sample	Stored carrots color change							
		Δa				ΔE			
		Nov 7	Dec 12	Jan 19	Feb 23	Nov 7	Dec 12	Jan 19	Feb 23
CA	Conventional	-3.31	1.55	1.88	0.64	3.53	3.96	2.48	2.08
CA	Control	0.99	-0.57	3.71	0.02	1.16	1.13	3.75	1.42
CA	2.5 cm manure	-2.10	-1.80	-0.45	-0.47	2.80	3.31	2.44	1.50
CA	5.0 cm manure	0.74	0.29	4.81	3.34	1.93	3.83	6.45	4.38
CA	7.5 cm manure	0.66	-3.23	-1.17	-0.82	3.44	3.44	1.79	1.49
Refrigerated	Conventional		-0.71	3.78			4.73	6.74	
Refrigerated	Control		0.04	3.27			4.83	4.56	
Refrigerated	2.5 cm manure		-0.92	0.54	2.15		1.47	1.72	3.35
Refrigerated	5.0 cm manure		2.11	3.30	5.20		4.68	3.86	7.20
Refrigerated	7.5 cm manure		2.19	1.52	8.19		2.58	4.64	9.81