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Full Length Research Paper

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

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An evaporative cooler (EC) unit, which allowed an average drop of 11.5°C in temperature and a rise of 43.93% in relative humidity relative to environmental conditions was used to store tomatoes. The quality of tomatoes stored in this cooler were maintained better with more than 70% shelf life extension compared to tomatoes stored at ambient conditions. Preharvest ComCat® treated tomatoes contained lower TSS, reducing sugars and total sugars at harvest, and showed better keeping quality in terms of PWL, juice content, TSS and sugars, compared to untreated controls. No distinct effect of ComCat® treatment on microbial populations was found. Disinfecting with chlorinated water controlled total aerobic bacteria, moulds and yeasts during storage in the EC. MAP and EC temperatures helped to control weight loss, improve juice content, total aerobic bacteria, moulds and yeasts and resulted in lower pH of stored tomatoes. Microperforated MAP film prevented condensation inside packages and resulted in better marketability when combined with EC. The benefits from the combined effect of pre- and postharvest treatment on tomatoes include: reduction of PWL and loss of fruit juice, better keeping quality in terms of TSS, pH, non-reducing sugar content, total sugar content, microbiological quality, and marketability.

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

INTRODUCTION

Horticultural production gives a higher net value return to farmers in developing countries compared to other crop farming (Soerojo et al., 1991). Promotion of horticultural activities in Ethiopia is one of the means to improve the health status of the society (Haidar and Demissie, 1999; Wolde-Gebrial, 1993). During the years 1985-1988 of vegetables supplied to local market the quantity rejected was from 1.05-19.67%, the lowest being for cabbage and the biggest rejection being for tomatoes (Tadesse, 1991). Postharvest loss of tomato was reported to be greater than 25% during 1987-1988 crop season which was the highest compared to postharvest loss of melon, sweet potato, beet root, potato and onion (Tadesse, 1991). Also the production of tomato is limited mainly due to lack of production input, appropriate postahrvest handling methods and technology, especially packaging material and cooling (Kebede, 1991). However, literature review showed that there is no market problem for the fresh as well as processed tomato (US Dept. of Commerce, 1999a and 1999b). Since, agricultural inputs including fertilizers, pesticides, fungicides etc are imported from abroad, they are not affordable by the small scale scattered plot-farming society in Ethiopia. High yields of vegetables are desired to meet the ever-increasing consumer demand for food. Therefore, an alternative means of increasing yield of tomatoes and other vegetable could be sought to integrate productivity with ecologisation as well as consumer demand. ComCat® is a substance extracted from plants and consists of combinations of plant hormones (auxin, gibberellin, brassinosteroids, kinetins), aminoacids, natural metabolites and other ingredients, that were shown to increase the yield of vegetables (Schnabl et

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al., 2001). Carrots are a subsurface root part of a plant. The data obtained for carrots (Seyoum et al., 2003) may perhaps not be appropriate to predict the effect of preharvest ComCat® treatment on biological and biochemical changes in other parts of plants, such as the fruit, during storage. For comparison, an investigation on the effect of preharvest ComCat® treatment on biological and biochemical changes in a fruit was consequently carried out. In this respect, the performance of ComCat® treated tomatoes during storage is presented in this study. However, no data is available on the postharvest physiological, microbiological, chemical and biochemical quality aspects of preharvest ComCat® treated tomatoes. The environmentally friendly high yielding ComCat® treatment could be useful in this respect to increase yield. A question that should be answered is the postharvest performance of the high yielding ComCat® treated tomatoes at higher storage temperature and lower relative humidity. The major causes of tomato quality deterioration after harvest are associated with environmental factors such as temperature and relative humidity of the storage air. These factors play an important part in controlling tomato physiology, microbiological and chemical and biochemical changes after harvest. Higher temperature increases respiration rate and also activates enzymes responsible for off-flavor, loss of firmness and discoloration during storage. Low relative humidity favors physiological weight loss of vegetables. Therefore, the low temperature and relatively higher relative humidity should be retained in tomato store to maintain freshness quality. The optimum environmental conditions for tomato right after harvest, during transportation, storage and marketing could be maintained through cooling and humidification processes.

Several cooling methods such as room cooling, forced air cooling, hydrocooling, evaporative cooling (EC) and night ventilation cooling have been developed for maintaining storage temperature optimum to each crop during storage (Thompson et al., 1998). However, non-of these methods are applied in Ethiopia to maintain quality and reduce postharvest losses of tomatoes. Most of these methods are costly for most of those concerned with transportation, handling, storage and marketing of fresh vegetables in developing countries including Ethiopia. Evaporative cooling could be an ideal method for reducing temperature and increasing the relative humidity of storage air and product during storage. Evaporative cooling of vegetables is less costly and easy for construction from locally available materials and can be an efficient method for tomato storage for few weeks without quality deterioration (Seyoum and Kebede, 2000). In this study the principle of modified atmosphere packaging is combined with evaporative cooling for the first time. This is believed to enable us to generate preliminary data to further expand application of modified atmosphere packaging combined with evaporative cooling.

The objectives of the study are: to investigate the effecttiveness of forced ventilation EC in reducing temperature and increasing relative humidity during storage of tomatoes; to investigate the storability of preharvest ComCat® treated tomatoes using EC methods; and to explore the synergistic effect of pre-packaging treatments (chlorine supplemented water) when combined with modified atmosphere packaging and EC storage.

MATERIALS AND METHODS

Vegetable production

Tomatoes (*Leucopersicon esculentum*, cultivar malgrove) were grown during the summer season of 2001 at the experimental fields of the Haramaya University, in Eastern Ethiopia. ComCat® was administered by spraying tomato seedlings just before transplantation, and a second time at the start of flowering, with 10 g. ha^{-1} in 300 l water and, control plants with 0 g. ha^{-1}. All other agricultural practices were the same as those normally practiced by the University Farm Management Department during tomato production. Tomatoes were manually harvested at a green mature stage and immediately transported from the Haramaya University Campus to the Dire Dawa University Fruit and Vegetable Research Center, which is 30 km away. To protect the occurrence of mechanical injury during transportation tomatoes were packed in plastic crates.

Postharvest treatment

Tomatoes with visible defects were discarded. After washing, both ComCat® treated and untreated tomatoes were subjected to one of the following postharvest dipping treatments such as: dipping in chlorine supplemented water at ambient temperature that contained 100 µg ml^{-1} free chlorine made with sodium hypochlorite (5% NaOCl) for 20 min; 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 tomatoes were drip dried to avoid the occurrence of condensation inside the packages. Tomatoes were packed in 2 kg packages or unpackaged groups. Randomly, 2 kg samples of packaged or unpackaged tomatoes were taken from each of the 12 treatment replications and subjectted to physiological, microbiological and chemical analyses on each sampling time. Due to limited facilities, not all analyses could be carried out at all sampling times. PWL and percentage marketability were determined on 0, 4, 8, 12, 16, 20 and 24. Changes in juice content, TSS and pH were determined on days 0, 8, 16 and 24. The TTA, reducing sugar, total sugar, total aerobic bacteria and fungi population were determined on days 0, 8, and 16. Seventeen tomatoes from each treatment and replications were stored sepa-rately and used for subjective quality analysis.

Temperature and relative humidity measurement

The ambient air temperature and relative humidity were measured by using 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.

Physiological weight loss, moisture 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 PWL was determined by periodical weighing tomatoes on interval after packaging. The differential weight loss was calculated for each interval and converted into percentage by dividing the change with the initial weight recorded on each sampling interval. The cumulative PWL was expressed in percent with respect to different treatments.

Chemical analysis

The pH of tomatoes was measured with a TOA pH meter (model HM-20E, Ogawa Seiki Co., Ltd., Japan). The total soluble solids (TSS) was determined using 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 et al (1945). The same procedure was used to estimate reducing and total sugar in carrots during storage (Phan et al., 1973).

Total aerobic bacteria and fungi

The procedure used for estimating the microbial populations was the same as that of Brackett (1990). Samples of 25 g were sterilely blended with 225 ml 0.1% peptone water (pH 7.0) in a stomacher bag for 3 min manually. The slurries were serially diluted in 9 ml 0.1% peptone water. To determine populations of total aerobic microorganisms, duplicate samples were plated on plate count agar (PCA, Oxoid CM463, and pH 7.0±0.2) and incubated at 30ºC for 2 days. For the determination of moulds and yeasts, duplicate samples were plated on Rose-Bengal Chlorampehnicol Agar Base (Oxoid CM549) and incubated at room temperature for 3 to 5 days. In all the cases pour plate methods were used. The mean $\log_{10}$ of viable counts from duplicate plates were determined.

Subjective quality analysis

The descriptive quality attributes were assessed according to Mohammed et al. (1999). On each sampling time a package of tomatoes containing 5 fruit was randomly selected from each treatment group. The number of marketable fruit was used as measure to calculate the percentage marketable fruits during storage. A rating scale of 1 - 9 was used, with 1 = unusable, 3 = unsaleable 5 = fair, 7 = good and 9 = excellent. The colour, shininess, surface defects, signs of mould growth and dehydration were visual parameters for the rating. Tomatoes that 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) were 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 air-dry bulb temperature was 25 - 36.5°C with the average being 32°C during the 24 days of storage. The dry bulb temperature of the air inside the EC was found to be from 14.4 - 23.5°C with the average being 20.5°C during the storage period. An average drop in dry bulb temperature of 11.5°C was observed in this study. The air temperature is an important factor for controlling tomato flesh temperature. Higher temperatures increase the tissue temperature of tomatoes, which initiate biological and biochemical processes responsible for postharvest quality deterioration. Fresh horticultural commodities respire at rates which double, triple, or even quadruple for every 10°C increase in temperature (Sargent et al., 1991). It was therefore possible to reduce the temperature inside the EC by more than 10°C during storage, which in turn should have reduced the respiration rate of the tomatoes during storage. The relative humidity of the environmental air during the storage period was between 24.0 and 62.2% with an average of 40.0%. The relative humidity of the air inside the EC was 73.0 - 92.0% with an average of 83.9% during the storage period. The average difference between the inside and outside relative humidity during the storage period was 43.9%.During the storage period, the highest mean temperature and minimum relative of ambient air were found to be at 12:00 AM (Figure 1 (a) and (b)). As can bee seen for the figure, the average temperature increased with time from 6:00 to12:00 AM and starts to slightly drop there after.

Physiological weight loss (PWL), moisture content and juice content

Table 1 shows the PWL of tomatoes stored under evaporative cooling as well as ambient temperature. The Table 1 shows the PWL of tomatoes stored under evaporative cooling as well as ambient temperature. The PWL was

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

Treatment	Storage period, day					
	4	8	12	16	20	24
ComCat®, Cl_2, MAP, EC	1.660^{b}	3.437^{cde}	5.168^{cd}	7.343^{cde}	9.037^{bc}	10.474^{cde}
Control, Cl_2, MAP, EC	1.260^{b}	2.819^{de}	4.590^{ef}	6.208^{de}	9.641^{bc}	13.414^{ab}
ComCat®, Cl_2, EC	1.823^{b}	3.445^{cde}	4.733^{de}	7.714^{b}	9.942^{b}	12.079^{bcd}
Control, Cl_2, EC	2.436^{b}	4.951^{ab}	6.384^{bc}	8.417^{c}	11.157^{a}	13.744^{ab}
ComCat®, H_2O, MAP, EC	1.078^{b}	2.841^{de}	4.992^{cde}	7.474^{cde}	8.944^{c}	9.717^{def}
Control, H_2O, MAP, EC	1.577^{b}	3.133^{de}	4.873^{cde}	7.086^{cde}	9.796^{b}	12.106^{abc}
ComCat®, Cl_2, MAP, RT	3.473^{a}	6.807^{ab}	10.578^{a}	12.965^{ab}	-	-
Control, Cl_2, MAP, RT	3.059^{ab}	5.720^{ab}	8.828^{b}	11.758^{ab}	-	-
ComCat®, H_2O, EC	1.889^{b}	3.862^{abc}	4.790^{cde}	7.239^{de}	10.804^{ab}	13.790^{a}
Control, H_2O, EC	1.978^{b}	3.563^{bcd}	6.052^{cd}	8.332^{c}	10.294^{b}	12.559^{abc}
ComCat®, H_2O, RT	3.225^{ab}	7.600^{a}	9.531^{ab}	13.244^{a}	-	-
Control, H_2O, RT	3.459^{a}	6.375^{ab}	11.117^{a}	13.172^{ab}	-	-
Significance						
Preharvest treatment (A)			*			
Disinfecting treatment (B)			NS			
Packaging + Storage temperature (C)			***			
A X B			NS			
A X C			***			
B X C			NS			
A X B X C			NS			

NS, *, *** Non significant or significant at $P \leq 0.05$ 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 0.166 and 0.791 respectively. LSD Value = 2.213. Cl_2 = Chlorinated water dipping treatment.

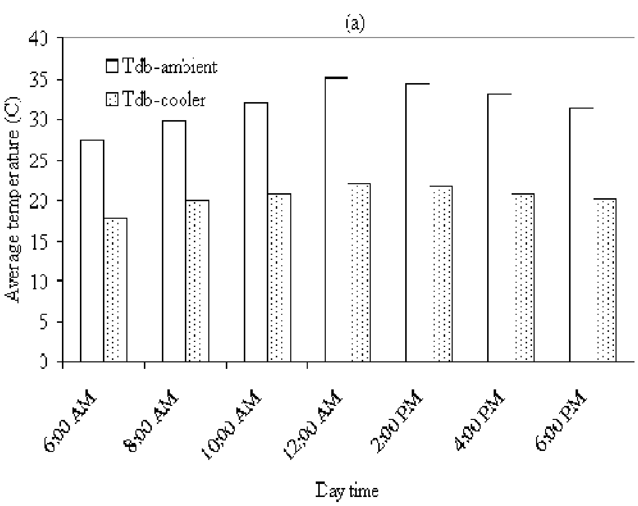

Figure 1 (a). The effect of daytime on the average environmental and evaporative cooler temperatures (°C) during storage of tomatoes.

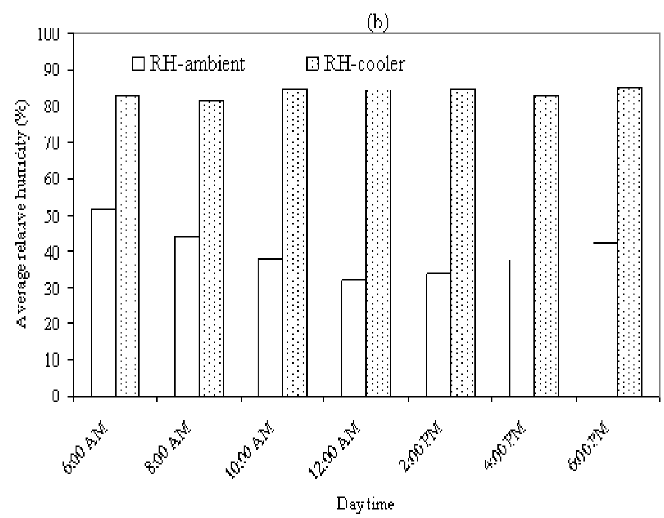

Figure 1 (b). The effect of daytime on the average environmental and evaporative cooler relative humidity (%) during storage of tomatoes.

higher in tomatoes stored at ambient temperature. While the PWL was between 10 and 13.5% for MAP tomatoes in EC after 24 days, the same PWL was reached within 16 days at ambient temperature storage. Preharvest treatment had a significant effect ($p \leq 0.05$) on PWL of the tomatoes. The PWL of ComCat® treated tomatoes seemed to be more during storage at ambient temperature. However, the PWL of disinfected and packaged ComCat® treated tomatoes was more up to 24 days of storage in EC. During 24 days of storage, the cumulative effect of modified atmosphere packaging and storage conditions were highly significant ($p \leq 0.001$) on the response of tomatoes to PWL. The moisture loss was significantly ($p \leq 0.001$) reduced with the help of MAP, reduced temperature and increased relative humidity during storage. It is known that EC reduces the loss of moisture, PWL and loss of juice content (Lingaiah and Huddar, 1991; Sunil et al., 1997; Ashok et al., 1999), which was also confirmed in the present study. Prepackaging dipping tomatoes either in chlorinated water or washing by tap water treatments had no significant ($p > 0.05$) effect on the PWL of tomatoes. The interaction between preharvest treatments, MAP and storage temperature for the PWL during the 24 days of storage was significant ($p \leq 0.001$).

At harvest the moisture content of tomatoes was found to be 94.421 and 93.980% for ComCat® treated and untreated samples, respectively, and remained above 90% during storage, with not much variation during the 24 days of storage, irrespective of the storage conditions. The recorded data are therefore not shown.

At harvest, the juice content was higher in ComCat® treated than in control tomatoes (Table 2), although not significant ($p > 0.05$). Although only significant in some cases, the ComCat® treated tomatoes maintained a higher juice content throughout the storage time in the EC. The packaging and storage temperature were the most important factors affecting the juice content of tomatoes and was highly significant ($p \leq 0.001$).

The interaction between disinfecting, MAP and storage temperature was highly significant ($p \leq 0.001$) on the changes in juice content of tomatoes during the 24 days of storage. During the same interval, the three-way interaction between pre- and postharvest treatments on the changes of juice content of tomatoes subjected to different pre- and postharvest treatments was significant ($p \leq 0.05$).

Chemical changes

Total soluble solid (TSS)

The ComCat® treatment did not express a significant ($p >0.05$) effect on the TSS of tomatoes at harvest (Table 3), but the effect was significant in few samples ($p \leq 0.05$) during storage. In general, the TSS increased during storage from around 4.6°Brix to almost 5.5°Brix in some cases. The results showed that the TSS content of ComCat® treated tomatoes generally remained higher during 24 days of storage in EC, compared to the control tomatoes. The changes in TSS were found to be faster in fruits stored at ambient conditions, which is supported by the work of Waskar et al. (1999) for pomegranate. Surprisingly, the effect of MAP and storage temperature on the TSS content of tomatoes was not significant ($p > 0.05$).The interactive effect of prepackaging chlorinated water disinfecting, MAP and storage temperature on the changes of TSS of tomatoes during storage was significant ($p \leq 0.05$). Similarly, the three-way interaction between pre- and postharvest treatments on the changes of TSS was also significant ($p \leq 0.05$). In general, there was a positive effect of pre- and postharvest treatments on the TSS content of tomatoes stored in EC, when compared to the TSS content of tomatoes stored at ambient conditions.

pH

At harvest the pH of ComCat® treated and controltomatoes were not significantly ($p>0.05$) different. There were also no significant ($p>0.05$) differences in the changes in pH values of ComCat® treated and control tomatoes during the 24 days of storage (Table 4). The pH of tomato juice increased continuously with the progress in storage period regardless of pre- and postharvest treatments from around 4.1 to as high as 4.6, which is in agreement with the results reported by Mohammed et al. (1999). The prepackaging chlorine disinfecting had a significant effect on the pH values of tomatoes during storage.

After 24 days in EC, the pH of disinfected, packaged tomatoes was significantly ($p \leq 0.05$) higher than the pH of water washed ComCat® treated tomatoes. The pH remained significantly ($p \leq 0.05$) higher in unpackaged, disinfected control tomatoes, compared to the ComCat® treated ones after 24 days in EC. However, the opposite trends were observed in the case of water washed, unpackaged control and ComCat® treated tomatoes stored in EC for 24 days. During 8 days of storage, the packaged, or unpackaged, tomatoes stored at ambient temperature displayed a lower pH compared with those stored in EC. After 24 days of storage, the pH of tomatoes were significantly ($p \leq 0.05$) higher in packaged samples stored in EC than that of unpackaged ones stored under similar conditions. This could be associated with the higher rates of respiration at relatively higher storage temperature, since acid is produced from catabolism of sugar.

The interactive effect of preharvest ComCat® treatment, packaging and storage conditions on the pH values of tomatoes was significant ($p \leq 0.001$). Similarly, the three-way interaction between all the pre-and postharvest treatments on the changes of pH values of tomatoes was highly significant ($p \leq 0.001$).

Total titratable acidity (TTA)

The TTA decreased dramatically in the tomatoes during

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

Treatment	Storage period, day			
	0	8	16	24
ComCat®, Cl_2, MAP, EC	64.698 [a]	61.138 [ab]	60.178 [ab]	59.046 [a]
Control, Cl_2, MAP, EC	61.796 [ab]	61.007 [ab]	56.985 [abc]	55.610 [abc]
ComCat®, Cl_2, EC	64.698 [a]	59.739 [bc]	52.674 [cd]	43.689 [def]
Control, Cl_2, EC	61.796 [ab]	54.291 [bcd]	48.010 [de]	40.259 [fg]
ComCat®, H_2O, MAP, EC	64.698 [a]	64.310 [a]	63.787 [a]	57.825 [ab]
Control, H_2O, MAP, EC	61.796 [ab]	59.961 [bc]	53.514 [bcd]	52.284 [bcde]
ComCat®, Cl_2, MAP, RT	64.698 [a]	53.763 [bcd]	52.325 [cd]	-
Control, Cl_2, MAP, RT	61.796 [ab]	47.818 [def]	45.761 [de]	-
ComCat®, H_2O, EC	64.698 [a]	61.499 [abc]	59.113 [ab]	57.483 [ab]
Control, H_2O, EC	61.796 [ab]	57.581 [abc]	50.682 [cde]	50.612 [bcde]
ComCat®, H_2O, RT	64.698 [a]	48.954 [def]	32.184 [fgh]	-
Control, H_2O, RT	61.796 [ab]	42.736 [fg]	35.917 [fg]	-
Significance				
Preharvest treatment (A)		NS		
Disinfecting treatment (B		NS		
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 $P \leq 0.05$ 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 0.088 and 0.935 respectively. LSD Value = 7.775.

ripening from the green mature to the red mature stages during 16 days of storage from around 0.6 to as low as 0.4 (Table 5), confirming the results of Shi et al. (1999). However, the TTA obtained in the current study were relatively higher, which could be due to the different growing practice or climate and soil type. At harvest, the TTA was higher in ComCat® treated tomatoes than in the control fruit, however, not significantly ($p > 0.05$) in this case. The effect of higher TTA on microbial populations associated with ComCat® treated tomatoes, compared to the controls was evident and is confirmed by the work of Mohammed et al. (1999). After 16 days storage, the TTA of ripe tomatoes was generally higher in ComCat® treated tomatoes than in the controls, suggesting that ComCat® treatment resulted in more acidity to protect against microbiological proliferation.

The TTA declined at a faster rate in controls than in ComCat® treated tomatoes during storage. The reduction in TTA in ComCat® treated whole tomatoes subjected to different postharvest treatments, and stored inside the EC for 16 days, varied from 22.5-27.9%. During the same interval, the reduction in TTA in control tomatoes subjected to the similar postharvest treatments varied between 26.4 and 34.1%. However, the difference in TTA was not significant ($p > 0.05$). After 16 days of storage, the highest loss of TTA in tomatoes stored at ambient temperature and humidity, was evident from the results presented in Table 5. The TTA in packaged ComCat® treated tomatoes dipped in chlorinated water and stored at ambient conditions was reduced by 32.3%, whereas the control tomatoes subjected to the same postharvest treatment had lost 34.4%. The TTA in unpackaged ComCat® treated and control tomatoes was reduced by 35.0 and 39.0%, respectively. These results showed that, the higher the storage temperature of fruit, the higher the reduction in the TTA during ripening and storage. This could be associated with rapid ripening and senescence properties of tomatoes when stored at higher

Sugar changes during storage

The total sugars decreased during the storage period temperatures. (Table 6). At harvest the total sugar content was significantly higher ($p \leq 0.05$) in ComCat® treated tomatoes compared to the controls, and remained higher ($p \leq 0.05$) through all the postharvest treatments and during 16 days of storage in EC. Again, this could be an indication of delayed ripening affected by the preharvest ComCat® treatment, while the sugar content was rapidly

Table 3. Changes in total soluble solids of tomatoes stored in evaporative cooling chamber and ambient temperature (24) for 24 days.

Treatment	Storage period, day			
	0	8	16	24
ComCat®, Cl_2, MAP, EC	4.575^{a}	4.867^{abcd}	4.700^{cde}	5.133^{abc}
Control, Cl_2, MAP, EC	4.690^{a}	4.883^{abcd}	4.500^{abcd}	4.767^{cde}
ComCat®, Cl_2, EC	4.575^{a}	5.333^{a}	5.483^{a}	5.483^{a}
Control, Cl_2, EC	4.690^{a}	4.700^{bcd}	4.367^{cde}	4.550^{de}
ComCat®, H_2O, MAP, EC	4.575^{a}	5.417^{a}	5.093^{abc}	4.867^{abcd}
Control, H_2O, MAP, EC	4.690^{a}	4.800^{bcd}	4.933^{de}	4.850^{bcd}
ComCat®, Cl_2, MAP, RT	4.575^{a}	5.100^{ab}	4.917^{ab}	-
Control, Cl_2, MAP, RT	4.690^{a}	4.967^{abcd}	4.533^{bcd}	-
ComCat®, H_2O, EC	4.575^{a}	4.267^{d}	5.000^{abcd}	4.900^{abcd}
Control, H_2O, EC	4.690^{a}	4.717^{bcd}	4.733^{abcd}	4.733^{cde}
ComCat®, H_2O, RT	4.575^{a}	4.800^{bcd}	5.193^{ab}	-
Control, H_2O, RT	4.690^{a}	5.067^{ab}	4.867^{abcd}	-
Significance				
Preharvest treatment (A)		*		
Disinfecting treatment (B)		NS		
Packaging + Storage temperature (C)		NS		
A X B		NS		
A X C		NS		
B X C		*		
A X B X C		*		

NS, *Non significant or significant at $P \leq 0.05$.
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 0.065 and 0.027 respectively. LSD Value = 0.505.

depleted in control tomatoes due to faster ripening. The total sugars decreased rapidly in the control tomatoes stored at ambient conditions compared to those stored in EC. In this case the EC retarded the ripening and sense-cence process, while the respiration and metabolism of tomatoes stored at ambient temperature was high, and utilized much of the available sugar. At harvest the control tomatoes contained a higher content ($p \leq 0.05$) of reducing sugars compared to the ComCat® treated ones, and remained so during storage (Table 6). In general, the reducing sugars decreased during 16 days of storage. The preharvest ComCat® treatment had a significant ($p \leq 0.05$) effect on the changes of reducing sugar contents of tomatoes during storage in EC, while the reducing sugar decreased faster in the controls. This could be due to a higher respiration rate of the control tomatoes. The calculated non-reducing sugar content increased during the first 8 days of storage and was followed by a faster decline in some of the tomatoes subjected to different post-harvest treatment. After 8 days of storage, ComCat® treated tomatoes had a higher content of non-reducing sugars, but after 16 days storage, this trend was not observed for the disinfected samples. The two-way interaction between postharvest treatments such as disinfecting and Map + storage temperature had a significant ($p \leq 0.01$) effect on the changes in total sugar and non-reducing sugar in tomatoes during 16 days at EC temperature. The two-way interaction between the preharvest Com-Cat® treatment and disinfecting had a significant ($p \leq 0.05$) influence on the changes in non-reducing sugar. Similarly, the three-way interaction between the preharvest treatment, disinfecting and Map + storage temperature on the changes of total sugar content of tomatoes was significant ($p \leq 0.05$) during storage. These results thus demonstrated that ComCat® treatment in general has an effect on the sugar content of tomatoes.

Microbiological changes

Total aerobic bacteria

Table 7 shows the changes in population of total aerobic bacteria in tomatoes during storage. The numbers of aerobic bacteria in tomatoes disinfected in chlorinated water were significantly ($p \leq 0.001$) decreased and remained low only up to 8 days, but then increased during storage in EC. Their growth was not suppressed to the same extend when compared to that of low tempera-

Table 4. Changes in pH of tomatoes subjected to different pre- and postharvest treatments and stored in evaporative cooling chamber and ambient temperature (RT) for 24 days.

Treatment	Storage period, day			
	0	8	16	24
ComCat®, Cl_2, MAP, EC	4.111 [a]	4.253 [ab]	4.347 [bc]	4.625 [a]
Control, Cl_2, MAP, EC	4.109 [a]	4.270 [a]	4.393 [ab]	4.640 [a]
ComCat®, Cl_2, EC	4.111 [a]	4.213 [abc]	4.180 [fgh]	4.180 [ij]
Control, Cl_2, EC	4.109 [a]	4.273 [a]	4.357 [ab]	4.490 [bc]
ComCat®, Cl_2, MAP, RT	4.111 [a]	4.180 [cd]	4.417 [a]	-
Control, Cl_2, MAP, RT	4.109 [a]	4.217 [abc]	4.273 [cd]	-
ComCat®, H_2O, MAP, EC	4.111 [a]	4.220 [abc]	4.360 [ab]	4.477 [bcd]
Control, H_2O, MAP, EC	4.109 [a]	4.260 [ab]	4.407 [a]	4.510 [b]
ComCat®, H_2O, EC	4.111 [a]	4.187 [abc]	4.243 [def]	4.317 [fg]
Control, H_2O, EC	4.109 [a]	4.223 [abc]	4.210 [efg]	4.210 [hi]
ComCat®, H_2O, RT	4.111 [a]	4.177 [bcd]	4.270 [cde]	-
Control, H_2O, RT	4.109 [a]	4.147 [cd]	4.200 [efg]	-
Significance				
Preharvest treatment (A)		NS		
Disinfecting treatment (B)		*		
Packaging + Storage temperature (C)		***		
A X B		NS		
A X C		***		
B X C		NS		
A X B X C		***		

NS, *, *** Non significant 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 coefficient of variation and standard error were 0.011 and 0.0258 respectively. LSD Value = 0.073.

ture refrigerated storage. MAP + storage temperature had a significant ($p \leq 0.001$) effect on the estimated population of total aerobic bacteria during the storage of tomatoes in EC. Compared with the other postharvest treatments, chlorinated water treatment coupled with MAP, were the best for both reducing and limiting the growth of aerobic bacteria during storage.

The population of aerobic bacteria was higher in packaged fruits washed in water than in unpackaged tomatoes subjected to chlorine disinfecting during storage in the EC. This clearly showed the danger of using MAP at higher storage temperatures. Obviously, the humidity in the headspace air of packaged products is high, and creates favourable conditions for the proliferation of microorganisms in packaged fruit and vegetables. The results therefore show that commodities should be disinfected prior to storage in EC. It should, however, be noted that, although water washed packaged tomatoes showed higher total aerobic bacteria populations than disinfected ones, the quality of the fruit remained good in the sense that no increased spoilage of edible flesh was noted. ComCat® had no significant ($p > 0.05$) effect on the aerobic bacteria in this experiment, although the aerobic bacteria population was higher in control than in ComCat® treated fruits at harvest, but not significantly (0 > 0.05). This coincides with the TTA being higher in ComCat® treated tomatoes, although also not significantly ($p>0.05$). The three-way interaction between the preharvest ComCat® treatment and postharvest treatments was significant ($p \leq 0.05$) on the changes in total aerobic bacteria during storage in the EC.

Total moulds and yeasts

The populations of moulds and yeasts was less on ComCat® treated tomatoes, although it had no significant ($p>0.05$) effect on their numbers, both at harvest and during storage (Table 8). The number of moulds and yeasts on tomatoes decreased after disinfecting or water washing, and stayed low up to 8 days in EC. The prepackaging disinfecting treatment was highly significant ($p \leq 0.001$) on the populations of moulds and yeasts during storage of tomatoes. These numbers stayed suppressed on the chlorine disinfected tomatoes up to 16 days storage in EC. The estimated number of moulds and yeasts highly increased in control tomatoes stored at ambient temperature, indicating the benefit of EC and MAP on the storage quality. The effect of MAP + storage temperature was highly significant ($p \leq 0.001$) on the numbers of moulds and yeasts.

Table 5. Changes in total titratable acidity (mg citric acid/100 g) of tomatoes subjected to different pre- and postharvest treatments and stored in evaporative cooling chamber and ambient temperature (RT) for 16 days.

Treatment	Storage period, day		
	0	8	16
ComCat®, Cl_2, MAP, EC	0.663^{a}	0.628^{a}	0.487^{ab}
Control, Cl_2, MAP, EC	0.637^{ab}	0.621^{a}	0.444^{abc}
ComCat®, Cl_2, EC	0.663^{a}	0.538^{abcd}	0.490^{ab}
Control, Cl_2, EC	0.637^{ab}	0.487^{cde}	0.420^{bc}
ComCat®, H_2O, MAP, EC	0.663^{a}	0.536^{abcd}	0.478^{ab}
Control, H_2O, MAP, EC	0.637^{ab}	0.516^{bcde}	0.465^{ab}
ComCat®, Cl_2, MAP, RT	0. 663^{a}	0.590^{abc}	0.449^{abc}
Control, Cl_2, MAP, RT	0.637^{ab}	0.570^{abc}	0.418^{bc}
ComCat®, H_2O, EC	0.663^{a}	0.505^{bcde}	0.514^{a}
Control, H_2O, RT	0.637^{ab}	0.496^{cde}	0.389^{c}
ComCat®, H_2O, RT	0.663^{a}	0.586^{abc}	0.431^{abc}
Control, H_2O, EC	0.637^{ab}	0.607^{ab}	0.469^{ab}
Significance			
Preharvest treatment (A)	NS		
Disinfecting treatment (B)	NS		
Packaging + Storage temperature (C)	NS		
A X B	NS		
A X C	NS		
B X C	*		
A X B X C	NS		

NS, * Non significant or significant at P ≤ 0.08, respectively.
[a, b, c, d, e] 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 0.100 and 0.012 respectively. LSD Value = 0.089.

Table 6. Changes in reducing, non-reducing and total sugar contents of tomatoes stored in the 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 8	Day 16	Day 0	Day 8	Day 16	Day 0	Day 8	Day 16
ComCat®, Cl_2, MAP, EC	5.101^{a}	4.665^{ab}	4.444^{ab}	3.867^{ab}	2.517^{bc}	3.206^{a}	1.233^{a}	2.148^{abc}	1.238^{cd}
Control, Cl_2, MAP, EC	5.227^{ab}	3.722^{de}	2.535^{e}	3.988^{a}	2.527^{bc}	1.174^{e}	1.240^{a}	1.195^{de}	1.361^{bcd}
ComCat®, Cl_2, EC	5.101^{a}	4.489^{abc}	3.706^{c}	3.867^{ab}	1.629^{d}	3.084^{ab}	1.233^{a}	2.860^{a}	1.380^{bc}
Control, Cl_2, EC	5.227^{ab}	3.834^{cde}	3.027^{de}	3.988^{a}	1.727^{cd}	1.644^{de}	1.240^{a}	1.584^{cd}	1.333^{bcd}
ComCat®, H_2O, MAP, EC	5.101^{a}	4.902^{a}	4.917^{a}	3.867^{ab}	2.929^{a}	2.304^{bcd}	1.233^{a}	1.973^{de}	2.613^{a}
Control, H_2O, MAP, EC	5.227^{ab}	4.106^{bcd}	3.502^{cd}	3.988^{a}	2.329^{bc}	2.075^{cd}	1.240^{a}	1.777^{cd}	1.427^{bcd}
ComCat®, H_2O, RT	5.101^{a}	4.282^{bcd}	4.006^{bc}	3.867^{ab}	2.755^{ab}	2.878^{abc}	1.233^{a}	1.527^{cde}	1.127^{cd}
Control, H_2O, RT	5.227^{ab}	3.399^{ef}	1.665^{f}	3.988^{a}	1.958^{c}	1.504^{de}	1.240^{a}	1.440^{cde}	0.161^{def}

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

NS, *, **, *** Nonsignificant 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 0.155 and 0.047 for reducing sugar, 0.322 and 0.266 for nonreducing sugar and 0.088 and 0.218 for total sugar respectively. LSD Value = 0.723, 0.760 and 0.622 for reducing, nonreducing and total sugar respectively.

Table 7. Populations of total aerobic bacteria (Log CFU/ml FW) in tomatoes packaged or unpackaged and stored in evaporative cooling chamber or at ambient temperature (RT) for 16 days.

Treatment	Storage period, day		
	0	8	16
ComCat®, Cl_2, MAP, EC	4.995 [ab]	3.146 [f]	3.763 [f]
Control, Cl_2, MAP, EC	5.089 [a]	3.646 [ef]	4.115 [de]
ComCat®, Cl_2, EC	4.995 [ab]	4.204 [de]	4.706 [bcd]
Control, Cl_2, EC	5.089 [a]	4.155 [de]	4.528 [cde]
ComCat®, H_2O, MAP, EC	4.995 [ab]	5.617 [abc]	5.227 [ab]
Control, H_2O, MAP, EC	5.089 [a]	5.850 [ab]	5.397 [a]
ComCat®, H_2O, EC	4.995 [ab]	5.945 [ab]	5.037 [abc]
Control, H_2O, RT	5.089 [a]	6.187 [a]	-
Significance			
Preharvest treatment (A)	NS		
Pre packaging treatment (B)	***		
Packaging + storage temperature (C)	***		
A X B	NS		
A X C	NS		
B X C	NS		
A X B X C	*		

NS, *, *** Nonsignificant or significant at P ≤ 0.05 or 0.001, respectively.
[a, b, c, d, e, f] 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 0.064 and 0.088 respectively. LSD Value = 0.522.

Table 8. Populations of moulds and yeasts (Log CFU/ml FW) in tomatoes packaged or unpackaged and stored in the evaporative cooling chamber or at ambient temperature (RT) for 16 days.

Treatment	Storage period, day		
	0	8	16
ComCat®, Cl_2, MAP, EC	4.208 [a]	3.144 [d]	3.326 [d]
Control, Cl_2, MAP, EC	4.186 [a]	3.844 [cd]	3.796 [d]
ComCat®, Cl_2, EC	4.208 [a]	3.398 [d]	4.099 [cd]
Control, Cl_2, EC	4.186 [a]	3.451 [d]	4.350 [bcd]
ComCat®, H_2O, MAP, EC	4.208 [a]	3.787 [d]	5.121 [abc]
Control, H_2O, MAP, EC	4.186 [a]	3.845 [cd]	5.107 [abc]
ComCat®, H_2O, EC	4.208 [a]	4.391 [bcd]	5.107 [abc]
Control, H_2O, RT	4.186 [a]	6.046 [a]	-
Significance			
Preharvest treatment (A)	NS		
Prepackaging treatment (B)	***		
Packaging (C)	**		
A X B	NS		
A X C	NS		
B X C	NS		
A X B X C	NS		

NS, **, *** Nonsignificant or significant at P ≤ 0.01 or 0.001, respectively.
[a, b, c, d] 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 0.155 and 0.128 respectively. LSD Value = 1.088.

Table 9. Percentage marketable ComCat® treated and control tomatoes subjected to different treatments after 4, 8, 12, 16, 20 and 24 days of storage at evaporative cooling and ambient temperatures (RT) for 24 days.

Treatment	Storage period, day						
	0	4	8	12	16	20	24
ComCat®, Cl_2, MAP, EC	100^{a}	100^{a}	100^{a}	100^{a}	96.3^{a}	90.7^{a}	83.3^{a}
Control, Cl_2, MAP, EC	100^{a}	100^{a}	100^{a}	100^{a}	92.6^{ab}	85.2^{abc}	79.6^{ab}
ComCat®, Cl_2, EC	100^{a}	100^{a}	96.3^{ab}	90.7^{abcd}	74.1^{ef}	68.5^{fgh}	68.5^{cdef}
Control, Cl_2, EC	100^{a}	100^{a}	100^{a}	98.5^{ab}	87.0^{abc}	75.9^{cdef}	64.8^{efg}
ComCat®, Cl_2, MAP, RT	100^{a}	96.3^{ab}	75.9^{cd}	46.3^{e}	44.4^{gh}	-	-
Control, Cl_2, MAP, RT	100^{a}	92.6^{ab}	70.4^{de}	46.3^{e}	46.3^{g}	-	-
ComCat®, H_2O, MAP, EC	100^{a}	100^{a}	98.2^{ab}	96.3^{ab}	92.6^{ab}	85.2^{abc}	75.9^{abcd}
Control, H_2O, MAP, EC	100^{a}	100^{a}	100^{a}	98.5^{ab}	98.2^{a}	90.7^{a}	77.8^{abc}
ComCat®, H_2O, EC	100^{a}	100^{a}	98.5^{ab}	92.6^{ab}	85.2^{bcd}	70.4^{efg}	55.6^{g}
Control, H_2O, EC	100^{a}	100^{a}	96.3^{ab}	94.4^{abc}	75.9^{de}	66.7^{fhg}	59.3^{fg}
ComCat®, H_2O, RT	100^{a}	85.2^{c}	64.8^{ef}	35.2^{fg}	27.8^{i}	-	-
Control, H_2O, RT	100^{a}	83.2^{cd}	61.1^{f}	31.5^{g}	29.6^{i}	-	-

Significance	
Preharvest treatment (A)	NS
Pre packaging 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 $P \leq 0.05$ or 0.001, respectively.

$^{a, b, c, d, e, f, g, h, i}$ 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 0.070 and 1.276 respectively. LSD Value = 9.045.

Subjective quality analysis

The percentage marketable fruits decreased rapidly during 12 days of storage at ambient conditions (Table 9). After 12 days of storage at ambient conditions, the packaged fruits were over 53% unmarketable. During the same interval, unpackaged fruits stored at ambient condition dropped to below 30% marketability due to excessive moisture loss, as well as decay. Similar findings were reported by Ashok et al. (1999) who showed that unwrapped and wrapped tomatoes became unacceptable after 3 and 10 days at ambient temperature respectively. According to this author, the main reason for unacceptability of these tomatoes was PWL. However, in the current study, over-ripening and soft rot were the most serious problems associated with tomatoes stored at ambient temperature and humidity.

Tomatoes stored in EC fared better, as the temperature inside the store was nearer to the optimum temperature of 13°C for storage of tomatoes than the ambient temperature. Packaged tomatoes could then be kept for more than 24 days without loss of freshness quality inside the EC. All packaged ComCat® treated tomatoes, as well as controls, disinfected in chlorinated water were 100% marketable up to 12 days in EC storage. After 12 days of storage, the percentage marketability of these fruit remained higher than 96%.

Preharvest ComCat® treatment had no significant effect on the marketability of tomatoes after storage in EC, but the interactive effect of pre- and postharvest treatments on the marketability of tomatoes was found to be significant at $p \leq 0.05$. The percentage marketable ComCat® treated packaged fruits disinfected in chlorinated water was found to be 3.7% higher than the control fruits subjected to the same postharvest treatment. After 24 days at EC, the packaged ComCat® treated tomatoes that were dipped in chlorinated water showed the highest percentage marketability.

Previous studies by Acedo (1997) also showed that the prestorage treatment delayed the ripening and reduced incidence of decay, supporting the results obtained in this study. It was noticed that a colour change from green at harvest to red was most retarded in packaged tomatoes stored in EC. These results therefore demonstrated the importance of combining preharvest treatment aimed at increasing yield and quality, with proper postharvest treatments to improve the shelf life and maintain the quality of perishable vegetables such as tomatoes under hot and dry climatic conditions.

The higher relative humidity in the EC, which was higher than that of the room temperature helped to improve the marketability. In the EC, tomatoes were only 83 and 79% marketable after 24 days storage for the ComCat® treated and control tomatoes, respectively, compared to the 75 and 77% at the room temperature conditions. The water washed samples showed a similar difference.

Conclusions

An EC unit that maintained a temperature between 14.4 and 23.5°C and relative humidity between 73.0 and 92% during storage was used to store tomatoes. The higher humidity was advantageous for maintaining some of the chemical quality characteristics such as moisture content and TSS, but seemed to favour microbial growth due to a combined effect with high temperature. The quality parameters tested were maintained better in EC, and resulted in an extension of over 70% in shelf life of tomatoes. This method has been shown to have great potential for application in the study site in Ethiopia to reduce huge postharvest vegetable losses. It is suggested that the EC air temperature can be further reduced until it falls in the range of 8-13°C, which is optimum for tomato storage, by installing a multi-stage EC pad connected in series.

At harvest, the green mature ComCat® treated tomatoes contained lower TSS, reducing sugar, non-reducing sugar, and total sugar. These parameters also remained higher in ComCat® treated tomatoes during storage in EC. The PWL, TSS, sugars were significantly ($p \leq 0.05$) affected by the preharvest ComCat® treatment during storage in EC. Preharvest ComCat® treatment of tomato plants can therefore contribute to improve quality of tomatoes during storage in EC. Disinfecting treatment of tomatoes did not have any effect on the chemical parameters during storage in EC, although, the pH of tomatoes was significantly ($p \leq 0.05$) influenced by this treatment resulting in an increase in pH. The disinfecting treatment significantly affected the postharvest microbial populations associated with tomatoes stored in EC.

Protection against microorganisms resulted in the marketability of tomatoes being significantly higher ($p \leq 0.001$). These results showed that the postharvest disinfecting treatment was important to control decay, although not as effective as at low temperature storage. It is possible that the high humidity of the EC contributed to the re-establishment of microorganisms.

MAP in microperforated Xtend® film, together with the storage temperature in EC, had a highly significant ($p \leq 0.001$) effect on the PWL, juice content and pH of stored tomatoes, but had no significant effect on the reducing, non-reducing and total sugars, and TTA of the tomatoes. It had a highly significant ($p \leq 0.001$) effect on the total aerobic bacteria, and moulds and yeasts during storage of tomatoes in the EC. MAP + storage temperature in EC reduced the rate of ripening of tomatoes and PWL during storage, and resulted in significant ($p \leq 0.001$) improvement of the marketability of tomatoes. The microperforations associated with Xtend® film had several benefits such as preventing condensation and maintaining optimum gas levels for normal respiration.

The combinations of preharvest ComCat® treatment of tomato plants, disinfecting, and MAP storage in EC was shown to benefit the storage quality of tomatoes. A higher juice content was obtained, higher contents of TSS and total sugars, lower pH and lower growth by aerobic bacteria and finally, better marketability, compared to the controls. Since the latter room temperatures and the temperature in EC were almost the same, it seems as if the high relative humidity when combined with relatively high EC temperature, used in this study, may contribute to faster deterioration of tomatoes. Adaptation of the EC to lower temperatures should therefore also incorporate alterations to address the relative humidity, otherwise higher relative humidity ranging from 85% up to 90% are desirable for tomato storage.

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