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Full Length Research Paper

Integrated agrotechnology with preharvest ComCat® treatment, modified atmosphere packaging and forced ventilation evaporative cooling of carrots

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Preharvest ComCat® treatment of carrots was investigated for storage characteristics of treated vegetables in forced ventilation evaporative cooling. The forced ventilation evaporative cooling system was designed such that the temperature could be reduced by 8.4 - 13.4°C below ambient temperature, while maintaining a relative humidity up to 91%. Storage in this EC increased shelf lives of carrots to 24 days, compared to 4 days when stored at ambient conditions. ComCat® treatment of carrots significantly (P ≤ 0.05) affected pH, total sugar content and the population of moulds and yeasts during storage at evaporative cooling. Modified atmosphere packaging significantly (P ≤ 0.001) reduced physiological weight loss, moisture and juice content of carrots stored inside evaporative cooling. Modified atmosphere packaging coupled with evaporative cooling reduced the rate of sugar utilization for metabolic activities, compared to unpackaged carrots stored at ambient conditions. The populations of aerobic bacteria and fungi were significantly (P ≤ 0.001) affected by modified atmosphere packaging coupled with evaporative cooling temperature. Disinfecting with chlorinated water helped additionally to limit microbial growth during evaporative cooling storage.

Key words: ComCat®, modified atmosphere packaging, evaporative cooling, temperature, relative humidity, carrot.

INTRODUCTION

During development and storage, carrots undergo a complex series of physiological, biochemical and micro-biological events, which affect changes in postharvest quality (Phan et al., 1973; Nilsson, 1987; Hole and McKee, 1988; Rosefeld et al., 1998; Suojala, 1999; Suojala, 2000). During storage, the quality of carrots is preserved by controlled conditions, making use of modified atmosphere packaging (MAP), which reduces metabolic activities by controlling the levels of O_2 and CO_2 in packages (Zagory and Kader, 1988) and low temperatures (Zagory and Kader, 1988).

It was also shown that the respiration rate of carrots is affected by preharvest treatments, which may add to extension of shelf life (Salunkhe et al., 1971). Depending on the history, fresh vegetables may respond differently to postharvest factors. A preharvest treatment, ComCat®, has recently been developed from plant extracts, which was shown to improve general strength and development of plants, activate inherent plant defence mechanisms via induced resistance and increase yield (Schnabl et al., 2001).

ComCat® is a natural biocatalysts, which is extracted from seeds of plants and mainly consists of aminoacids, 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.

Investigations on quality of ComCat® treated vege-

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tables both at harvest and during storage are yet to be explored. Ethiopia has a wide variety of climatic and soil types that can enable it to produce crops for both home consumption and the export market (Agonafir, 1991). Agriculture is the mainstay of the economy, with vegetable production around 2.86 million tons. Ninety five per cent of the total volume of horticultural products is fresh vegetables. There is a need for high crop yield in Ethiopia to feed its increasing population, but due to a lack of agricultural input, such as fertilizers, the production of vegetables is low and fully dependent on traditional farming systems.

Postharvest handling of vegetables is also poor, and causes losses of 25%, mainly because there are very few modern means of transportation, storage and processing of fresh vegetables in Ethiopia. Wolde (1991) pointed out the necessity of improvement of packaging, cold storage, grading and transportation facilities, in order to maintain quality of vegetables for markets both local and abroad. A storage facility, which is suited for use in developing countries, was described earlier (Seyoum and W/Tsadik, 2000) and was improved for the current investigation.

The aim of this research was to investigate the postharvest performance of vegetables produced with normal agricultural procedures in general and ComCat® treated vegetables in specific, in this low-cost evaporative cooling chamber at temperatures between 16°C and 22°C and relative humidity of 78%-91%. Pre-packaging disinfecting (in chlorine supplemented water) and modified atomsphere packaging (MAP) was included as post harvest treatments, to round off the investigation of a complete agrotechnology to control post harvest losses.

MATERIALS AND METHODS

Evaporative cooling chamber

In earlier work, a naturally ventilated EC was designed and constructed using locally available and low cost materials (Seyoum and W/Tsadik, 2000), which was able to reduce the storage temperature relative to the surrounding air temperature. To further reduce the temperature, as well as increase the relative humidity of the inner air, it was modified as forced ventilation EC (Figure 1). The cooler consists of three major units: the air conditioning unit, watering pipe systems and cool storage chamber. The inner dimensions of the unit were $2 \times 2 \times 1.3$ m, to hold a capacity 0.5 ton vegetable. The frame is constructed from $25 \times 25 \times 4$ mm angle iron, to which sheet metal (1 mm thick) is welded.

A water tank is placed below ground level beneath the water pump (N) and a vertical water pipe is installed to withdraw water from the tank during operation (D). During operation, water is sprinkled by a small 0.186 KW water pump (A) over the top surface, to wet the top surface and all four sides of cooling pad layers by a horizontal perforated pipe (B). The three side surfaces and the door were covered with a thin-layer pad of 5 mm jutty sack (M), which was sandwiched between sheet metal, on the inside (J) and mesh wire (L), on the outside, facing the ambient air, to allow evaporation (K). In this way, the maximum surface area from which evaporation of water can take place is exposed. Reduction in surface temperature would therefore directly be related to the rate of evaporation. The hose is connected from a vertical pipe to sprinkle water continuously on the cooling pad filled with charcoal (E) from the top (C). An in-built fan (F) blows air through the cooling pad (E) into the evaporative cooling chamber, to effectively increase the relative humidity, while the temperature is decreased.

In figure 1, the directions of arrows show the airflow pattern after passing through the cooling pad. To minimize bruising of perishable produce and improve airflow, three equally spaced shelves (H) are inserted. The dry-bulb air temperature inside the EC was monitored by thermocouples at the center of the middle shelf (G). An air vent is inserted in the top of the cooler (I). This cooling chamber could be used by peasants and small-scale farmers from the sub sector and the structure could be modified to cool vegetables and fruits during local transportation by truck or long distances by train.

Temperature and relative humidity measurement

Ambient air temperature and relative humidity were measured with a Jenway-digital psychrometer 5105, UK. The psychrometer recorded dry bulb temperature, wet bulb temperature, dew point temperature and relative humidity. The dry bulb air temperature inside the EC was monitored using a thermocouple installed at the center of the chamber (G) connected to a digital temperature control. Simultaneously, a hygrometer (0 - 50°C) with dry and wet bulb thermometers was used to monitor the dry and wet bulb temperature of air inside the EC.

Vegetable production

Carrots (var. Nantes) were grown during the summer season of 2001 at the experimental fields of the Alemaya University, in Eastern Ethiopia. During the growing period, carrots were treated twice with ComCat®. Experimental plants were treated with 10 g ha^{-1} ComCat® in 300 l of water and control plants 0 g ha^{-1}. Carrots were sprayed once at the three leaves unfolding stage and a second time at a vegetative stage. All other agricultural practices were the same as those normally practiced by the Farm Management Department of Alemaya University during carrot production.

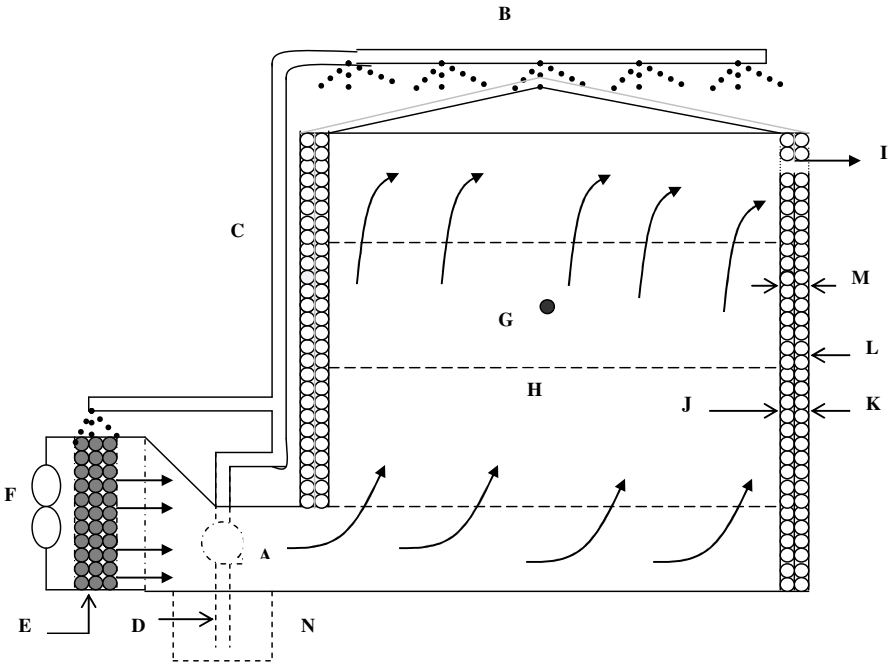
At a proper maturity stage, carrots were harvested and topped in the field and were immediately transported from the farm to the Dire Dawa University Fruit and Vegetable Research Station which is 30 km away. The topping, harvesting and transportation of carrots were made early in the morning before the temperature was too high. For protection against mechanical injury during transportation, carrots were packed in plastic crates.

Postharvest treatment

Following washing, both ComCat® treated and untreated carrots were subjected to one of the following postharvest treatments according to the procedures: dipping in chlorinated water (100 µg. ml^{-1} chlorine, made with 5% NaOCl) at ambient temperature for 20 min. before packaging and stored in EC; dipping in chlorine supplemented water, unpackaged and stored in EC; water washed, packaged and stored in EC; water washed, unpackaged and stored in EC; water washed, packaged and stored at ambient conditions to serve as a postharvest control; and water washed and stored under ambient conditions without packaging to serve as a postharvest control.

These treatments were performed in three different containers, each as a replication for each treatment group. After washing and dipping treatments, the surfaces of carrots were drip dried to avoid the occurrence of condensation inside the packages. Carrots were packed in 2 kg packages or unpackaged groups. Randomly, 2 kg samples were subjected to physiological, microbiological and chemical analyses.

Due to limited facilities, not all analyses could be carried out at the same sampling times. PWL and percentage marketability were



A = Water pump (0.5 HP)
B = perforated horizontal water pipe
C = hose
D = Vertical pipe connected to water pump surface cooling pad
E= Cooling pad (Charcoal)
F = Fan
G = Location of thermocouple and hygrometer
H = Storage chamber
I = Ventilation port
J = Sheet metal
K = Meshed wire holding
L = mesh wire
M = Wet jutty sack layer
N = water tank

Figure 1. Schematic diagram of an experimental evaporative cooler for vegetable under hot arid and semi-arid conditions.

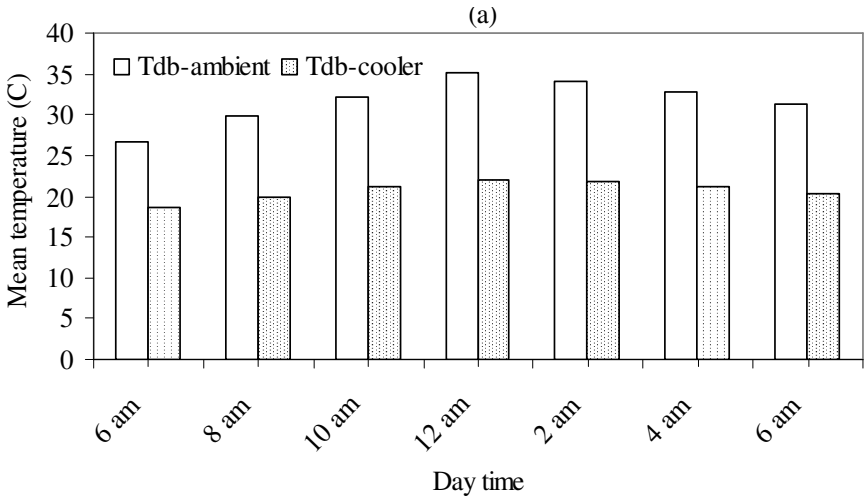


Figure 2. (a). The effect of daytime on the average environmental and evaporative cooler temperatures (°C) during storage of carrots.

determined on day 0, 4, 8, 12, 16, 20 and 24 changes in moisture content, juice content, pH, TSS, populations of total aerobic bacteria and fungi were determined on day 0, 8 and 16 and sugars were determined on day 0 and 16.

Physiological weight loss, moisture content and juice content

The physiological weight loss (PWL) was determined using the methods as described by Pirovani et al. (1997) and Waskar et al. (1999). The moisture contents of carrots were determined by drying approximately 20 g of sample at 105°C for 24 h (Mohammed et al., 1999). The juice of carrots was extracted using a juice extractor (Kenwood) and the juice percentage expressed as percentage of initial carrot mass according to the methods described by Waskar et al. (1999).

Chemical analyses

The pH of carrots was measured with a TOA pH meter (model HM-20E, Ogawa Seiki Co., Ltd., Japan). The total soluble solids (TSS) were determined by the procedures as described by Waskar et al. (1999). 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. Reducing and total sugars were estimated by using the techniques of Somogyi, (1945). The same procedure was used to estimate reducing and total sugar in carrots during storage (Phan et al., 1973).

Microbiological analysis

Microbial populations were estimated by the poured plate methods of Brackett (1988, 1990). Total aerobic microorganisms were determined on plate count agar (Oxoid CM463) and moulds and yeasts on Rose-Bengal Chlorampehnicol Agar Base (Oxoid CM549). Microbial populations were not analysed immediately after disinfection, as they were assumed to be around 0 $\log_{10}$ CUF.g^{-1} as was previously shown (Seyoum et al., 2003).

Subjective quality analysis

The marketable quality was subjectively assessed according to Mohammed et al. (1999). On each sampling time, a package containing 5 carrots was randomly selected from each treatment group. The number of marketable fruit was used to calculate the percentage marketable fruit during storage. A 1 – 9 rating with 1 = unusable, 3 = unsaleable, 5 = fair, 7 = good and 9 = excellent was used to evaluate the fruit quality. The color, shininess, surface defects, sign of moulds growth and dehydration as visual parameters were estimated for rating. Carrots received a rating of 5 or above were considered marketable, while those rated less than 5 were considered unmarketable.

Data analysis

A factorial experiment with 2 preharvest treatments, 2 prepackaging disinfecting treatments, 2 storage temperatures and 3 replications were used in the study. The experimental design was arranged in a factorial type of randomized complete block design (RCBD), with three samples from each treatment combination. A pack of carrots were taken randomly from each treatment group on each sampling day and used for the different quality analyses. Each replicate sample for analysis of microbiological quality and free sugar content (sucrose, glucose and fructose) was analysed in duplicate.

Statistical significant differences between the treatments were determined by analysis of variance (ANOVA) with a 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). The effect of two different types of packaging films with different levels of permeability to O_2, CO_2 and H_2O vapour on microbiological, physiological and chemical quality of stored carrots were investigated earlier (Seyoum et al., 2001).

Therefore, during the current investigation, the statistical analysis of the MAP was coupled with storage temperature in order to see the overall effect of these treatments on the quality parameters. The individual effect of MAP and storage temperature was analyzed using multiple comparison of each treatment means by mean separation of Duncan's multiple range test.

RESULTS AND DISCUSSION

Temperature and relative humidity

The ambient dry bulb environmental air temperature and relative humidity varied from 25.0-36.0°C and 25.4- 53.0 % during the storage period respectively. Inside the evaporative cooler, the dry bulb temperature and relative humidity were between 16.4-22.6°C and 78.0-91.0% respectively. The differences in dry bulb temperature between environmental air and the air inside the cooler ranged from 8.6-13.4°C.

During the storage of 24 days, the differences in temperature were found to be at a minimum (8.6°C) at 6 a.m., whereas the maximum difference (13.4°C) was recorded at 12 a.m. (Figure 2). This can be ascribed to the rate of evaporation of water from the wet cooling pad being higher at higher environmental temperature and is supported by earlier work (Rama and Narasimham, 1991; Nadre et al., 1999; Seyoum and W/Tsadik, 2000). Evaporative cooling is therefore very efficient under hot and dry conditions of arid or semi-arid regions, where the problem of postharvest losses of vegetables and fruit is severe due to the effect of high temperature and low relative humidity.

However, if the ambient temperature is very high, this decrease in temperature may not be sufficient to suppress microbial development at high relative humidity. From the data presented in figure 2, it was evident that at 12 a.m., vegetables stored under environmental conditions are exposed to harsh conditions due to a coupled effect of both high temperature and low relative humidity. The EC was therefore effective in minimizing these extremes.

Physiological weight loss, moisture and juice content

Dipping carrots in chlorine supplemented water seemed to have an effect on the PWL during storage (Table 1), although only significant at $P \leq 0.09$. The PWL was higher in carrots dipped in chlorinated water, compared to those dipped in tap water. The combined effect of MAP and storage temperature was found to be highly significant ($P \leq 0.001$) in reducing the PWL during storage. The loss in PWL was higher from unpackaged than packaged carrots stored in the EC.

The results in table 2 show the importance of MAP for use in combination with EC to maintain freshness and

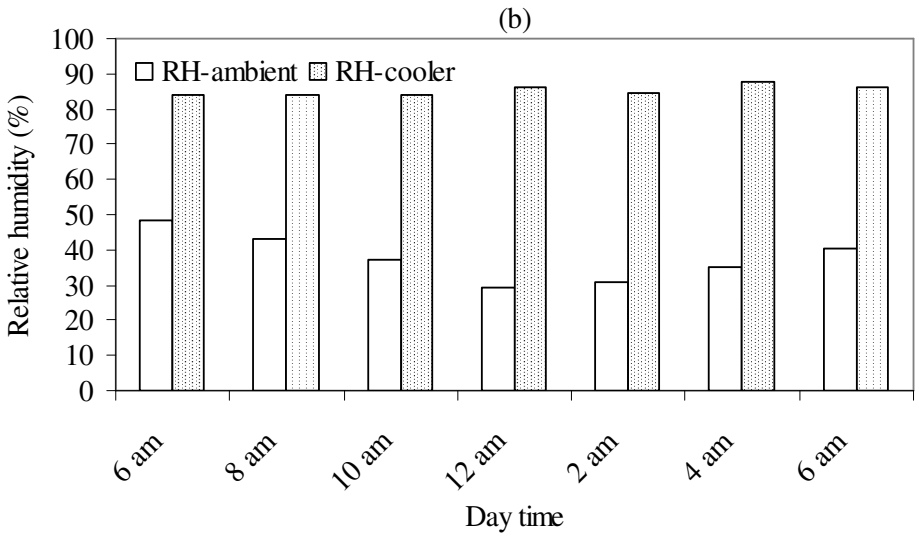


Figure 2(b). The effect of daytime on the average environmental and evaporative cooler relative humidity (%) during storage of carrots.

Table 1. Changes in physiological weight loss of carrots stored in evaporative cooling chamber and ambient temperature (RT) for 24 days.

	Physiological loss in weight (%)					
Treatment	**Day 4**	**Day 8**	**Day 12**	**Day 16**	**Day 20**	**Day 24**
ComCat®, Cl_2, MAP, EC	0.568^{d}	4.970^{ef}	10.291^{d}	12.807^{d}	17.100^{b}	20.649^{b}
Control, Cl_2, MAP, EC	0.877^{d}	6.752^{e}	12.056^{d}	15.093^{c}	19.485^{b}	23.108^{b}
ComCat®, Cl_2, EC	1.286^{cd}	10.718^{cde}	20.361^{bc}	25.947^{b}	36.272^{a}	45.084^{a}
Control, Cl_2, EC	6.667^{bcd}	13.867^{cd}	24.603^{bc}	30.545^{b}	41.626^{a}	50.107^{a}
ComCat®, H_2O, MAP, EC	0.688^{d}	5.097^{e}	7.907^{e}	10.645^{de}	14.841^{c}	18.625^{c}
Control, H_2O, MAP, EC	0.700^{d}	5.363^{e}	8.628^{e}	11.429^{d}	15.858^{bc}	20.246^{bc}
ComCat®, Cl_2, MAP, RT	8.724^{abc}	16.137^{bc}	22.275^{bc}	26.323^{b}	33.553^{a}	40.600^{a}
Control, Cl_2, MAP, RT	12.096^{ab}	20.298^{b}	26.867^{b}	31.580^{b}	38.016^{a}	44.598^{a}
ComCat®, H_2O, EC	0.506^{d}	9.246^{de}	16.595^{cd}	22.598^{bc}	34.424^{a}	43.479^{a}
Control, H_2O, EC	2.043^{cd}	10.621^{de}	20.653^{bc}	26.768^{b}	33.968^{a}	41.986^{a}
ComCat®, H_2O, RT	9.993^{ab}	47.452^{a}	70.810^{a}	88.604^{a}	-	-
Control, H_2O, RT	14.034^{a}	44.656^{a}	70.254^{a}	84.399^{a}	-	-
Significance						
Preharvest treatment (A)			NS			
Disinfecting treatment (B)			*			
Packaging + Storage temperature (C)			***			
A X B			NS			
A X C			NS			
B X C			***			
A X B X C			*			

NS, *, *** Non significant or significant at $P \leq 0.09$ 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 coefficient of variation and standard error were 0.150 and 1.196 respectively. LSD Value

increase shelf life. The PWL from unpackaged carrots stored at ambient temperature was above 85% at the end of 16 days of storage, whereas for carrots packaged and stored at ambient temperature, the PWL was found to be below 32% during the same storage time. While the unpackaged carrots were dried out after 16 days, the

Table 2. Changes in moisture content of carrots stored in evaporative cooling chamber and ambient temperature (RT) for 24 days.

	Moisture content (% w.b.)			
Treatment	**Day 0**	**Day 8**	**Day 16**	**Day 24**
ComCat®, Cl_2, MAP, EC	88.205 [a]	88.079 [a]	87.711 [a]	86.819 [a]
Control, Cl_2, MAP, EC	88.002 [a]	87.828 [a]	87.060 [ab]	85.806 [ab]
ComCat®, Cl_2, EC	88.205 [a]	87.335 [ab]	86.096 [ab]	84.312 [ab]
Control, Cl_2, EC	88.002 [a]	87.703 [a]	86.656 [ab]	83.771 [bc]
ComCat®, H_2O, MAP, EC	88.205 [a]	87.362 [a]	87.174 [ab]	85.685 [ab]
Control, H_2O, MAP, EC	88.002 [a]	87.508 [ab]	86.533 [a]	84.763 [ab]
ComCat®, Cl_2, MAP, RT	88.205 [a]	87.585 [a]	85.408 [b]	84.296 [b]
Control, Cl_2, MAP, RT	88.002 [a]	85.469 [bc]	84.953 [bc]	83.681 [c]
ComCat®, H_2O , EC	88.205 [a]	85.878 [bc]	84.917 [abc]	82.989 [c]
Control, H_2O, EC	88.002 [a]	85.278 [bc]	83.007 [cd]	81.747 [d]
ComCat®, H_2O, RT	88.205 [a]	79.117 [d]	72.700 [e]	-
Control, H_2O, RT	88.002 [a]	83.936 [b]	75.144 [e]	-
Significance				
Preharvest treatment (A)		NS		
Disinfecting treatment (B)		*		
Packaging + Storage temperature (C)		***		
A X B		NS		
A X C		NS		
B X C		***		
A X B X C		*		

NS, *, *** Nonsignificant or significant at $P \leq 0.07$ 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 coefficient of variation and standard error were 0.027 and 0.303 respectively. LSD Value = 3.643.

packaged ones lasted up to 24 days storage, with a PWL of 40-45%. The effect of EC on the PWL was also significant ($P \leq 0.05$) during the storage period.

Due to the lower temperature and higher relative humidity, the PWL was significantly reduced ($P \leq 0.05$), which was in agreement with previous studies by Roy and Pal (1994) and Waskar et al. (1999). The PWL in packaged carrots stored in EC was only 18 - 23%, while unpackaged carrots stored in EC showed a PWL of 41 - 50%. Disinfecting with chlorinated water had no significant effect on PWL. The PWL was higher in control carrots, compared to ComCat® treated ones, however not significant ($P > 0.05$).

It could be that, the smaller sizes of the control carrots resulted in a somewhat higher evaporation, which was detectable as higher PWL. However, plant growth hormones (gibberilin and auxin) play an important role in reducing the PWL during storage (Salunkhe et al., 1991; Rodrigues and Subramanyam, 1966). These hormones are the major constituent of ComCat® and hence could have contributed to the reduction in PWL during storage of carrots Table 2 shows moisture loss of carrots during EC storage. General trends of higher moisture content in. packaged ComCat® treated carrots dipped in chlorinated water and stored in EC were noticed, however not significant ($P > 0.05$). The conservation or loss of moisture was due to MAP and storage at EC temperature or the lack thereof, respectively. The moisture content of e carrots was therefore significantly affected with packaging and storage temperature ($P \leq 0.001$). Chlorin-disinfecting did not affect ($P > 0.05$) moisture loss, although the loss was significant at $P \leq 0.07$. Since these results basically are the same as that of PWL (Table 1), it can be concluded that the PWL observed, is mainly due to the loss of moisture, and not due to metabolic activity in the form of CO_2.

The changes in juice content (Table 3) explain nothing more than PWL and moisture loss. However, this analysis was included, mainly to investigate differences between ComCat® treated and control carrots, as a measurement of water binding, due to possible differences in structural components such as cellulose and other fibers. There are thus no differences of that kind.

Chemical changes

Total soluble solids (TSS)

The results presented in table 4 showed that, there was a

Table 3. Changes in juice content of carrots stored in evaporative cooling chamber and ambient temperature (RT) for 24 days.

	Juice Content (%)			
Treatment	**Day 0**	**Day 8**	**Day 16**	**Day24**
ComCat®, Cl_2, MAP, EC	64.467 ^{a}	62.193 ^{a}	60.194 ^{a}	59.062 ^{a}
Control, Cl_2, MAP, EC	60.421 ^{ab}	60.051 ^{ab}	58.625 ^{ab}	57.793 ^{ab}
ComCat®, Cl_2, EC	64.467 ^{a}	54.413 ^{bcd}	53.870 ^{bc}	51.208 ^{b}
Control, Cl_2, EC	60.421 ^{ab}	55.383 ^{bcd}	53.428 ^{abc}	52.547 ^{b}
ComCat®, H_2O, MAP, EC	64.467 ^{a}	60.509 ^{ab}	57.051 ^{abc}	57.030 ^{ab}
Control, H_2O, MAP, EC	60.421 ^{ab}	58.208 ^{abc}	56.125 ^{abc}	55.156 ^{ab}
ComCat®, Cl_2, MAP, RT	64.467 ^{a}	59.604 ^{bc}	52.516 ^{c}	51.058 ^{b}
Control, Cl_2, MAP, RT	60.421 ^{ab}	53.786 ^{cde}	49.346 ^{c}	46.698 ^{cd}
ComCat®, H_2O, EC	64.467 ^{a}	56.827 ^{bcd}	54.879 ^{bc}	52.728 ^{b}
Control, H_2O, EC	60.421 ^{ab}	54.247 ^{bcd}	51.047 ^{bc}	48.575 ^{bcd}
ComCat®, H_2O, RT	64.467 ^{a}	39.107 ^{e}	27.472 ^{d}	-
Control, H_2O, RT	60.421 ^{ab}	46.596 ^{de}	29.610 ^{d}	-
Significance				
Preharvest treatment (A)		NS		
Disinfecting treatment (B)		*		
Packaging + Storage temperature (C)		***		
A X B		NS		
A X C		NS		
B X C		**		
A X B X C		*		

NS, *, **, *** Non-significant or significant at P ≤ 0.09 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 coefficient of variation and standard error were 0.103 and 1.010 respectively. LSD Value = 9.089.

general trend of an increase in TSS of carrots during storage from around 8.3 to maximum 13.67 °Brix at EC after 24 days and as high as 18°Brix for carrots stored unpackaged at ambient temperature after 16 days. Lingaiah and Huddar (1991), Waskar et al. (1999) and Jitender-Kumar et al. (1999) also showed an increasing trend of TSS in carrots, but at lower numbers, that is, from 1.9 - 2.9°Brix, for packaged carrots stored in EC.

At harvest, the TSS content of ComCat® treated carrots was slightly lower than that of the control and remained that way during storage; however, these differences were not significant (P > 0.05). However, the two-way interaction between preharvest and prepackaging treatments was significant at P ≤ 0.09 on the changes in TSS of carrots. The effect of disinfecting carrots in chlorinated water was found to be not significant (P > 0.05) on the changes of TSS of carrots during storage. The combined effect of packaging and storage at environmental conditions were highly significant (P ≤ 0.001) on the TSS content of carrots.

The result also showed that there is an overall interaction (P ≤ 0.001) between prepackaging disinfecting of carrots, MAP and EC temperatures during storage. In general, the TSS of carrots was better maintained in the packaged carrots stored inside the EC. The TSS of carrots was affected by the interaction between the pre- and postharvest treatments during storage, however, only at a significance level of P ≤ 0.09. These results thus indicate that the quality of carrots may be maintained better by applying the combinations of pre- and post-harvest treatments such as ComCat® treatment, disinfect-ting, MAP and followed by EC during storage.

pH

The initial pH values of ComCat® and control carrots were 6.01 and 5.98 respectively, but the difference was not significant (P > 0.05) (Table 5). The pH of ComCat® treated carrots were maintained around 6.00 during the 24 days of storage in the EC. The pH of ComCat® treated carrots significantly (P ≤ 0.05) differed from the pH of control carrots after 8 days of storage at room temperature.

The changes in pH of the packaged ComCat® treated carrots dipped in chlorinated water showed significant (P ≤ 0.05) differences from that of the packaged control carrots treated with chlorine during storage at ambient temperature, although there was no significant difference in those stored at EC. MAP had a slight effect on the pH

Table 4. Changes in TSS of carrots stored in evaporative cooling chamber and ambient temperature (RT) for 24 days.

	Total soluble solid (°Brix)			
Treatment	**Day 0**	**Day 8**	**Day 16**	**Day 24**
ComCat®, Cl_2, MAP, EC	8.30 ^{ab}	10.77 ^{cd}	9.97 ^{c}	10.20 ^{d}
Control, Cl_2, MAP, EC	8.60 ^{a}	10.77 ^{cd}	10.20 ^{c}	11.40 ^{cd}
ComCat®, Cl_2, EC	8.30 ^{ab}	10.53 ^{cd}	11.30 ^{bc}	11.38 ^{cd}
Control, Cl_2, EC	8.60 ^{a}	11.43 ^{bc}	10.87 ^{bc}	13.67 ^{a}
ComCat®, H_2O, MAP, EC	8.30 ^{ab}	10.48 ^{cd}	9.96 ^{c}	10.67 ^{d}
Control, H_2O, MAP, EC	8.60 ^{a}	10.55 ^{cd}	9.25 ^{c}	11.50 ^{bcd}
ComCat®, Cl_2, MAP, RT	8.30 ^{ab}	10.50 ^{cd}	11.17 ^{bc}	12.73 ^{abc}
Control, Cl_2, MAP, RT	8.60 ^{a}	10.33 ^{cd}	10.97 ^{bc}	12.87 ^{ab}
ComCat®, H_2O, EC	8.30 ^{ab}	9.78 ^{d}	12.70 ^{b}	12.70 ^{abc}
Control, H_2O, EC	8.60 ^{a}	10.75 ^{cd}	11.23 ^{bc}	13.10 ^{a}
ComCat®, H_2O, RT	8.30 ^{ab}	14.87 ^{a}	18.15 ^{a}	-
Control, H_2O, RT	8.60 ^{a}	14.62 ^{a}	17.00 ^{a}	-
Significance				
Preharvest treatment (A)		*		
Disinfecting treatment (B)		NS		
Packaging + Storage temperature (C)		***		
A X B		*		
A X C		NS		
B X C		***		
A X B X C		*		

NS, *, *** Non-significant or significant at $P \leq 0.09$ 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 coefficient of variation and standard error were 0.077 and 0.084 respectively. LSD Value = 1.397.

of carrots. The rate at which the pH was increasing in packaged ComCat® treated carrots was lower, compared to unpackaged ones.

Similarly, general trends of rapid increase in pH of control carrots were noticed during storage. The storage temperature also affected the pH significantly ($P \leq 0.05$) during storage. As a general trend, a drop in pH of carrots was observed during storage at ambient temperature, which could be associated with higher rates of respiration, since acids are formed due to the catabolism of carbohydrates (Hao and Papadopoulos, 1999). However, the results of Hao et al. (1999) do not agree that packaging material and storage temperature significantly affected the pH of carrot s ($P \leq 0.05$).

Chlorine treatment had no significant effect on the pH of stored carrots, but the two-way interaction between postharvest treatment, that is, disinfecting treatment, MAP and storage temperature was highly significant. The combined effect of preharvest and disinfecting treatment was significant, but only at $P \leq 0.09$. There was also a significant two-way interaction between preharvest and MAP + storage temperature during storage at $P \leq 0.09$ level. The three-way interaction between ComCat® treatment, disinfecting treatment, MAP and storage temperature was found to be significant at $P \leq 0.05$ level.

Sugar analysis

The sugar dynamics during storage are shown in table 6. The non-reducing and total sugars of carrots decreased consistently during the 16 days of storage, while the reducing sugar contents seemed to increase in some carrot samples subjected to different treatments during 16 days, confirming the findings of Phan et al. (1973) and Nilsson (1987).

The ComCat® treatment significantly affected the changes in reducing sugars at $p \leq 0.09$). At harvest, there was no significant difference ($P > 0.05$) in total and non-reducing sugar content between ComCat® treated and untreated control carrots, however at $p \leq 0.09$, ComCat® treated carrots had a lower reducing sugar content compared to the controls. It should be mentioned that a concentration effect could play a role in the results, as it was noted that ComCat® treated carrots contain slightly more juice than the control carrots (Table 3).

After 16 days of storage, the highest total sugar content was maintained in disinfected and packaged carrots

Table 5. Changes in pH of carrots stored in evaporative cooling chamber and ambient temperature (RT) for 24 days.

	pH			
Treatment	**Day 0**	**Day 8**	**Day 16**	**Day 24**
ComCat®, Cl_2, MAP, EC	6.01 ^{a}	6.08 ^{bc}	6.08 ^{ab}	6.06 ^{a}
Control, Cl_2, MAP, EC	5.98 ^{ab}	6.02 ^{cde}	6.02 ^{bc}	6.06 ^{a}
ComCat®, Cl_2, EC	6.01 ^{a}	6.26 ^{a}	6.12 ^{a}	6.08 ^{a}
Control, Cl_2, EC	5.98 ^{ab}	6.04 ^{bcd}	6.06 ^{bc}	5.99 ^{bc}
ComCat®, H_2O, MAP, EC	6.01 ^{a}	6.08 ^{bc}	6.01 ^{bc}	5.98 ^{abc}
Control, H_2O, MAP, EC	5.98 ^{ab}	5.95 ^{de}	5.99 ^{cd}	6.03 ^{a}
ComCat®, Cl_2, MAP, RT	6.01 ^{a}	5.93 ^{de}	6.00 ^{bc}	5.87 ^{bc}
Control, Cl_2, MAP, RT	5.98 ^{ab}	5.91 ^{e}	5.91 ^{de}	5.64 ^{d}
ComCat®, H_2O, EC	6.01 ^{a}	6.11 ^{b}	6.02 ^{bc}	6.00 ^{ab}
Control, H_2O, EC	5.98 ^{ab}	5.98 ^{cde}	6.01 ^{bc}	6.03 ^{a}
ComCat®, H_2O, RT	6.01 ^{a}	6.12 ^{b}	5.84 ^{e}	5.84 ^{c}
Control, H_2O, RT	5.98 ^{ab}	5.98 ^{cde}	5.97 ^{cd}	5.97 ^{abc}
Significance				
Preharvest treatment (A)			**	
Disinfecting treatment (B)			NS	
Packaging + Storage temperature (C)			***	
A X B			*	
A X C			*	
B X C			***	
A X B X C			**	

NS, *, **, *** Non-significant or significant at P ≤ 0.09, 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 coefficient of variation and standard error were 0.010 and 0.004 respectively. LSD Value = 0.103.

stored at EC. This result shows that the postharvest treatments, such as disinfecting, MAP and EC, can maintain the chemical quality, regarding the sugars, better during short storage periods.

A considerable decrease in total sugar content was found in carrots stored at ambient temperature compared to EC. There was 74% depletion in total sugar content in unpackaged carrots stored at ambient conditions. The reason for this could be associated with a high respiration rate of carrots stored at relatively higher temperature. High temperature increases the metabolic activity and therefore also the activity of enzymes, responsible for biochemical reactions, in carrots during storage. Faster utilization of freely available sugars by microorganisms could also contribute to the reduction of sugars.

The interaction between disinfecting, MAP and storage temperature had a significant (P ≤ 0.05) effect on the changes in reducing sugars in carrots during 16 days at EC temperature. The reducing sugars were significantly higher in both ComCat® treated carrots and controls that were disinfected in chlorinated water, packaged and stored in EC. The two-way interaction between the preharvest ComCat® treatment and disinfecting had a significant (P ≤ 0.05) influence on the changes of non-reducing sugar content. The three-way interaction between the pre- and postharvest treatment on the changes of reducing sugar content of carrots was significant (P ≤ 0.09) during storage.

Microbiological changes

Total aerobic bacteria

Table 7 displays the estimated populations of total aerobic bacteria in stored carrots. The populations of total aerobic bacteria on carrots were significantly (P ≤ 0.01) affected by disinfecting in chlorinated water, which significantly reduced microbial populations for up to 16 days.
MAP had a significant effect (P ≤ 0.01) on the popu-lation of the total aerobic bacteria. The populations of total aerobic bacteria were lower in packaged carrots at the end of 16 days at EC, compared to those in unpackaged carrots.

Table 8 shows that, the estimated population of total aerobic bacteria was higher in carrots stored at ambient conditions, than in carrots stored in the EC for 8 days. A sharp increase in the populations of aerobic bacteria in

Table 6. Changes in reducing, non-reducing and total sugar contents of carrots stored in evaporative cooling chamber and ambient temperature (RT) for 24 days.

Treatment	Total Sugar (g/100g)		Reducing sugar (g/100g)		Non-reducing Sugar (g/100g)	
	Day 0	Day 16	Day 0	Day 16	Day 0	Day 16
ComCat®, Cl_2, MAP, EC	6.910 [a]	7.187 [a]	2.670 [a]	4.784 [a]	4.240 [ab]	2.978 [bc]
Control, Cl_2, MAP, EC	7.412 [a]	6.917 [a]	2.694 [a]	2.763 [b]	4.981 [a]	4.154 [ab]
ComCat®, Cl_2, EC	6.910 [a]	4.934 [b]	2.670 [a]	2.245 [bc]	4.240 [ab]	2.689 [c]
Control, Cl_2, EC	7.412 [a]	5.315 [b]	2.694 [a]	0.971 [d]	4.981 [a]	4.344 [a]
ComCat®, H_2O, MAP, EC	6.910 [a]	5.127 [b]	2.670 [a]	2.586 [bc]	4.240 [ab]	2.541 [c]
Control, H_2O, MAP, EC	7.412 [a]	3.782 [c]	2.694 [a]	1.948 [c]	4.981 [a]	1.835 [cd]
ComCat®, H_2O, EC	6.910 [a]	3.906 [c]	2.670 [a]	2.969 [b]	4.240 [ab]	0.936 [d]
Control, H_2O, RT	7.412 [a]	1.924 [d]	2.694 [a]	0.979 [d]	4.981 [a]	0.945 [d]

Significance	Total sugar	Reducing sugar	Non-reducing sugar
Preharvest treatment (A)	NS	*	NS
Disinfecting treatment (B)	***	**	***
Packaging + storage temperature (C)	****	****	*
A X B	*	NS	*
A X C	NS	NS	NS
B X C	*	**	NS
A X B X C	**	*	NS

NS, *, **, ***, **** Non-significant or significant at P ≤ 0.09, 0.05, 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 coefficient of variation and standard error were 0.195 and 0.180 for reducing sugar, 0.192 and 0.306 for non-reducing sugar and 0.086 and 0.217 for total sugar respectively. LSD Value = 0.836, 1.158 and 0.872 for reducing, non-reducing and total sugar respectively.

carrots stored at ambient temperature during the first few days were observed, followed by a slight drop thereafter. The reason for this was due to the availability of free moisture in carrots during the first few days, after which they tended to dry out, leaving less moisture for microbial development. The lower sugar contents in these carrots (Tables 2, 3 and 6) could also contribute to this observation.

The preharvest ComCat® treatment had an effect on the estimated populations of total aerobic bacteria at p ≤ 0.09. The preharvest ComCat® treatment was shown to have a significant effect on the pH of carrots during storage, which could be the reason for the effect of the preharvest treatment on microbial growth and their population during storage. The two- and three-way interactions between the preharvest treatment and postharvest treatments were not significant for the total aerobic microorganisms in carrots stored in EC.

Total moulds and yeasts

The populations of moulds and yeasts remained lower throughout the storage period of 16 days in ComCat® treated, packaged carrots dipped in chlorinated water and stored in EC (P ≤ 0.05) (Table 8). Disinfecting carrots in chlorinated water also highly affected (P ≤ 0.001) the populations of moulds and yeasts during 16 days of storage. This indicated that the use of EC combined with disinfecting treatments significantly reduced decay during storage.

Two-way interactions were observed between packaging + storage temperature and both preharvest treatment (P ≤ 0.05) and disinfecting treatment (P ≤ 0.001). With EC, the minimum temperature attained was only 16°C, which could mean that disinfecting carrots in chlorinated water would have little effect in reducing and limiting the growth of aerobic bacteria during higher storage temperature.

The other possible reason for the presence of higher microbial populations after disinfecting with chlorine, could be associated with the effect of the chlorine solution on the surface tissue of carrots (Seyoum et al., 2003), which could make conditions favorable for microorganisms to grow again. Work of other researchers on the EC of fruits and vegetables focused more on the physiological and chemical changes during evaporative cooling storage, without emphasis on the hazard of postharvest microbiological aspects (Roy and Pal, 1993; Pal and Roy, 1988; Waskar et al., 1999).

The relative humidity in this study was also high, aiding to the proliferation of microorganisms associated with

Table 7. Populations of total aerobic bacteria in carrots packaged or unpackaged and stored in evaporative cooling chamber or at ambient temperature (RT) for 16 days.

	Total aerobic bacteria (Log CFU/g)		
Treatment	**Day 0**	**Day 8**	**Day 16**
ComCat®, Cl_2, MAP, EC	4.845 ^{ab}	4.823 ^{d}	4.712 ^{c}
ComCat®, Cl_2, EC	4.845 ^{ab}	5.125 ^{cd}	5.273 ^{bc}
ComCat®, H_2O, MAP, EC	4.845 ^{ab}	5.996 ^{abc}	5.823 ^{b}
ComCat®, H_2O, EC	4.845 ^{ab}	6.378 ^{ab}	7.022 ^{a}
Control, Cl_2, MAP, EC	5.463 ^{a}	5.120 ^{cd}	5.038 ^{c}
Control, Cl_2, EC	5.463 ^{a}	5.697 ^{bcd}	5.822 ^{b}
Control, H_2O, MAP, EC	5.463 ^{a}	6.230 ^{abc}	6.664 ^{a}
Control, H_2O, RT	5.463 ^{a}	7.174 ^{a}	6.500 ^{a}
Significance			
Preharvest treatment (A)		*	
Disinfecting treatment (B)		**	
Packaging + storage temperature (C)		**	
A X B		NS	
A X C		NS	
B X C		NS	
A X B X C		NS	

NS, *, **, *** Non-significant or significant at P ≤ 0.05, 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 coefficient of variation and standard error were 0.093 and 0.268 respectively. LSD Value = 0.854.

Table 8. Populations of moulds and yeasts in carrots packaged or unpackaged and stored in evaporative cooling chamber or at ambient temperature (RT) for 16 days.

	Moulds and yeasts		
Treatment	**Day 0**	**Day 8**	**Day 16**
ComCat®, Cl_2, MAP, EC	4.521 ^{ab}	3.856 ^{d}	3.693 ^{d}
ComCat®, Cl_2, EC	4.521 ^{ab}	4.682 ^{c}	4.248 ^{d}
ComCat®, H_2O, MAP, EC	4.521 ^{ab}	5.534 ^{b}	5.460 ^{bc}
ComCat®, H_2O, EC	4.521 ^{ab}	5.686 ^{b}	5.655 ^{bc}
Control, Cl_2, MAP, EC	4.841 ^{a}	4.055 ^{d}	3.705 ^{d}
Control, Cl_2, EC	4.841 ^{a}	5.525 ^{b}	5.121 ^{c}
Control, H_2O, MAP, EC	4.841 ^{a}	5.824 ^{ab}	6.026 ^{ab}
Control, H_2O, RT	4.841 ^{a}	6.308 ^{a}	6.268 ^{a}
Significance			
Preharvest treatment (A)		*	
Disinfecting treatment (B)		***	
Packaging + storage temperature (C)		***	
A X B		NS	
A X C		*	
B X C		***	
A X B X C		NS	

NS, *, **, *** Non-significant or significant at P ≤ 0.05, 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 coefficient of variation and standard error were 0.063 and 0.082 respectively. LSD Value = 0.514.

Table 9. Percentage marketable carrots of different treatments after 4, 8, 12, 16, 20 and 24 days of storage at evaporative cooling and ambient temperatures (RT) for 16 days.

	Marketable carrots (%)						
Treatment	**Day 0**	**Day 4**	**Day 8**	**Day 12**	**Day 16**	**Day 20**	**Day 24**
ComCat®, Cl_2, MAP, EC	100 [a]	100 [a]	100 [a]	100 [a]	100 [a]	100 [a]	98.3 [a]
Control, Cl_2, MAP, EC	100 [a]	100 [a]	100 [a]	100 [a]	100 [a]	96.7 [ab]	95 [ab]
ComCat®, Cl_2, EC	100 [a]	100 [a]	100 [a]	96.7 [ab]	96.7 [ab]	86.7 [def]	85 [de]
Control, Cl_2, EC	100 [a]	100 [a]	100 [a]	96.7 [ab]	93.3 [abcd]	93.3 [abcd]	91.7 [abcd]
ComCat®, H_2O, MAP, EC	100 [a]	100 [a]	93.3 [abcd]	93.3 [abcd]	93.3 [abcd]	93.3 [abcd]	93.3 [abc]
Control, H_2O, MAP, EC	100 [a]	100 [a]	100 [a]	100 [a]	91.7 [abcde]	86.7 [def]	83.3 [e]
ComCat®, Cl_2, MAP, RT	100 [a]	83.3 [c]	71.7 [e]	55 [f]	43.3 [g]	26.7 [h]	15 [g]
Control, Cl_2, MAP, RT	100 [a]	90 [bc]	73.3 [e]	56.7 [f]	43.3 [g]	26.7 [h]	8.3 [g]
ComCat®, H_2O, EC	100 [a]	100 [a]	98.3 [ab]	88.3 [cde]	85 [ef]	81.7 [f]	81.7 [e]
Control, H_2O, EC	100 [a]	100 [a]	96.7 [ab]	86.7 [de]	83.3 [ef]	78.3 [fg]	78.3 [ef]
ComCat®, H_2O, RT	100 [a]	41.7 [d]	-	-	-	-	-
Control, H_2O, RT	100 [a]	40 [d]	-	-	-	-	-

Significance	
Preharvest treatment (A)	NS
Disinfecting treatment (B)	*
Packaging + Storage temperature (C)	***
A X B	NS
A X C	NS
B X C	**
A X B X C	NS

NS, *, **, *** Non-significant or significant at $P \leq 0.05$, 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 coefficient of variation and standard error were 0.052 and 0.826 respectively. LSD Value = 6.826.

fruits and vegetables. In general, the preharvest Com Cat® treatment had a slight effect on the improvement of the microbiological quality of carrots in terms of less total aerobic bacteria and mould and yeast populations during storage.

The result demonstrated the importance of combining effective disinfecting treatments with packaging and EC of carrots, particularly under hot and arid conditions. The combined effect of pre- and postharvest treatments, including EC, could aid to solve the problems identified by several workers in Ethiopia (Wolde, 1991; Storck et al., 1991; Kebede, 1991; Agonifar, 1991).

Subjective quality analysis

MAP, storage in EC, as well as disinfecting treatment of carrots in chlorinated water, had significant ($P \leq 0.05$) effects on the percentage marketability of carrots (Table 9). These results indicated that preharvest disinfecting treatments must be coupled with EC in order to decrease postharvest decay, insure a relatively longer shelf life of vegetables and maintain a better quality. It seemed as if the marketability of ComCat® treated carrots was, in general, somewhat better than the controls, however, not significantly ($P \leq 0.05$).

The combination of postharvest treatments including MAP and storage conditions, highly affected the marketability of carrots during the 24 days of storage, which was significant at $p \leq 0.001$ level. The percentage marketability of unpackaged carrots stored at ambient conditions dropped to 40% during the first 4 days of storage due to excessive dehydration and visible mould growth. Hardening of texture and visible mould growth were the problems in the case of packaged carrots stored at ambient conditions.

No sprouting of packaged carrots stored at ambient conditions was observed due to the high temperature that caused excessive dehydration. At EC, no sprouting was observed, which one of the major postharvest problems of carrots is during storage at temperatures higher than the advised storage temperature of 1°C (Berg and Lentz, 1966).

Conclusions

A forced ventilation EC unit was developed using cheap and locally available construction material in Ethiopia. This unit reduced the temperature by 8.4-13.4°C below ambient temperature, with a rise of relative humidity to 78 -91% during storage of carrots. The temperature and

relative humidity were maintained within constant limits, although the outside ambient temperature and relative humidity varied. The shelf life of carrots kept in the unit was dramatically increased from 4 days to 24 days, that is, 6 fold compared to storage at ambient conditions, mainly by preventing loss of moisture and controlling proliferation of microorganisms.

The quality of ComCat® treated carrots stored in the EC remained as good as the quality of the untreated control carrots. The PWL, loss in moisture and juice of carrots were slightly higher in untreated control carrots than in ComCat® treated carrots, although the differences were not significant ($P > 0.05$). The population of moulds and yeasts, pH value and total sugar content of carrots were affected significantly ($P \leq 0.05$) by the preharvest ComCat® treatment during 16 days of storage in EC. The ComCat® treated carrots had lower total sugars content at harvest. However, the effect of ComCat® treatment on reducing and non-reducing sugar was not significant ($P > 0.05$) at harvest as well as during the storage period of 16 days.

Disinfecting carrots in chlorinated water slightly affected non-reducing and reducing sugar content, population of total aerobic bacteria, moulds and yeasts, and marketability during the storage of carrots in EC, indicating its importance to be coupled with EC to maintain microbiological quality of carrots.

MAP + storage temperature improved all quality aspects tested. The physiology, biochemistry and microbiology of the root part of plants differ from the other physiological parts, such as fruit. The data obtained on the storability characteristics of ComCat® treated, (and control carrots) may not be appropriate to predict the storability of fruit by EC.

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