International Journal of Animal Breeding and Genetics Vol. 4 (6), pp. 001-010, June, 2015. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Physiological and chemical quality of carrots subjected to pre-and postharvest treatments

T. S. Workneh[1]*, G. Osthoff[2] and M. S. Steyn[2]

[1]School of Bioresources Engineering and Environmental Hydrology, Faculty of Engineering, University of Kwa-Zulu Natal, Private Bag X0l, Scottsville, 3209, Pietermaritzburg, South Africa. [2]Department of Microbial, Biochemical and Food Biotechnology, University of the Free State, P. O. Box 9300, Bloemfontein, South Africa.

Accepted 22 April, 2015

Quality changes in preharvest ComCat® treated and untreated control carrots stored at 1 ± 0.5°C and ambient temperatures (16.7 to 29.5°C) and relative humidity (31 to 68%) were studied for more than 4 weeks. The carrots were analysed for headspace gases (O_2, CO_2, and N_2), total soluble solids (TSS), ascorbic acid (AA) content, and peroxidase (POX) activity. The effect of chlorinated and anolyte water disinfecting treatments coupled with MAP was investigated. ComCat® treated carrots had higher TSS at harvest. TSS content was better maintained during storage in preharvest treated carrot. The preharvest ComCat® treatment had no significant effect on AA content and POX activity of carrots during storage, although it had slightly higher AA at harvest. During storage, these treatments when coupled with MAP which also had significant effects on TSS content of carrots. Disinfecting carrots in anolyte water significantly maintained the AA content and decreased the level of POX activity. The combined effect of pre-and postharvest treatments such as ComCat®, disinfecting, packaging and low temperature storage treatments had a significant positive effect on maintaining postharvest quality and improvement of the shelf-life of carrots.

Key words: ComCat®, disinfection, packaging, storage, refrigeration, pre-harvest treatment.

INTRODUCTION

Horticultural commodities are different from other foods with their high levels of respiration and other metabolic processes associated with maturation, ripening, and senescence after harvest. During development and storage, carrots undergo a complex series of physiological, biochemical and microbiological events involving changes in postharvest quality (Phan et al., 1973; Nilsson, 1987; Hole and McKee, 1988; Rosefeld et al., 1998; Suojala, 1999; Suojala, 2000). During storage, levels of O_2 and CO_2 are critical for carrot quality. With the use of modified atmosphere packaging (MAP), metabolic activities may be reduced by controlling the levels of O_2 and CO_2 in packages of fresh commodities (Zagory and Kader, 1988). Temperature and relative humidity are other important factors that affect the quality and shelf life (Seyoum, 2010, Tigist et al., 2011, Workneh et al. 2010 and 2011).

*Corresponding author. E-mail: Seyoum@ukzn.co.za

Low temperature reduces the rate of respiration and biochemical activities, which are responsible for quality changes of carrots (Zagory and Kader, 1988). The respiration rate of carrots can be lowered by preharvest treatments leading to longer shelf-lives (Salunkhe et al., 1971). The preharvest histories of vegetables are therefore very important, as fresh produce is responding differently to postharvest factors. A preharvest treatment, ComCat® from plant extracts, improves vegetable yield, general strength and development of plants, and activates inherent plant defence mechanisms via induced resistance (Hüster, 2001). ComCat® is a natural biocatalyst, which is extracted from seeds of plants and mainly consists of amino acids, gibberellin, kitenins, auxin (indole-3-acitic acid), brassinosteroids, natural metabolites, pathogen-related (PR) - proteins with defence reactions, terpenoids, flavonoids, vitamins, inhibitors, other signal molecules, biocatalysts and cofactors.

In a study carried out in South Africa, the preharvest ComCat® treatment was shown to increase carrot yield

by 32% (Schnabl et al., 2001). ComCat® could also be an alternative to other agrochemicals such as fertilizers, as it is required in low doses and it is also environmentally and ecologically friendly. Investigation on quality of ComCat® treated carrots both at harvest and during storage is yet to be explored. The objectives of this study were to investigate the storage physiology and selected quality, of preharvest ComCat® treated carrots using MAP at 1°C and ambient temperature.

MATERIALS AND METHODS

Carrot production

Carrots were planted in the Bloemfontein area, South Africa. During the growing period, carrots were treated twice with ComCat®. Experimental plants were treated with 10 g ha^{-1} ComCat® in 350 L of water, and control plants with 0 g ha^{-1}. Carrots were sprayed once at the three leaves stage, and a second time at a vegetative stage. All other agricultural practices were kept the same between the treatments during carrot production. At a maturity stage of 5 months, carrots were harvested and topped in the field, and were immediately transported to the vegetable laboratory of the University of Free State. The topping, harvesting and transportation of carrots were made early in the morning before the temperature was too high.

For protection against mechanical injury during transportation, carrots were packed in plastic crates. ComCat® treated and untreated carrots were harvested manually from four randomised blocks. Carrots free of blemishes or defects were selected and topped by carefully retaining the crown of the root. The working surfaces and all tools were washed and disinfected prior to use by 1% Chlorobac (Syndachem, Pty, LTD). The carrots were hand washed with water at a temperature of 4°C, to remove field heat and soil particles and to reduce surface microbes. Disinfecting treatments and packaging of carrots were performed on the same day.

Postharvest treatment

After washing, a total amount of 144 kg ComCat® treated carrots were subdivided into three groups of 48 kg each, in preparation for dipping treatments in chlorinated water, anolyte water or tap water, at 4°C. Plastic containers were washed, disinfected and rinsed with distilled water prior to use for the dipping treatments. Plastic containers were used to avoid losses of charged ions from anolyte water to metal containers. Tap water in these plastic containers was adjusted to 100 μg ml^{-1} free chlorine with sodium hypochlorite (5% NaOCl). A 20 min dipping time in 100 μg ml^{-1} chlorine supplemented water solutions was selected, as this was reported to be the optimum effective dipping time without significant effect on the overall quality of vegetables (Nunes and Emond, 1999). The free chlorine was determined using a test kit from Hach (Model CN-66; USA). The temperature was maintained at 4°C during the measurements of free chlorine.

Anolyte water was prepared electrochemically from saline water containing 5% NaCl with an ionyzer (Radical Waters Pty Ltd, South Africa) operating at a pressure of 50 kpa. The pH of anolyte water was adjusted to 6.1 and it contained 3.55% total dissolved solids. Immediately after preparation, anolyte water was cooled to 4°C, and carrots were dipped without delay to avoid loss of inhibitory characteristics. The optimum dipping time of carrots in anolyte water was determined as 5 min in a trial experiment where carrots were dipped in anolyte water for 5, 10, and 20 min and compared with the efficacy of 20 min dipping in chlorinated water (100 μg ml^{-1}) on microorganisms (Seyoum et al., 2002). Carrots were dipped for 20 min in tap water.

Modified atmosphere packaging

Low-density polyethylene (LDPE) bags were the preferred packaging film over polypropylene (PP) for storage at 1°C (Seyoum et al., 2001). Other researchers recommend micro-perforated LDPE for MAP of carrots and tomatoes (Lipton, 1977; Seyoum et al., 2001). In this study, the micro-perforated bags specifically designed and manufactured for carrot and tomato storage were used (Xtend® Film, Patent No. 6190710, StePac L.A., Ltd., Israel). Carrots were subdivided and packaged as 1 kg samples, and stored at 1°C or room temperature. The unpackaged 1 kg sample carrots, for each treatment combination, were placed in perforated plastic bags and left open during storage at 1°C or room temperature.

On each sampling date, packages of carrots (1 kg each) were randomly taken in triplicate from each treatment for quality analyses. A new package was taken each time in order to maintain the microenvironment and avoid contamination through repeated opening and sealing.

Gas sampling and analysis

Micro atmosphere gas analysis was performed at days 0, 3, 5, 9, 17, 25 and 32 of the storage period. Gas samples were withdrawn from the package by piercing the test film with a pressure lock syringe (Precision Sampling Crop, Baton Rouge, Louisiana) with a fine needle and withdrawing a 5 ml gas sample (Ballantyne et al., 1988 a, b; Gunes et al., 1997; Jeon and Lee, 1999). At each sampling date, three packages from each storage condition were tested.

CO_2, O_2 and N_2 concentrations were analysed by gas chromatography (GC) on a Varian 3300 equipped with a Porapak Q 1.2 m X 2.3 mm stainless steel column, with thermal conductivity detection at 200 mA and H_2 as carrier at 19.5 ml min^{-1} flow rate for CO_2 determination. For analysis of N_2 and O_2, a 0.8 m Molsieve column (PHASE SEP.) was used, with thermal conductivity detection operated at 200 mA and H_2 as carrier at 12.5 ml min^{-1}. The GC oven temperature was set at 45°C for both analyses. The opening made by the needle during gas sampling was immediately sealed with drawing tape, to avoid leaking of gas from the packages.

Total soluble solids (TSS)

The TSS was determined using the procedures as described by Waskar et al. (1999). An aliquot of juice was extracted using a Kenwood juice extractor, and 50 ml of the slurry was centrifuged for 15 min at 5000 x g at 4°C. The TSS was determined by an Atago N1 hand refractometer with a range of 0 to 32°Brix, and resolutions of 0.2°Brix by placing 1 to 2 drops of clear juice on the prism. Between samples the prism of the referactrometer was cleaned with tissue paper soaked in methanol, washed with distilled water and dried before use. The refractometer was standardised against distilled water (0% TSS).

Ascorbic acid analysis (AA)

The AA of carrots was determined by the 2, 6–dichloro-phenolindophenol method (AOAC, 1970). An aliquot of 10 ml carrot juice extract was diluted to 50 ml with 3% metaphosphoric acid in a volumetric flask. An aliquot was centrifuged at 10 000 x g for 15 min and titrated with the standard dye to a pink end-point (persisting for

Table 1. Changes in total soluble solid (°Brix) of carrots subjected to both pre- and postharvest treatment and stored at 1°C and room temperature for 28 days.

Treatment		Storage period (days)			
Preharvest	**Postharvest**	**0**	**14**	**21**	**28**
ComCat®	Cl_2, MAP, 1°C	9.7 ^{a}	9.2 ^{ef}	9.9 ^{cd}	9.7 ^{f}
	Anolyte, MAP, 1°C	9.7 ^{a}	9.5 ^{ef}	9.2 ^{de}	9.3 ^{fg}
	Cl_2, MAP, RT	9.7 ^{a}	10.4 ^{cd}	10.7 ^{bc}	12.1 ^{abc}
	Anolyte , MAP, RT	9.7 ^{a}	10.2 ^{cd}	10.8 ^{b}	12.5 ^{ab}
	H_2O, MAP, 1°C	9.7 ^{a}	9.7 ^{ef}	8.9 ^{de}	9.5 ^{f}
	H_2O, MAP, RT	9.7 ^{a}	9.9 ^{cde}	10.1 ^{bcd}	11.3 ^{cd}
	H_2O, 1°C	9.7 ^{a}	10.4 ^{cd}	11.0 ^{ab}	11.6 ^{bc}
	H_2O, RT	9.7^{a}	12.9 ^{a}	-	-
Control (0 ComCat®)	Cl_2, MAP, 1°C	8.8 ^{ab}	9.2 ^{ef}	9.5 ^{cd}	9.7 ^{f}
	Anolyte , MAP, 1°C	8.8 ^{ab}	9.3 ^{ef}	8.9 ^{de}	9.8 ^{f}
	Cl_2, MAP, RT	8.8 ^{ab}	10.3 ^{cd}	10.1 ^{bcd}	11.3 ^{bc}
	Anolyte , MAP, RT	8.8 ^{ab}	9.6 ^{ef}	10.6 ^{bc}	11.5 ^{bc}
	H_2O, MAP, 1°C	8.8 ^{ab}	9.1 ^{ef}	9.4 ^{cd}	9.3 ^{fg}
	H_2O, MAP, RT	8.8 ^{ab}	9.9 ^{cde}	10.2 ^{bcd}	10.8 ^{cde}
	H_2O, 1°C	8.8 ^{ab}	12.3 ^{ab}	12.0 ^{a}	13.1 ^{a}
	H_2O, RT	8.8 ^{ab}	12.5^{ab}	--	-
Significance					
Preharvest treatment (A)			NS		
Disinfecting + MAP (B)			***		
Storage temperature (C)			***		
A X B			NS		
A X C			**		
B X C			NS		
AXBXC			NS		

NS, **, *** Nonsignificant or significant at P≤ 0.01 or 0.001 respectively. Means within a column followed by the same letter(s) are not significantly different according to Duncan's multiple range test (P < 0.05). The LSD Value = 1.104, S.E. = 0.133, MSE = 0.466 and C.V. = 0.067. Cl_2, chlorinated water; MAP, modified atmosphere packaging; RT, room temperature.

15 s). AA (%) was calculated from the titration value, dye factor, dilution and volume of the sample.

Peroxidase activity (POX)

Carrot tissue (12.5 g) was homogenised in 25 ml of citrate-phosphate buffer (pH 6.5) (made with 0.05 M citric acid and 0.1 M Na_2HPO_4) for 2 min (Howard et al., 1994). The homogenate was held at 4°C for 2 h and centrifuged at 10 000 X g for 15 min at 4°C. Prior to POX activity determination, a reaction mixture was prepared by adding 0.05 ml of 1% o-dianisidine dye in methanol to 6 ml of 30% H_2O_2 substrate.

Then 2.9 ml of this dye-substrate mixture was transferred to a 3 ml test cuvette. Enzyme supernatant (0.1 ml) was introduced into the test cuvette from a 0.1 ml pipette with the tip below the surface. The control consisted of the same reaction mixture, but with 0.1 ml extraction buffer instead of enzyme extract. The cuvettes were covered with parafilm, and the solution mixed by inversion. The rate of peroxidase activity was followed spectrophotometrically at 460 nm (Howard et al., 1994). The increase in absorbency was recorded at 15 s intervals for 2 min. POX activity was expressed as increase in absorbancy at 460 nm g^{-1} tissue min^{-1} at 25°C.

Experimental design and data analysis

A factorial randomised complete block design (RCBD) experiment with 2 preharvest treatments, 3 prepackaging disinfecting treatments, 2 storage temperatures and 3 replications was used. A pack of carrots were taken randomly from each treatment group on each sampling day and used for the different quality analyses. Statistical differences between the treatments were determined by analysis of variance (ANOVA) with an MSTAT-C software package (MSTAT, Michigan State Univ., East Lansing) and multiple comparison of the treatment means by Duncan's multiple range test (Duncan, 1955).

RESULTS

Total soluble solid (TSS)

Table 1 displays the changes in TSS of carrots subjected to different pre- and postharvest treatments. The TSS significantly increased with storage time (P ≤ 0.001) and

Table 2. Changes in ascorbic acid content (mg 100^{-1} g FW) of carrots subjected to both pre and postharvest treatment and stored at 1°C and room temperature (RT) for 28 days.

Treatment		Storage period (days)				
Preharvest	**Postharvest**	**0**	**7**	**14**	**21**	**28**
ComCat®	Cl_2, MAP, 1°C	10.5 ^{a}	10.1 ^{a}	9.8 ^{a}	8.5 ^{abc}	9.0 ^{ab}
	Anolyte, MAP, 1°C	10.5 ^{a}	9.9 ^{a}	10.0 ^{a}	9.4 ^{a}	9.6 ^{a}
	Cl_2, MAP, RT	10.5 ^{a}	8.0 ^{cde}	8.0 ^{de}	5.9 ^{de}	3.9 ^{de}
	Anolyte, MAP, RT	10.5 ^{a}	9.5 ^{ab}	9.4 ^{ab}	7.0 ^{bc}	4.2 ^{d}
Control (0 ComCat®)	Cl_2, MAP, 1°C	9.6 ^{ab}	9.2 ^{ab}	9.2 ^{ab}	8.1 ^{bcd}	7.9 ^{bc}
	Anolyte, MAP, 1°C	9.6 ^{ab}	9.7 ^{a}	8.7 ^{ab}	9.0 ^{ab}	8.8 ^{ab}
	Cl_2, MAP, RT	9.6 ^{ab}	8.5 ^{bcd}	8.4 ^{cd}	6.2 ^{cde}	2.8 ^{e}
	Anolyte, MAP, RT	9.6 ^{ab}	8.9 ^{ab}	8.6 ^{ab}	6.8 ^{cd}	4.0 ^{d}
Significance						
Preharvest treatment (A)			NS			
Disinfecting (B)			*			
Storage temperature (C)			***			
A X B			NS			
A X C			NS			
B X C			NS			
AXBXC			NS			

NS, *, *** Nonsignificant or significant at P 0.05 or 0.001 respectively. Means within a column followed by the same letter(s) are not significantly different according to Duncan's multiple range test (P < 0.05). The LSD value = 2.065, S.E. = 0.252, MSE = 1.610 and C.V. = 0.150. Cl2, chlorinated water; MAP, modified atmosphere packaging; RT, room temperature.

temperature in all samples. Individually, MAP highly influenced the changes in the TSS contents of carrots stored at 1°C and room temperature (P ≤ 0.001). TSS increased at a lower rate in packaged versus unpackaged carrots. Storage temperature also had a highly significant (P ≤ 0.001) effect on the changes in TSS content of carrots during storage.

As shown in Table 1, the TSS content increased faster and to higher levels in carrots stored at room temperature than at 1°C. At harvest and 28 days later, the ComCat® treated carrots had no significant higher TSS than control carrots. The group mean differences in TSS of ComCat® treated and untreated carrots were 0.467, 0.228, 0.142, and 0.339°Brix for 0, 14, 21 and 28 days of storage, respectively (P > 0.05). The two-way interaction between preharvest ComCat® treatment and storage temperature was significant (P ≤ 0.01) on the changes in TSS content of carrots during storage. The three-way interaction between preharvest ComCat® treatment, disinfecting together with packaging and storage temperature was only approaching significance at P ≤ 0.096.

Ascorbic acid content

The decrease in AA content of carrots in the course of storage was highly dependent (P ≤ 0.001) on the storage temperatures (Table 2). The rate of reduction with the progression of storage time at 1°C was not significant (P > 0.05). Disinfecting treatment significantly affected (P ≤ 0.05) the AA content of carrots during storage. The AA content of carrots dipped in chlorinated water decreased and remained lower during the storage period at both temperatures than in carrots dipped in anolyte water. The decrease in AA content of carrots dipped in either chlorinated or anolyte water was higher during storage at room temperature than at 1°C. The ComCat® treated carrots had approximately 0.5 mg 100^{-1} g more ascorbic acid at harvest and was higher than the control carrots 28 days later but not significant (P > 0.05). The interactive effect of pre- and postharvest treatment had no significant (P > 0.05) influence on the changes in AA content of carrots.

Headspace gas concentration

Storage temperature had the greatest effect on changes in headspace gas concentration (Figures 1, 2 and 3). O_2 consumption differed between carrots stored at 1°C and ambient temperature during the 32 days of storage (P ≤ 0.001). During the first 3 days, the O_2 level decreased faster in packages of carrots stored under room temperature than in those stored at 1°C. After 3 days of

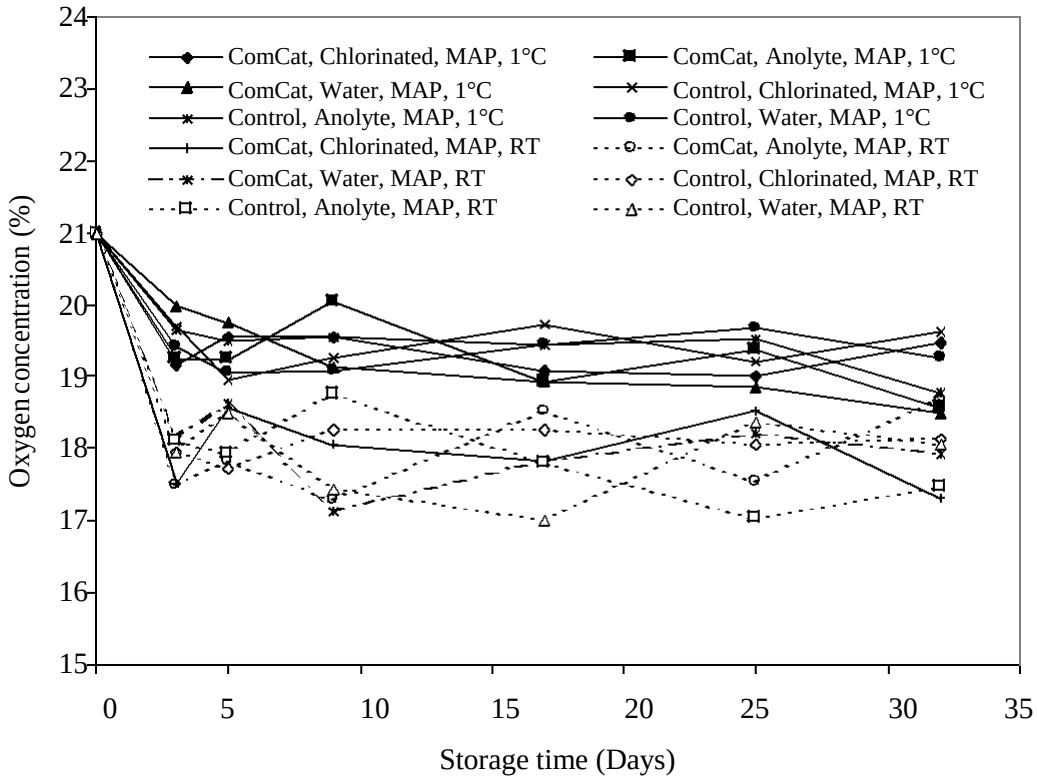

Figure 1. Changes in O_2 content (%) in packages of carrots in Xtend® film stored at 1°C and room temperature (RT) for 32 days (n = 3 over six storage times). $LSD_{0.05}$ Value = 0.378, S.E. = 0.024 and C.V. = 0.035. MAP, modified atmosphere packaging; RT, room temperature.

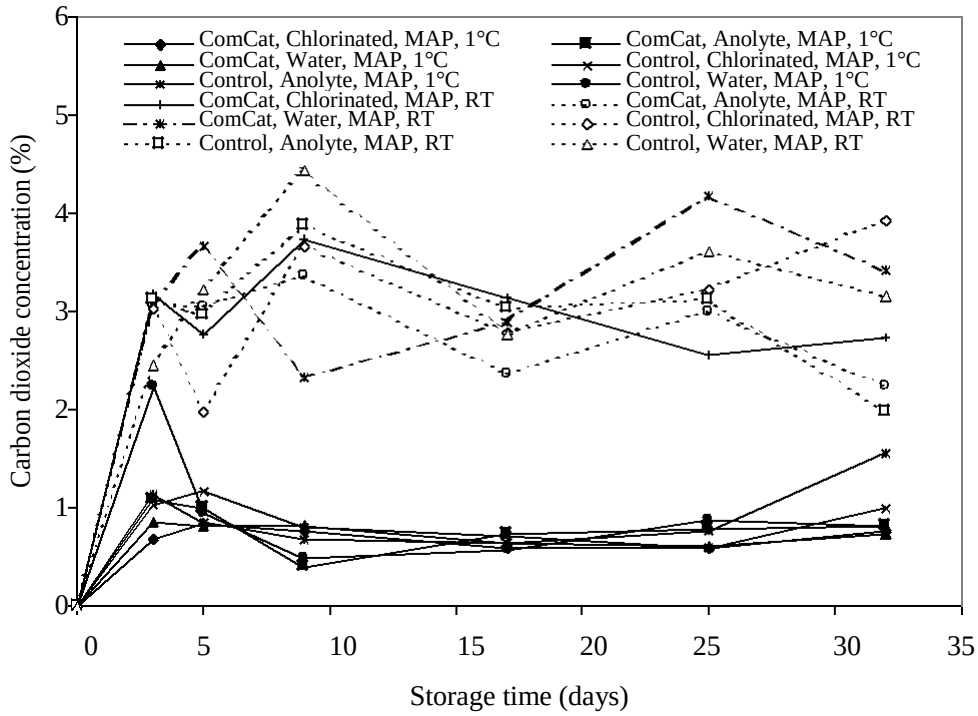

Figure 2. Changes in CO_2 content (%) in packages of carrots in Xtend® film stored at 1°C and room temperature (RT) for 32 days (n = 3 over six storage time). $LSD_{0.05}$ Value = 0.826, S.E. = 0.074 and C.V. = 0.277. MAP, modified atmosphere packaging; RT, room temperature.

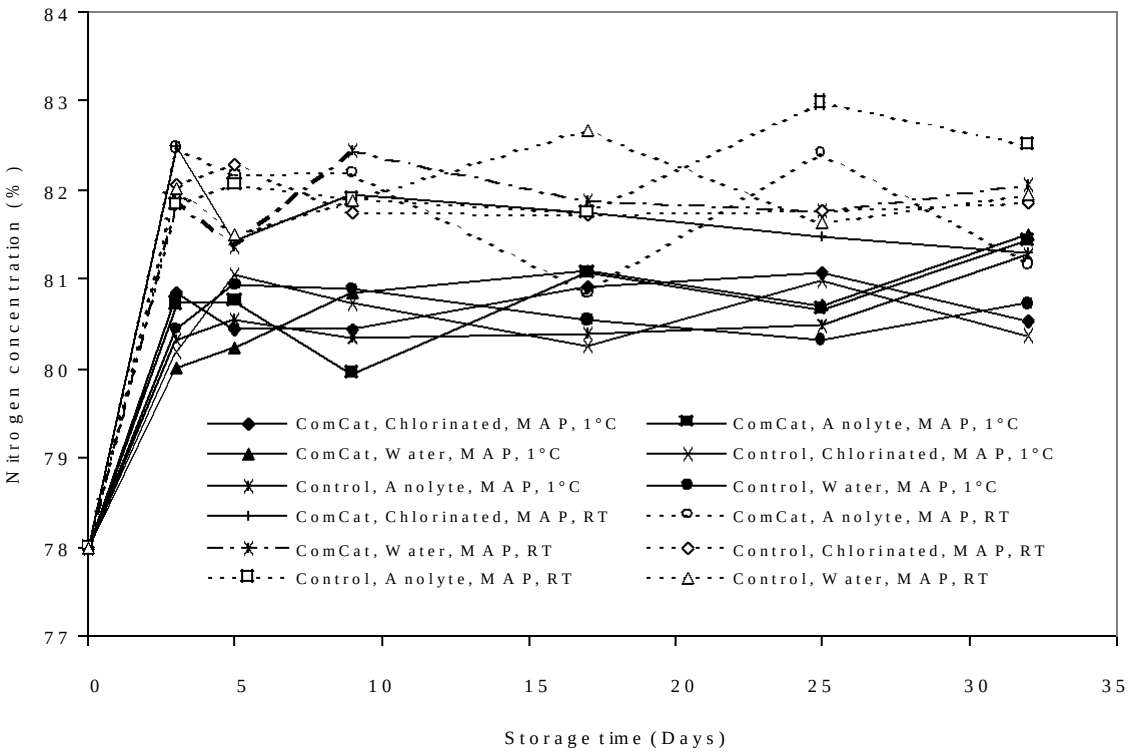

Figure 3. Changes in N_2 content (%) in packages of carrots in Xtend® film stored at 1°C and room temperature (RT) for 32 days (n = 3 over six storage time). LSD0.05 Value = 1.068, S.E. = 0.059 and C.V. = 0.081. MAP, modified atmosphere packaging; RT, room temperature.

storage, the O_2 concentrations remained near equilibrium that is 19 to 20% at 1°C and 17.5 to 18.5% at room temperature.

The effect of storage temperature on the headspace CO_2 concentration was also significant ($P \leq 0.001$). The CO_2 level increased rapidly at room temperature during the first 9 days. In the packages of carrots stored at 1°C, the CO_2 increased the first 3 to 5 days, and then decreased slightly to stabilise after 9 days. The CO_2 level equilibrated after 9 days, that is, below 1% at 1°C and 2 to 4% at room temperature. Storage temperature was also an important factor affecting N_2 concentration. The headspace N_2 concentration was significantly ($P \leq 0.001$) affected with the storage temperature. The N_2 levels increased during the first 3 days with a rapid rise in packages of carrots stored at room temperature and equilibrated after 3 days, that is, at 80 to 81% at 1°C and 81.5 to 82.5% at room temperature.

The effect of preharvest ComCat® treatment on changes in O_2, CO_2 and N_2 concentrations in the packages of carrots was not significant ($P \geq 0.05$). Nitrogen concentrations were not different with respect to preharvest treatments ($P \geq 0.05$). For all three gases, a greater fluctuation after equilibration was observed at room temperature, compared to storage at 1°C. There were no significant differences in gas concentrations inside packages of carrots treated with chlorinated and anolyte water. However, the interactive effect of disinfecting with storage temperature, had a significant ($P \leq 0.05$) influence on the changes in the level of CO_2 during storage.

Peroxidase activity (POX)

The POX activity rapidly increased during the first one or two weeks of storage (Figure 4). POX was lower in carrots stored at room temperature during the first week when compared to those at 1°C ($P \leq 0.05$). Hence, it seemed that carrots stored at 1°C are suddenly exposed to different conditions than those in the soil, resulting in more respiratory enzyme activity during the early adjustment period. After one week of storage, POX seemed to equilibrate in carrots stored at 1°C, while it increased at room temperature until two weeks of storage. The overall effect of storage temperature was highly significant ($P < 0.001$) on POX levels during the third and fourth weeks of storage. The higher POX levels at room temperature could indicate increased oxidation status compared to 1°C.

In fact, POX equilibrated at 1°C after one week of storage, and could be responsible for the protection of cell walls and normal respiration and metabolism during the long-term storage POX activity was not affected by

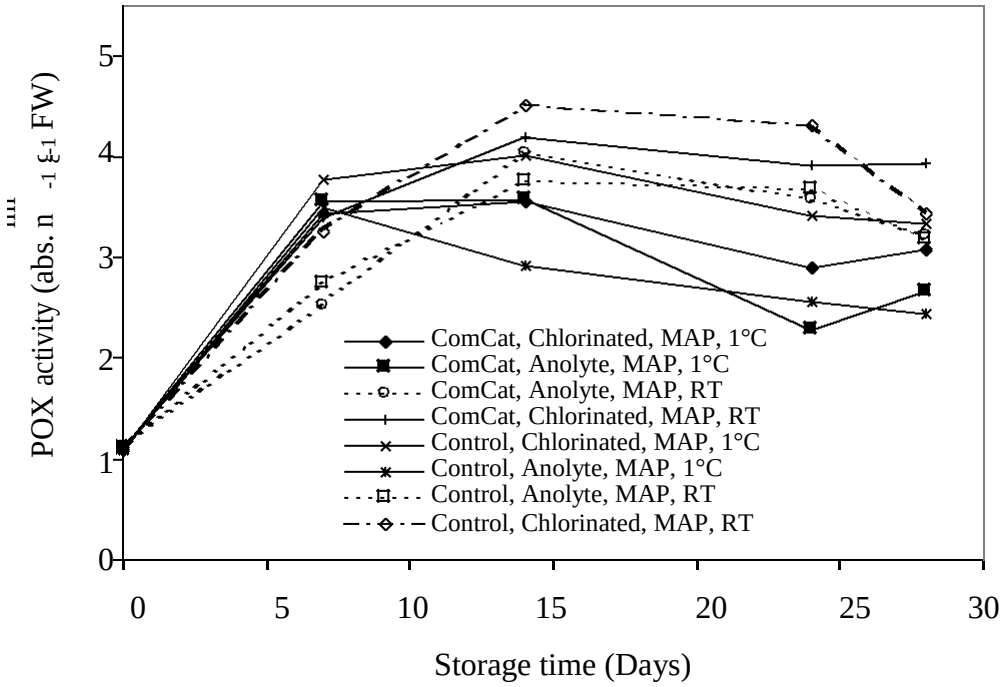

Figure 4. Changes in levels of activities of peroxidase in carrots subjected to different pre- and postharvest treatments and stored at 1°C and room temperature (RT) for 28 days. The $LSD_{0.05}$ Value = 0.517, S.E. = 0.063 and C.V. = 0.171. MAP, modified atmosphere packaging; RT, room temperature.

the interactive effect between pre- and postharvest treatments with storage temperature. The data presented in Figure 4 clearly demonstrated the effect of pre-packaging treatment (chlorinated or anolyte water) on the biochemical changes of carrots during storage. Disinfecting treatment on POX was significant ($P \leq 0.01$) and generally higher in carrots dipped in chlorinated water, when compared to anolyte water, at a significance level of $P \leq 0.09$. At the end of day 7 at room temperature, the POX in carrots was significantly ($P \leq 0.09$) lower in carrots dipped in anolyte water.

After 28 days at 1°C the levels of POX were again significantly lower in carrots dipped in anolyte water. The levels of POX in carrots were not significantly ($P > 0.05$) affected by the preharvest ComCat® treatment both at harvest as well as during storage. The interactive effect of postharvest treatment with preharvest treatments was not significant ($P > 0.05$) on the changes of the level of POX in carrots during storage. This similarity in their biochemical changes could suggest that the shelf life of carrots treated with ComCat® was as good as normal carrots at both temperatures.

DISCUSSION

The permeability and microperforations of the Xtend® packaging film used in this study, allowed sufficient O_2 and CO_2 concentrations in the headspace of carrot packages (Figures 1, 2 and 3). The microperforations associated with this flexible packaging bag allowed to have a balanced normal respiration of the carrots. The O_2 and CO_2 concentrations remained above 15 and below 5% during the storage period of 32 days, respectively. Normal respiration without the incidence of anaerobic metabolism (Exama et al., 1993) was on the same order as the results that have been reported by other researchers (Berg and Lentz, 1966; Phan, 1994). The microperforated film controlled the concentration of respiration gases within the sealed bags (Figures 1 and 2). At room temperature the Xtend® film did not cause excessive depletion of O_2 and accumulation of CO_2, although the respiration rate was found to be higher (Wiley, 1994).

The TSS content of carrots that were subjected to room temperature storage increased during the storage periods (Table 1), which is in agreement with the findings of Lingaiah and Huddar (1991) and Jitender-Kumar et al. (1999). MAP significantly ($P \leq 0.05$) affected the changes in TSS content of carrots during storage period (Table 1). The increase in TSS of unpackaged carrots was rapid, while that of packaged carrots was maintained. The excessive increase in TSS is an indication of quality deterioration (Pal and Roy, 1988; Wasker et al., 1999). The changes in TSS content of carrots and the PWL had a direct relationship during storage (Jitender-Kumar et al., 1999; Seyoum et al., 2009). This evidence suggests the importance of reducing PWL through increasing storage

air relative humidity and by the use of MAP. The increase in TSS may partially result from desiccation, which in turn leads to a concentrating effect on TSS. Since packaging prevented excessive moisture loss (Seyoum et al., 2009), the TSS content of carrots was maintained better in samples stored at 1°C (Table 1).

Storage temperature was the most important factor affecting postharvest quality of carrots (Table 1 and 2). The gas concentrations and TSS were significantly influenced by the storage temperature. Varoguaux and Wiley (1994) showed that storage temperature highly affects the physiology and biochemistry of vegetables, which was also demonstrated in the current study. Room temperature storage increased the utilization of O_2 and production of CO_2 compared to 1°C, which according to Wiley (1994), was due to the higher temperature effect. The main physical change that occurred was loss of moisture, which is one of the most important aspects related to perishable vegetables that reduces the saleable weight and can induce senescence of the products (Grierson and Wardwski, 1978).

The PWL was much higher in carrots stored at room temperature than 1°C (Seyoum et al., 2009). At room temperature, the relative humidity of air usually is lower than the vapour pressure exerted by water in the carrots, which creates vapour pressure differences that are the deriving force for moisture movement outward (Salunkhe et al., 1991; Ryall and Lipton, 1979). The surface tissue and skin of carrots seemed to be poor barriers to moisture transfer from the flesh to the surrounding air. This results in a higher rate of moisture transfer when stored at room temperature. The AA content of carrots decreased during storage (Table 2) and after two weeks the decrease in TSS of carrots was much more in carrots stored at room temperature, Odebode and Unachukwu (1997) reported that the AA in infected carrots decreased as the storage period increased. The low temperature maintained the TSS content, which increased to higher levels in carrots stored at room temperature than at 1°C (Pal and Roy, 1988; Lingaiah and Huddar, 1991; Waskar et al., 1999; Jitender-Kumar et al., 1999). This was partly attributed to higher moisture loss due to high temperature and low relative humidity. Pal and Roy (1988) and Waskar et al. (1999) reported similar trends on the changes in the TSS during storage at different storage temperatures.

Since POX is a respiratory enzyme, the results show that the rates of oxidative processes in the respiration increase during the first few days of storage. Berg and Lentz (1966) and Phan et al. (1973) suggested that the rates of metabolic processes increase in order to adjust the carrot roots to the new conditions immediately after they are detached from the plant and exposed to environmental conditions that were different from the underground conditions. The effect of storage temperature on POX activity of carrots was significant ($P \leq 0.05$) during storage. The higher levels of POX in carrots stored at room temperature during the later weeks of storage could indicate the increased oxidation status of the carrots, compared to those stored at 1°C. Similar to MAP, storage temperature influenced the effectiveness of pre- and postharvest treatments on keeping the qualities of carrots during storage, which was demonstrated by the interactive effect of storage temperature with the other pre- and postharvest treatments (Tables 1 and 2).

Low temperature storage supported the postharvest washing, disinfecting and MAP towards the achievement of the improvement of shelf-life of ComCat® treated and untreated carrots. The coupled effect of MAP and storage temperature seemed to have a synergistic effect on storage quality. As mentioned earlier, MAP reduced O_2 concentration in the headspace of packages of carrots, and reduced the rate of respiration (Wiley, 1994), while low temperature reduces both biological and biochemical activities in the produce. In comparison to carrots dipped in chlorinated water, the carrots dipped in anolyte water displayed better fresh quality properties, such as a smooth and shiny surface, for one month of storage. Etching of the surface of carrots by chlorinated water was observed, while carrots dipped in anolyte water remained shiny and smooth. Chlorinated water may not be the optimum disinfecting treatment for carrots and an alternative treatment, such as anolyte water, is recommended.

Disinfecting treatment had a significant ($P \leq 0.05$) effect on the reduction of AA (Table 2). The decrease of AA of carrots dipped in chlorinated water was higher than that of anolyte washed samples during storage at room temperature. The chlorinated water treatment also increased the level of POX in carrots during storage. Again, this could be due to the wounding effect of chlorine on the surface, resulting in increased metabolic activities during storage. While both disinfectants were effective in killing and controlling postharvest decay during storage, these results showed that disinfecting with anolyte water proved to be superior to chlorinated water in maintaining the optimum physiological condition, nutritional value, and some biochemical processes. The best quality properties of carrots were maintained due to the interactive effect between anolyte water disinfecting, use of MAP, and low temperature storage.

Therefore, suitable combinations of preharvest practice, pre-packaging treatments, packaging and control of environmental factors should be used to improve the quality and shelf-life of packaged carrots. The TSS was slightly higher in ComCat® treated carrots compared to the controls during storage, although only significant at $P \leq 0.09$. The interesting point was that in most of the sampling intervals, the TSS values remained higher in ComCat® treated carrots (Table 1). This pattern of TSS was consistent in the case of carrots stored in MAP at 1°C as well as room temperature for 28 days, but not in unpackaged carrots. The interactive effect of preharvest ComCat® treatment and storage temperature

was significant ($P \leq 0.01$) on the changes in TSS content. This shows the necessity of proper storage temperature in order to maintain the TSS of fresh harvest ComCat® treated carrots. The plant growth regulators in ComCat®, such as gibberellin, indole-3-acetic acid and brassinosteroids, with their individual functions during plant growth and development, seemed to have promoted the accumulation of TSS.

Conclusions

Anolyte water dipping treatment was found to be a better disinfectant treatment for carrots than chlorine, because it did not etch the surface tissues, and resulted in higher contents of TSS and AA, without affecting the other quality properties. Disinfecting with anolyte water also proved to be superior to chlorinated water in maintaining the optimum physiological conditions and hence biochemical processes. MAP reduced the rate of respiration while low temperature reduces both biological and biochemical activities in the carrots.

Preharvest ComCat® treatment improved the quality properties of carrots at harvest and during storage. The advantages gained by the preharvest ComCat® treatment are better chemical quality characteristics during storage at 1°C in terms of higher TSS in ComCat® treated carrots. Similarly, there was better maintenance of TSS and AA in ComCat® treated carrots during storage at room temperature and improved keeping quality in relation to better overall visual appearance during storage at 1°C. Combinations of preharvest practice, pre-packaging treatments, packaging and control of environmental factors is recommended to improve the quality and shelf-life of carrots.

REFERENCES

AOAC (1970). Official Methods of analysis. Assoc. Offic. Agr. Chemist. Washington, D.C.

Ballantyne A, Stark R, Selman JD (1988a). Modified atmosphere packaging of shredded lettuce. Inter. J. Food Sci. Technol., 23: 267-274.

Ballantyne A, Stark R, Selman JD (1988b). Modified atmosphere packaging of broccoli florets. Inter. J. Food Sci. Technol., 23: 353-360.

Berg LVD, Lentz CP (1966). Effect of temperature, relative humidity, and atmospheric composition on changes in quality of carrots during storage. Food Technol., 20(7): 104-107.

Duncan DB (1955). New multiple range and multiple F tests. Biometerics, 11: 1.

Exama A, Arul J, Lenckiand R, Li Z (1993). Suitability of various plastic films for modified atmosphere packaging of fruits and vegetables: gas transfer properties and effect of temperature fluctuation. Acta Hort., 343: 175-180.

Grierson W, Wardowski WF (1978). Relative humidity effects on the postharvest life of fruits and vegetables. HortSci., 13: 157.

Gunes G, Splittstoesser DF, Lee CY (1997). Microbial quality of fresh potatoes: Effect of minimal processing. J. Food Prot., 60(7): 863-866.

Hole CC, McKee JMT (1988). Changes in soluble carbohydrate levels and associated enzymes of field-grown carrots. J. Hort. Sci., 63(1): 87-93.

Howard LR, Griffin LE, Lee Y (1994). Steam treatment of minimally processed carrot sticks to control surface discoloration. J. Food Sci., 59(2): 356-358.

Hüster T (2001). Personal communication. AgraFurUm, Germany.

Jeon BS, Lee CY (1999). Shelf-life extension of American fresh ginseng by controlled atmosphere storage and modified atmosphere packaging. J. Food Sci., 64(2): 328-331.

Jitender K, Mangal JL, Tewatia AS, Kumar J (1999). Effect of storage conditions and packaging materials on shelf life of carrots cv. Hisar Gairic. Veg. Sci., 26(2): 196-197.

Lingaiah HB, Huddar AG (1991). Influence of pre-cooling, waxing and pre-packaging on the shelf life and quality of carrots (*Daucus Carota* L.). Mysore J. Agric. Sci., 25(2).

Lipton WJ (1977). Recommendations for CA storage of broccoli, brussels sprouts, cabbage, cauliflower, asparagus and potatoes. Horticultural Report No. 28, July 1977. Proceedings of the Second National Controlled Atmosphere Research Conference, April 5 - 7, Michigan State University.

Nilsson T (1987). Carbohydrate composition during long-term storage of carrots as influenced by the time of harvest. J. Hort. Sci., 62(2): 191-203.

Nunes MCN, Emond JP (1999). Chlorinated water treatments affects postharvest quality of green bell peppers. J. Food Qual., 22: 353-361.

Odebode AC, Unachukwu NE (1997). Effect of storage environment on carrot root rots and biochemical changes during storage. Zeitschung fur Lebensmittel Untersuchuning und Forschung, 205(4): 277-281.

Pal RK, Roy SK (1988). Zero-energy cool chamber for maintaining postharvest quality of carrot (*Daucus Carota* Var. sativa). Indian J. Agric. Sci., 58(9): 665-667.

Phan CT (1974). Use of plastic films in the storage of carrots. Acta Hort., 38: 345.

Phan CT, Hus H, Sarkar SK (1973). Physical and chemical changes occurring in the carrot root during storage. Can. J. Plant Sci., 53: 635-641.

Rosenfeld HJ, Samuelsen R, Lea P (1998). The effect of temperature on sensory quality, chemical composition and growth of carrots (*Daucus carota* L.). J. Hort. Sci. Biotechnol., 73(2): 275-288.

Ryall AL, Lipton WJ (1979). Handling, Transportation and Storage of Fruits and Vegetables. Vol. 1 Vegetable and Melons, 2nd ed, AVI Publishing, Westport, CT.

Salunkhe DK, Bolin HR, Reddy NR (1991). Storage, processing, and nutritional quality of fruits and vegetables. 2nd edition. Volume1. Fresh fruits and Vegetables.

Salunkhe DK, Wu M, Wu MT, Singh B (1971). Effect of Telone and Nemagon on Essential nutritive components and the respiratory rates of carrot (*Daucus carota* L.) roots and sweet corn (*Zea mays* L.) seeds. J. Am. Soc. Hort. Sci., 96(3): 357-359.

Schnabl H, Roth U, Friebe A (2001). Brassinosteroids-induced stress tolerances of plants. Recent Res. Dev. Phytochem., 5: 169-183.

Seyoum TW (2002). The improvement of the shelf life of vegetables through pre and postharvest treatment. Ph.D. Thesis Presented to the University of Free State. South Africa, pp. 1-270.

Seyoum TW (2010). Feasibility and economic evaluation of low-cost evaporative cooling system in fruit and vegetables storage. Afr. J. Food Agric. Nutr. Dev. 10(8): 2984-2997.

Seyoum TW, Osthoff G, Steyn MS (2001). Effect of modified atmosphere packaging on microbiological, physiological and chemical qualities of stored carrots. J. Food Technol. Afr., 6(4): 138-143.

Suojala T (1999). Effect of harvest time on the storage performance of carrot. J. Hort. Sci. Biotech., 74(4): 484-492.

Suojala T (2000). Variation in sugar content and composition of carrot storage roots at harvest and during storage. Scientia Hort., 85: 1-19.

Tigist M, Workneh TS, Woldetsadik K (2011). Effects of variety on the quality of tomato stored under ambient conditions. Journal of Food Science and Technology. J Food Sci Technol. DOI 10.1007/s13197-011-0378-0.

Varoquaux P, Wiley RC (1994). Biological and biochemical changes in minimally processed refrigerated fruits and vegetables. In: "Minimally processed refrigerated fruits and vegetables (by Robert C. Wiley). Chapman and Hall, 2-6 Boundary Row, London SEI 8HN, pp. 226-258.

Workneh TS, Osthoff G, Steyn MS (2010). A review on integrated agro-technology of vegetables. Afr. J. Biotechnol., 9(54): 9307-9327.
Workneh TS, Osthoff G, Steyn MS (2011). Effects of preharvest treatment, disinfections and storage environment on quality of tomato. J. Food Sci. Technol. DOI: 10.1007/s13197-011-0391-3.
Waskar DP, Khedkar RM, Garande VK (1999). Effect of post-harvest treatments on shelf life and quality of pomegranate in evaporative cool chamber and ambient conditions. J. Food Sci. Technol., 36(2): 114-117.
Wiley RC (1994). Minimally processed refrigerated fruits and vegetables. New York: Chapman and Hall, pp. 1-368.
Zagory D, Kader AA (1988). Modified atmosphere packaging of fresh produce. Food Technol., 42(9): 70-77.