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Effect of maturity stages, variety and storage environment on sugar content of tomato stored in multiple pads evaporative cooler

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The effect of cultivar, maturity stage and multi-pads evaporative cooling on sugar content, weight loss and marketability of tomatoes (*Lycopersicon esculentum* Mill.) was investigated. The experiment was conducted by combining cultivars, maturity stages and storage conditions in randomized complete block design. At harvest, Marglobe harvested at light-red stage showed higher total sugar and reducing sugar content compared to those in Roma VF, whereas the lowest total sugar and reducing sugar content were recorded in Roma VF harvested in mature-green stage. The overall total sugar and reducing sugar content of tomato fruit was maintained better in Roma VF harvested at mature-green and turning stages than Marglobe harvested at mature-green stage when stored under multiple pads evaporative cooling conditions. The cooling system maintained higher concentration of sugars, lower water loss and higher marketability during storage when compared to storage under ambient conditions. This study clearly demonstrated the importance of integrated agro-technology of combining cultivar, maturity stage and storage environment in shelf life improvement of tomato by reducing the rate of ripening and utilization of sugar, reducing water loss and maintaining marketability.

Key words: Tomato, maturity stage, cultivar, evaporative cooling, storage, reducing sugar, total sugar.

INTRODUCTION

Growing and marketing of fresh produce in Ethiopia is complicated by high postharvest losses, which are about 30% (EARO, 2000; Workneh et al., 2011a, b, c). This high loss is due to packaging, storage facilities and poor means of transportation such as human labor, donkeys and mules, public transport and rented trucks (Kebede, 1991, Awole et al., 2011). Research result suggests that the selection and careful handling of perishable products determine the quality of fresh produce. Harvesting products at optimum maturity, maintaining higher sanitation standards, decreasing injury incidence and maintaining environmental conditions guarantee excellent postharvest quality (Zagory and Kader, 1988, Workneh et al., 2011a, b, c).

Fresh produce needs low temperature and high relative humidity during the storage and transportation. Reduced temperature decreases physiological, biochemical and microbiological activities, which are the causes of quality deterioration such as flavor and colour (Kader et al., 1989; Workneh and Woldetsadik, 2004; Workneh et al., 2011a, b, c). The temperature of the surrounding can be reduced by zero energy cooling system (Rayaguru et al., 2010). Similarly, temperature of the surrounding air and produce can be reduced by forced air cooling, hydro cooling, vacuum cooling, ice cooling and adiabatic cooling (Thompson et al., 1998). However, those cooling methods with the exception of adiabatic cooling are expensive for small-scale peasant farmers, retailers and whole sellers in developing tropical regions, as they require high initial cost. In spite of that however, it is essential to control storage temperature and relative humidity during storage, as they are the main causes of fruit and vegetable deterioration during the ripening and

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storage. This can be achieved by using less expensive methods of cooling such as single pad evaporative cooler (Workneh and Woldetsadik, 2000, 2004).

In the evaporative cooled storage chamber, air temperature is decreased from 36 to 16.4°C, while relative humidity is increased from 25.4 to 91.1%, which is appropriate for reducing postharvest losses of fruits and vegetables due to physiological weight loss (Workneh, 2010). The forced ventilation evaporative cooler was found to be more effective in reducing storage air temperature by about 10°C with a rise in relative humidity by more than 27% during the storage over the ambient condition at relatively warmer area such as Dire Dawa (Workneh and Woldetsadik, 2004; Workneh et al., 2011a, b, c). On the other hand, Getinet et al. (2008) showed the influence of tomato cultivar and maturity stage on the postharvest quality of tomatoes stored under different conditions. Compositional changes are one of the most important indicators of tomato quality changes during storage. However, the effects of this low-cost multi-pads evaporative cooling system on the changes in sugars, a substrate in the respiration process, have to be investigated. Therefore, the objective of this study was to evaluate the changes in sugar content of two tomato varieties (Marglobe and Roma VF) harvested at three maturity stages and stored under multi-pads evaporative cooling system and ambient conditions.

MATERIALS AND METHODS

Sample preparation and storage

Two tomato cultivars ('Marglobe' and 'Roma VF') were grown from July to October 2006 at the Fruit and Vegetable Research field of the Haramaya University, under supplementary irrigation. Fertilizer was applied at the rate of 200 kg ha⁻¹ DAP at planting and 200 kg urea ha⁻¹ half at planting followed by a top dressing 30 to 60 days after transplanting. Marglobe, which has globular shape and an average fruit weight of 130 g, is commonly used for fresh market (Lemma, 2002). It has indeterminate growth habit. The cultivar Roma VF is a processing type with determinate growth habit. It has pear-shaped fruit with 2 to 3 locules, having average fresh weight of 55 g. Fruits were harvested at mature-green, turning, and light-red maturity stages. Fruits maturation was closely monitored and was determined in the field using colour chart of USDA (1991) depending on external colour of tomato fruit. Harvesting was carried out early in the morning and manually with care to minimize mechanical injury. Fruit with bruises, sign of infection or those different from the group were discarded from the samples. Uniform, unblemished tomatoes having similar size and colour were then selected and hand washed with tap water to remove field heat, soil particles, and to reduce microbial population on the surface. Then, the fruits were surface dried with new soft cloth which was clean from any contaminating materials, subdivided and then stored in evaporative cooling and at room temperature in three replications. Sample from each treatments and replication was taken for sugar analysis every four days starting from the day of harvest.

The cooler used in this study consisted of three major units: The air condition unit, watering pipe system and cool storage chamber (Figure 1). The chamber had an adiabatic cooling process whereby the air blowing in took some moisture and cooled down while passing through wet pad. The water distribution system was

designed so that the water is continuously pumped to the top surface of the cooler and to the cooling pad. The top surface of the structure was designed to enable water run down the four vertical surfaces by gravity into a water tank (Workneh and Woldetsadik, 2004). The dry bulb air temperature inside the evaporative cooling system was monitored by thermocouples at the center of the middle shelf. An air vent was inserted in the top of the cooler. The three side surfaces and the door were covered with a thin pad of 5 mm jute sack, which was sandwiched between sheet metal on the inside, and mesh wire on the outside facing the ambient air, to allow evaporation. The storage air temperature and relative humidity were measured throughout the storage period. Temperature was recorded using digital psychrometer (ALNOR®- Model 8612 S/N03057107) attached to thermocouples located in the evaporative cooler and outside of the evaporative cooler to record ambient temperature. The readings were taken at 2 h intervals during the daytime over the study period. The relative humidity of the air was monitored within the psychrometer used for temperature measurement, which was located at the center of the evaporative cooler and outside the evaporative cooler in an open air where the tomatoes were stored.

To calculate the cooling efficiency of the evaporative cooler, the cooler dry bulb temperature and ambient air dry bulb and wet bulb temperatures were recorded. Cooling efficiency (η) is an index used to assess the performance of evaporative cooler and was calculated using the following formula as described by Koca et al. (1994):

$$\eta = \frac{T_d - T_c}{T_d - T_w} \times 100$$

Where, T_d and T_w are the dry and wet bulb temperatures of the ambient air, respectively and T_c is the dry bulb temperature of air in the cooling chamber.

Treatments and experimental design

A factorial combination of two tomato cultivars, three maturity stage and two storage treatments with three replications were used in the study. The treatments were arranged in a randomized complete block design. A total of 162 kg of Roma VF and 162 kg of Marglobe were prepared for storage under ambient conditions and multi-layer pads evaporative cooling conditions. Each one of the three maturity stage consisted of 54 kg of Roma VF and Marglobe, which was subdivided into two lots of 27 kg (nine kg of three replications) in preparation for storage under ambient and evaporative cooling conditions. In order to avoid occurrence of error due to the effect of variations in air conditions at different locations inside the cooling chamber, the tomato samples were randomized by placing first replication on the bottom shelf, second replication on the middle shelf and the third replication on the top shelf. On each sampling date, a sample of 1 kg tomatoes was randomly taken from each replication in the treatment for quality analysis. Data were recorded on 0, 4, 8, 12, 16, 20, 24, 28 and 32 days after storage. Samples of tomatoes were randomly taken from each treatment for quality analyses.

Sugar analysis

Reducing and total sugars were estimated by using the calorimetric methods (Somogyi, 1945). Clear juice (10 ml) was added to 15 ml of 80% ethanol, mixed, and heated in a boiling water bath for 30

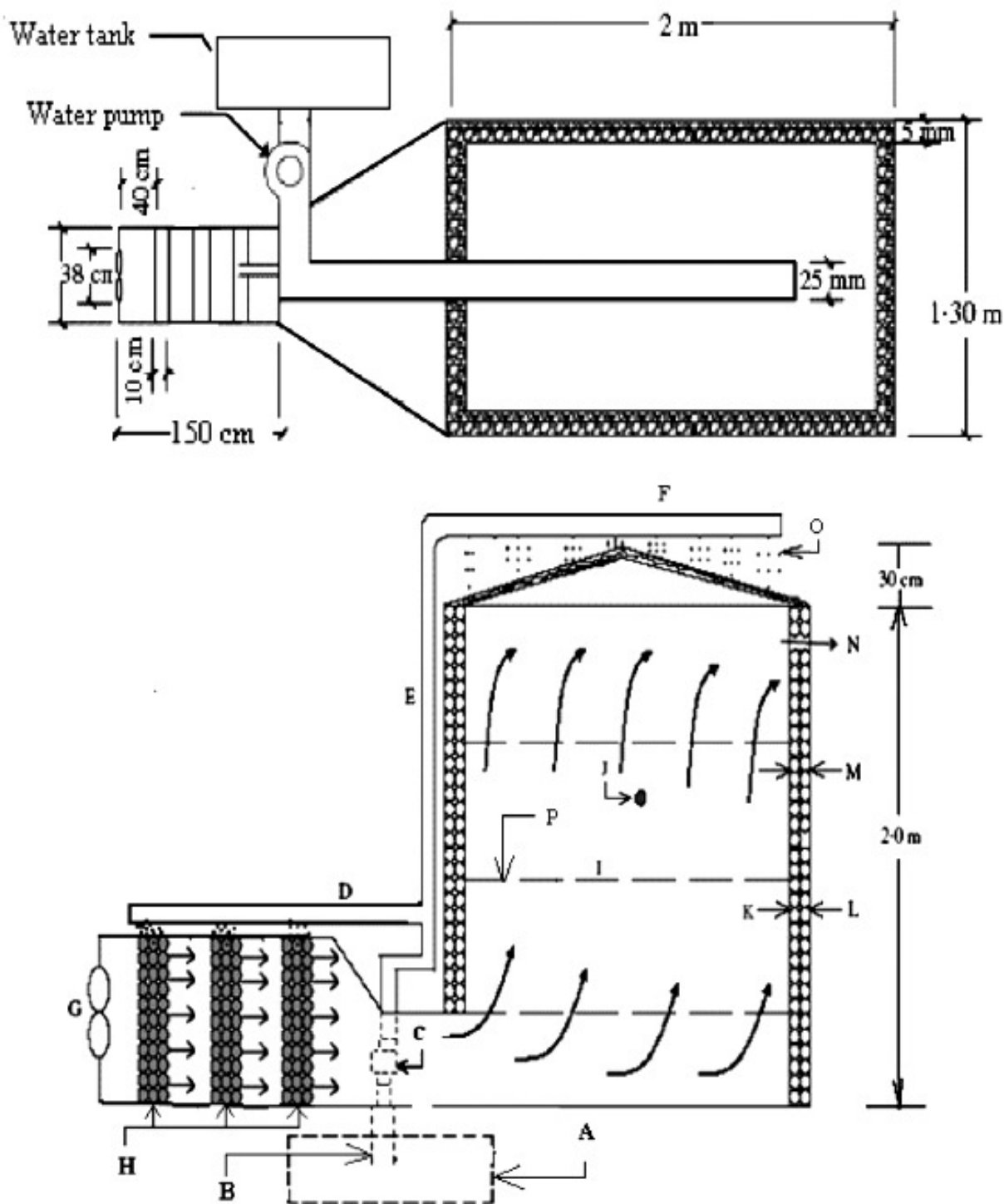


Figure 1. Schematic diagram of an experimental evaporative cooler: (A) water tank; (B) vertical pipe connected to water pump; (C) water pump (0.5 hp); (D) water hose to cooling pad; (E) vertical water pipe; (F) perforated horizontal water pipe; (G) fan; (H) cooling pad layers (charcoal); (I) storage chamber; (J) location of thermocouple and hygrometer; (K) sheet metal; (L) mesh wire; (M) wet jute sack layer; (N) ventilation port; (O) water dripping from horizontal water pipe; (P) shelves.

min. After extraction, 1 ml of saturated lead acetate ($\text{Pb}(\text{CH}_3\text{COO})_2 \cdot 3\text{H}_2\text{O}$) and 1.5 ml of saturated sodium hypophosphate (Na_2HPO_4) were added and the contents were mixed by shaking

gently. After filtration, the extract was made up to 50 ml with distilled water. An aliquot of 1 ml extract was taken and diluted to 10 ml with distilled water. Then, 0.5 ml aliquot of extract was taken and was

made up to 1 ml. To these, 1 ml of copper reagent was added in a test tube and heated for 20 min in a boiling water bath. Furthermore, after heating, the contents were cooled under running tap water without shaking. Arsenomolybdate colour reagent was added, mixed, made up to 10 ml, and left for about 10 min to allow colour development, after which the absorbance was determined by a spectrophotometer at 540 nm. For total sugar determination, sugar was first hydrolyzed with 1 N HCl by heating at 70°C for 30 min. After hydrolysis, the determination of total sugar was made by following the same procedure employed for the reducing sugar. Blanks were prepared using distilled water.

Data analysis

The difference between the treatments was determined by analysis of variance (ANOVA) for factorial experiment in randomized complete block design using MSTAT-C software (MSTAT, Michigan) and comparison of the treatment mean by Duncan's multiple range test.

RESULTS AND DISCUSSION

Temperature, relative humidity and cooling efficiency

The ambient dry bulb air temperature and relative humidity during the storage period varied from 23 to 39.5°C and 22 to 60%, respectively. Inside the evaporative cooler, the dry bulb temperature and relative humidity varied from 14 to 19°C and 82 to 96%, respectively (Figure 2). The ambient dry bulb air temperature and relative humidity varied from 28.3 to 36.3°C and 39 to 58% during the storage period, respectively. Previous findings showed that evaporative cooler maintained the temperature between 14.4 and 23.5°C and relative humidity between 73 and 92% during storage periods (Seyoum and Woldetsadik, 2004). In this study, the ambient dry bulb air temperature and relative humidity varied from 23 to 43°C and 16 to 79% during the storage period, respectively. The average differences in dry bulb temperature between ambient and inside the cooler was 15.14°C, whereas the average difference in relative humidity was found to be 54.83% during the 32 days of storage. It has been reported that ripe tomato can be stored for relatively longer period under temperature and relative humidity range of 10 to 15°C and 85 to 95%, respectively (Castro et al., 2005). In this study, it was noted that evaporative cooling system brought about similar conditions for tomato storage. Higher relative humidity and lower temperature was obtained in the multi-layer pads evaporative cooler compared with single pad evaporative cooler within the same geographical location (Tefera et al., 2007; Workneh et al., 2009a, b). The improvement in effectiveness of the evaporative cooler pad in lowering temperature and increasing relative humidity as compared to single pad evaporative cooler appeared to be due to the introduction of additional two cooling pads in the air passage of psychrometric unit. As air flows through the three pads,

heat was transferred from the dry air stream to the fluids in the wet pads. The air while passing three times through the three moist pads would pick up humidity from each pad and eventually cool down and add more moisture to the chamber.

Moreover, there were little fluctuation in temperature and relative humidity in evaporative cooler during the holding time as compared to the wide fluctuation observed in ambient temperature (Figure 2a and b). This is important from the point of view of safe and effective storage of perishable commodities (Burdon, 1997). From the data presented in Figure 1a and b, it is evident that fruit stored under ambient conditions between 14:00 to 16:00 h would be exposed to harsh conditions because of combined effect high temperature and low relative humidity. The evaporative cooler apparently was effective in minimizing these extremes. Throughout the 32 days of storage period, minimum and maximum difference in temperature between evaporative cooler and ambient temperature were found to be 10.05 and 18.98°C at 6:00 and 14:00 h, respectively. Similarly, the maximum and minimum difference in relative humidity was found to be 61.09 and 42.94% at 14:00 and 6:00 h, respectively. This can be ascribed to the rate of evaporation of water from the wet cooling pad being higher at higher air temperature, which was in agreement with previous findings (Rama and Narasimham, 1991). The cooler temperature decreased, whereas the relative humidity increased. Using the multi-layer evaporative cooling pads, the cooling efficiency varied between 68.27 and 92.02%. The cooling efficiency of the cooler was higher during the first two hours and relatively lower during the later hours of operation (Figure 3).

Total sugar

The total sugar content of tomatoes at harvest ranged from 2.030 to 3.335 g 100 g⁻¹ of fresh weight (Figure 4), which was in agreement with Yilmaz (2001). Marglobe harvested at light-red stage showed significantly ($P < 0.001$) higher total sugar content at the time of harvest. The lowest value was recorded in Roma VF harvested at mature-green stage. The lower total sugar content of Roma VF could be an indication of lower respiration and metabolism rates associated with this particular cultivar (Lurie and Klein, 1990). Tomatoes harvested at light-red stages of ripeness showed higher total sugar content than those harvested at green mature and turning stage. The lower value was noticed in tomatoes harvested at mature-green stage. It has been indicated that sugars increase during ripening for some time and declined after peak ripening (Salunkhe et al., 1974).

On day 4, the highest value was recorded in Marglobe harvested at turning and light-red stages and stored under evaporative cooling system. The lowest value was in Roma VF harvested at mature-green stage and stored

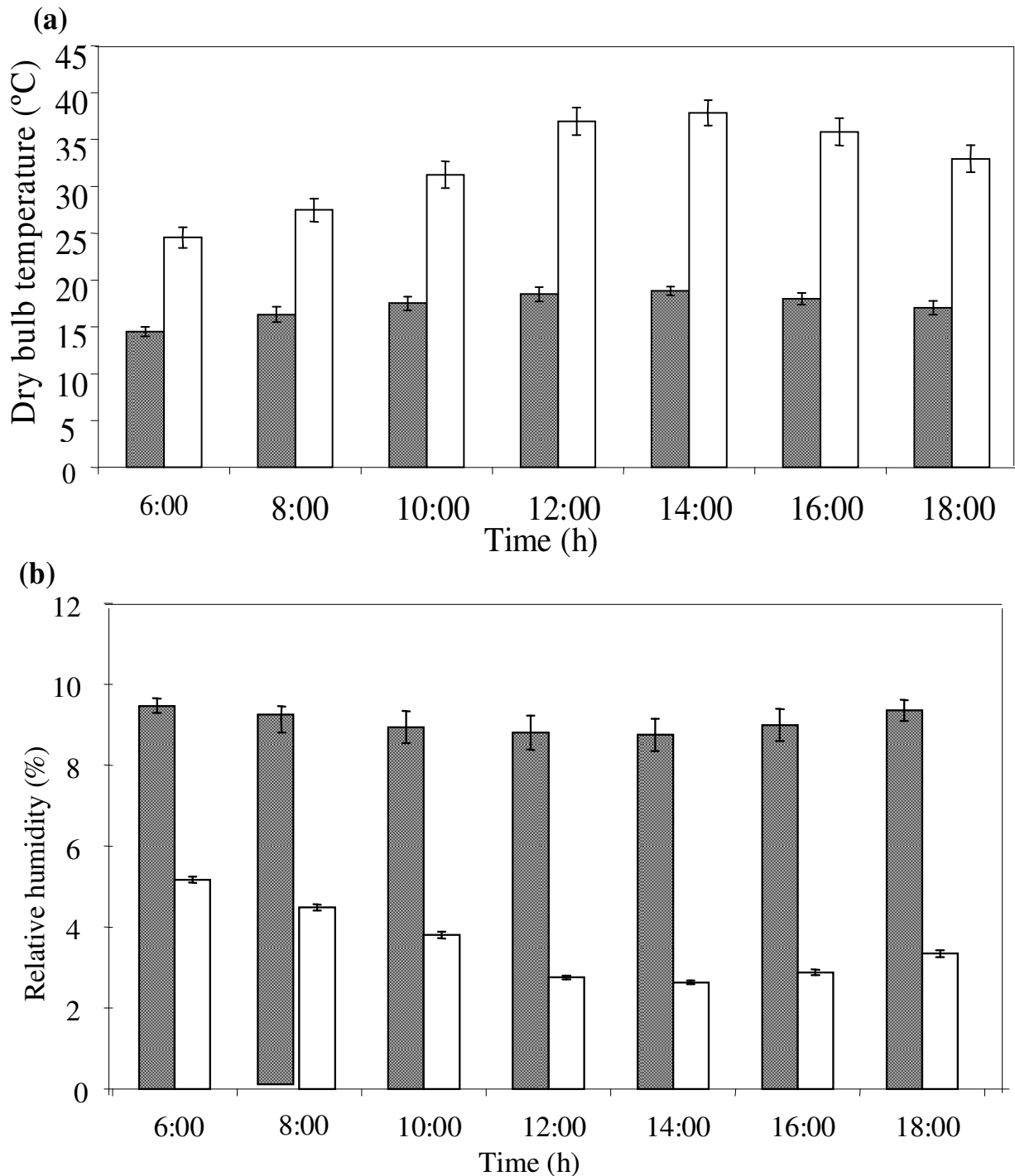


Figure 2. The effect of daytime on (a) dry-bulb average environmental and evaporative cooler temperature (°C) and (b) the average environmental and evaporative cooler relative humidity (%) during storage of tomato fruit. Data are means of three replications; bar are standard deviation. ■, Cooler and □, Ambient.

under multi-pads evaporative cooling system. From day 24 onwards, Roma VF tomatoes harvested at mature-green stage maintained higher total sugar content when compared to the other treatments. This indicated that the

ripening of tomato was delayed due to genetic factor in Roma VF than in Marglobe. Marglobe harvested at light-red maturity stage lost the highest total sugar content during ripening and storage under both conditions. In

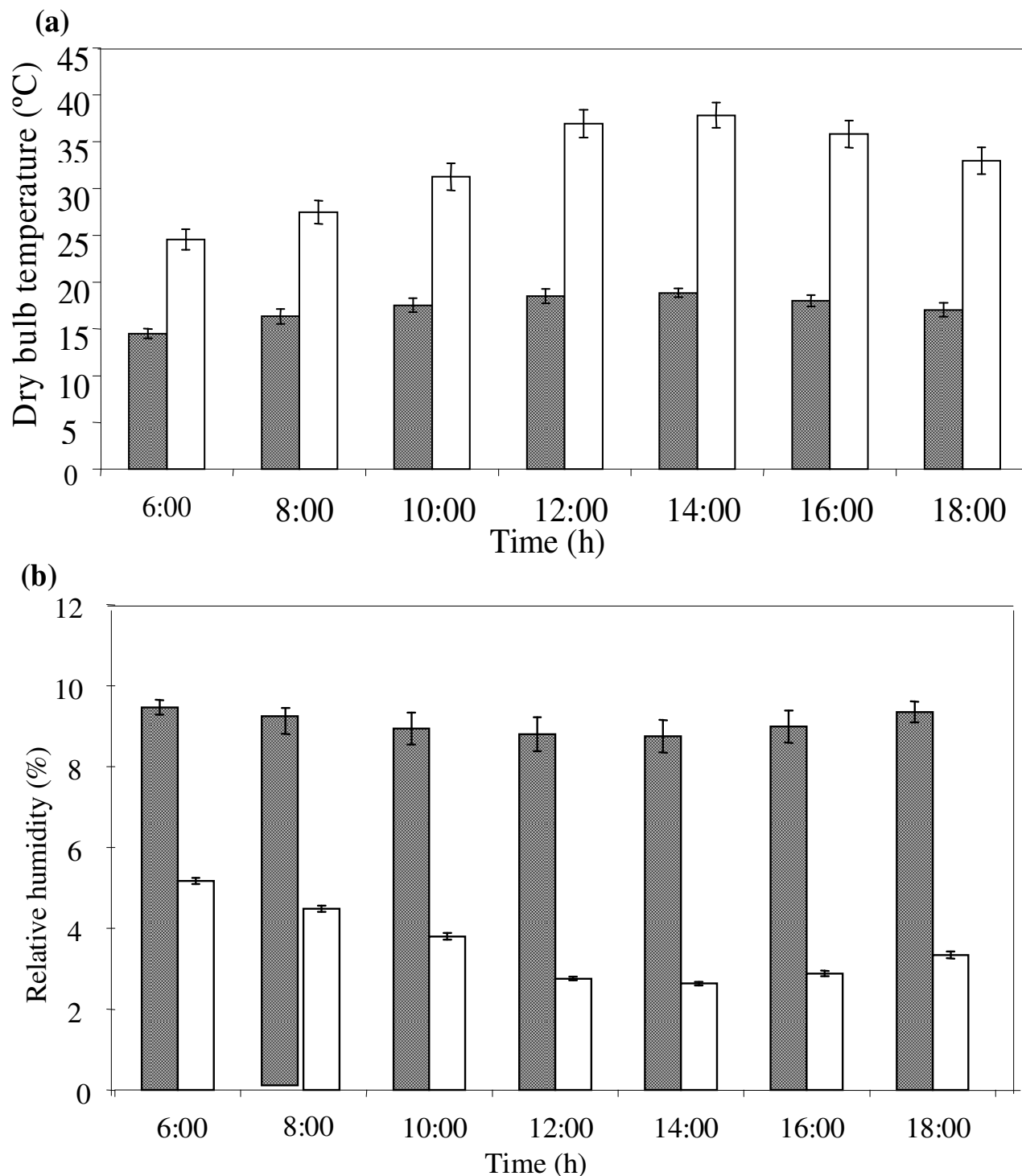


Figure 2. The effect of daytime on (a) dry-bulb average environmental and evaporative cooler temperature (°C) and (b) the average environmental and evaporative cooler relative humidity (%) during storage of tomato fruit. Data are means of three replications; bar are standard deviation. ■, Cooler and □, Ambient.

general, produce with a higher rate of respiration ripens faster and has a shorter shelf life than produce with a lower respiration rate. The metabolic activity of the tissue can be monitored through the respiration rate (Wills et al.,

1998). Accordingly, the rate of change in total sugar could be an indication of rate of respiration in the fruit. Further, the respiration rate gives an indication of the rate of breakdown of respiratory substrates such as starch,

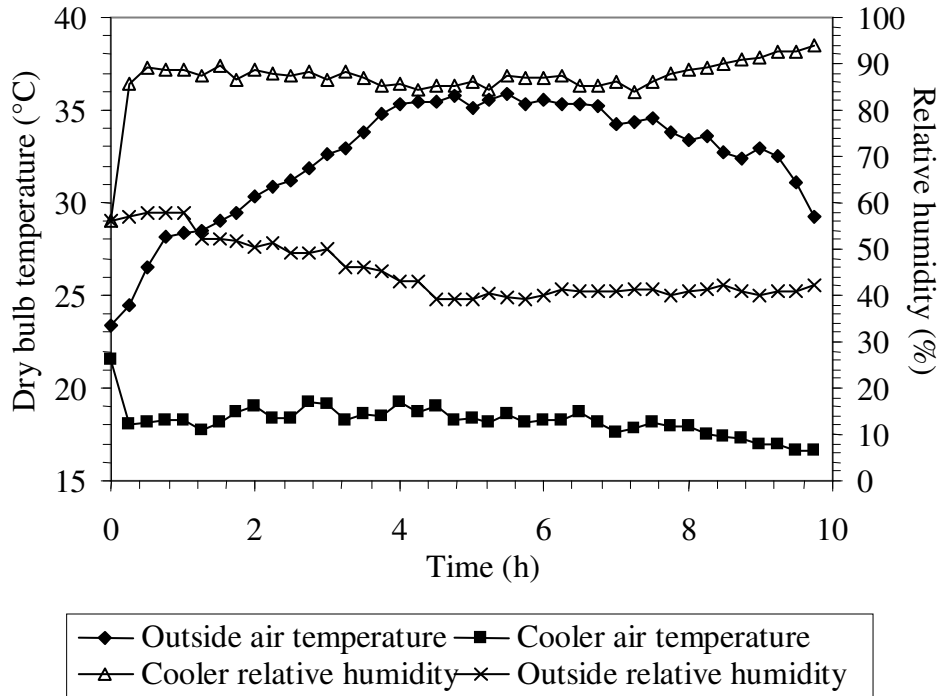


Figure 3. Effect of multi-layer evaporative cooling on relative humidity and temperature.

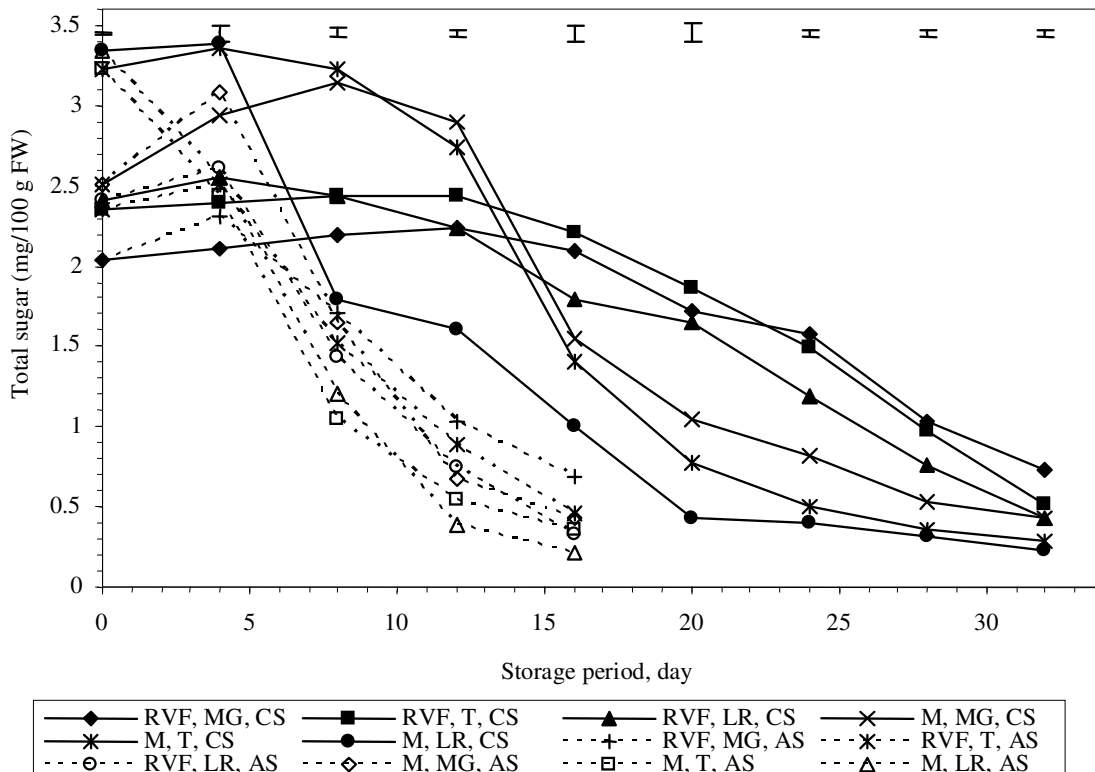


Figure 4. The interaction effect of storage environment type, cultivars, and maturity stage on the total sugar content of tomato fruit during 32 days of storage. Bars represent LSD_{0.05} for each storage interval. The data from day 20 onwards is meant for the evaporative cooling system only. RVF, Roma VF; GM, Green mature; CS, cool storage; T, Turning; LR, light-red; M, Marglobe; AS, Ambient storage. Bars represent LSD_{0.05} for each storage interval.

sugars and organic acids (Knee, 1995). Roma VF harvested at mature-green stage and stored in the evaporative cooler reached the maximum (2.2%) total sugar content on day 12 and declined thereafter. The same cultivar harvested at turning and light-red stages and stored in the same storage condition attained the maximum value on day 8 (2.4%) and 4 (2.6%), respectively. Marglobe, harvested at mature-green, turning and light-red stage and stored in the evaporative cooling system reached its maximum on day 8 (3.2%), 4 (3.4%) and 4 (3.4%), respectively.

An increase in total sugar content was found during the first few days of storage which was followed by a rapid decline in fruits stored under ambient conditions. Total sugar content of tomato was lower in tomatoes stored under ambient conditions throughout the storage period. This would again be associated with the higher rates of hydrolysis of higher molecule sugar under higher temperature. Similar observations were reported by Koksal (1989). A general trend of faster loss of total sugar content was found in Marglobe harvested at turning and light red stage during storage at ambient conditions. The onset of the transformation of starch to sugar occurs prior to the onset of the climacteric rise in respiration (Knee, 1995). Wills et al. (1998) summarized the need for low temperature storage of produce clearly by stating that the low temperature storage of produce is beneficial because the rates of respiration and general metabolism are reduced. In this study, the changes in total sugar content of tomatoes clearly indicated that integrating pre-harvest genetic factors with at harvest and postharvest handling techniques could maintain quality and improve the shelf life.

Reducing sugar

Figure 5 displays the effects of cultivar, stage of ripeness and storage type on the changes in reducing sugar content of tomato fruits during storage. The three-way interaction between cultivar, stage of ripeness and storage environment had significant ($P < 0.01$) effect on the changes in the reducing sugar content. At harvest, the reducing sugar content of the two cultivars ranged from 1.3 to 3.1 g 100 g⁻¹. Ereifej et al. (1997) reported that reducing sugar content in seven tomato cultivars ranged from 1.1 to 4.1%, which is in agreement with the findings of this study. The general trend observed was an initial increase followed by a decrease in reducing sugar content as the storage time advances in both cultivars and maturity stages. The increase in reducing sugar content could be due to the breakdown of polysaccharides into water-soluble sugar (Žnidarcic and Pozrl, 2006). Higher value in reducing sugar (3.139%) was found in Marglobe cultivar when harvested at light-red stage and the lowest (1.342%) reducing sugar content was recorded in Roma VF harvested at mature-

green stage. However, reducing sugar content increased by 61.25% in Roma VF and by 35% in Marglobe between tomatoes harvested at mature-green and light-red stage. This could be due to the difference in cultivars and maturity stages, which was in agreement with Getinet (2008) who crossed PI270248 (*Lycopersicon esculentum* var. *cerasiforme*) and large-fruited inbred line Fla.7833-1-1-1 (7833) and determined the plant habit after obtaining the plant from F₂ generation. It was shown that indeterminate plants had a higher sugar than determinate.

On day 4, reducing sugar content of Marglobe harvested at turning and light-red stages and stored under evaporative cooling conditions were the highest and the lowest values were recorded in Roma VF harvested at green-mature stage and stored under the same storage environment. On day 8, the highest values were recorded in Marglobe harvested at turning stage and stored under evaporative cooling conditions and the lowest was in the same cultivar that was harvested at the same stage and stored under ambient condition. On day 12, Marglobe harvested at mature-green stage had the highest (2.822%) and the same cultivar harvested at light-red stage and stored at ambient condition had the least (0.338%) reducing sugar content. Normally, reducing sugar decreases faster if there is high respiration rate (Varoquaux and Wiley, 1994). From day 16 onwards, Roma VF harvested at mature-green stage and stored under evaporative cooling system had the highest reducing sugar content. Marglobe harvested at light-red maturity stage lost more reducing sugar than tomatoes harvested at other maturity stages. Tomatoes harvested at mature-green and turning stage generally retained reducing sugar better under both storage environments, whereas, tomatoes harvested at light-red stage showed a greater loss of reducing sugar although the latter had higher initial reducing sugar and agrees with the findings of Trejo and Cantwell (1996).

At the end of the storage, Roma VF harvested at mature-green stage had higher (37.9%) reducing sugar which was found to be two-fold compared to the reducing sugar content of tomatoes harvested at turning and light-red, respectively. The reducing sugar content of Marglobe harvested at mature-green stage therefore retained 41.6 and 99.5% more reducing sugar compared to the tomatoes harvested at turning and light-red stage of ripeness, respectively.

Weight loss

Weight loss of fruits was significantly ($P < 0.05$) affected by the interaction effect of cultivars, maturity stages and storage conditions (Table 1), which was in agreement with the reports of Singh et al. (2010a, b). Marglobe harvested at light-red stage and stored under ambient storage conditions experienced the highest weight loss,

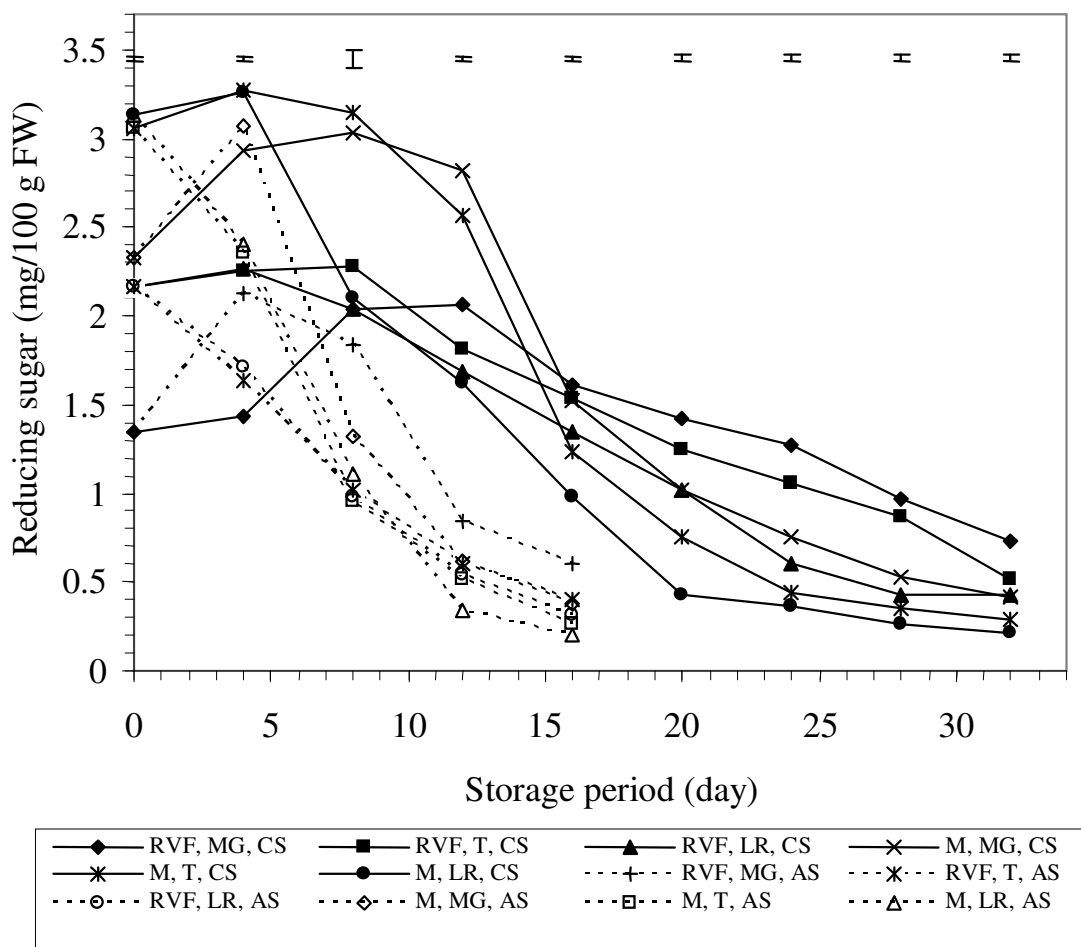


Figure 5. The interaction effect of storage environment, cultivar and maturity stage on the reducing sugar content of tomato during 32 days of storage. Bars represent $LSD_{0.05}$ for each storage interval. The data from day 20 onwards is meant for the evaporative cooling system only. RVF, Roma VF; GM, Green mature; CS, cool storage; T, Turning; LR, light-red; M, Marglobe; AS, Ambient storage. Bars represent $LSD_{0.05}$ for each storage interval.

Table 1. The interaction effect of storage environment, cultivars and maturity stage on the weight loss of tomato fruit during the 32 days of storage.

Treatment	Storage period (day)							
	4	8	12	16	20	24	28	32
Roma VF + evaporative cooling								
Mature-green	1.2 ^l	1.8 ^j	3.5 ^k	5.2 ^j	7.1 ^e	9.5 ^f	11.9 ^e	13.6 ^e
Turning	2.9 ^h	4.1 ^g	5.8 ^h	8.3 ^h	11.8 ^b	13.5 ^c	14.2 ^c	17.3 ^c
Light-red	3.4 ^g	5.2 ^f	7.5 ^g	11.3 ^f	14.1 ^a	15.3 ^b	17.6 ^a	19.0 ^a
Marglobe + evaporative cooling								
Mature-green	1.7 ^k	2.4 ⁱ	4.2 ^j	7.8 ⁱ	9.5 ^d	10.7 ^e	12.5 ^d	15.5 ^d
Turning	2.2 ^j	2.9 ^h	5.1 ⁱ	8.6 ^h	11.4 ^c	12.1 ^d	15.0 ^b	18.2 ^b
Light-red	2.6 ⁱ	4.2 ^g	5.8 ^h	9.2 ^g	14.1 ^a	16.6 ^a	17.7 ^a	19.4 ^a
Roma VF + ambient conditions								
Mature-green	3.6 ^f	8.5 ^e	12.9 ^f	15.4 ^e	-	-	-	-

Table 2. Contd

Turning	5.7 ^d	9.2 ^d	14.4 ^d	17.7 ^d	-	-	-	-
Light-red	6.7 ^c	10.9 ^c	18.8 ^b	20.3 ^a	-	-	-	-
Marglobe + ambient conditions								
Mature-green	4.2 ^e	9.1 ^d	13.6 ^e	15.5 ^e	-	-	-	-
Turning	6.9 ^b	11.2 ^b	16.1 ^c	18.2 ^c	-	-	-	-
Light-red	7.7 ^a	13.2 ^a	19.4 ^a	19.4 ^b	-	-	-	-
CV (%)	2.1	1.47	1.65	1.71	0.78	0.67	0.55	1.72

Means within a column followed by the same letter (s) are not significantly different according to Duncan's multiple range tests. The data from day 20 onwards is meant for the evaporative cooling system.

Table 2. The interaction effect of storage type, varieties and maturity stage on the percentage marketability of tomatoes (%) of fruit during the 32 days of storage.

Treatment	Storage period (day)							
	4	8	12	16	20	24	28	32
Roma VF + Evaporative cooling								
Mature-green	100.0 ^a	100.0 ^a	100.0 ^a	98.3 ^a	95.2 ^a	78.4 ^a	65.0 ^a	28.0 ^a
Turning	100.0 ^a	98.1 ^b	94.4 ^b	86.4 ^c	75.6 ^b	66.3 ^b	44.9 ^b	17.7 ^b
Light-red	100.0 ^a	95.1 ^d	90.5 ^c	79.4 ^d	61.7 ^c	48.5 ^c	35.6 ^c	8.0 ^d
Marglobe + Evaporative cooling								
Mature-green	100.0 ^a	100.0 ^a	94.6 ^b	88.2 ^b	75.1 ^b	66.8 ^b	44.3 ^b	18.0 ^b
Turning	100.0 ^a	96.2 ^c	90.4 ^c	72.7 ^e	55.1 ^d	42.3 ^d	33.3 ^d	10.7 ^c
Light-red	97.5 ^b	90.7 ^e	75.2 ^d	60.5 ^f	44.2 ^e	27.7 ^e	14.7 ^e	4.7 ^e
Roma VF + ambient conditions								
Mature-green	95.4 ^c	65.9 ^f	38.0 ^e	15.3 ^g	-	-	-	-
Turning	95.2 ^c	57.6 ^g	27.4 ^g	11.3 ^h	-	-	-	-
Light-red	86.0 ^e	49.5 ⁱ	25.6 ^h	6.7 ^{ij}	-	-	-	-
Marglobe + ambient conditions								
Mature-green	92.3 ^d	57.7 ^g	29.2 ^f	12.5 ^h	-	-	-	-
Turning	86.4 ^e	50.8 ^h	27.2 ^g	7.8 ⁱ	-	-	-	-
Light-red	80.3 ^f	45.2 ⁱ	13.2 ⁱ	5.6 ^j	-	-	-	-
CV (%)	0.28	0.59	0.97	1.79	1.26	1.59	2.94	9.42

Means within a column followed by the same letter (s) are not significantly different according to Duncan's multiple range test, (probability $P < 0.05$). The data from day 20 onwards is meant for the evaporative cooling system only.

while Roma VF harvested at mature-green stage and stored in evaporative cooler showed the lowest weight loss. The minimum loss was recorded in Roma VF harvested at mature-green stage. Marglobe fruit harvested at mature-green stage also maintained weight better next to Roma VF, which was harvested at the same maturity stage. In the case of Marglobe harvested at mature-green, turning, and light-red stages the threshold levels were reached on day 20 (9.5%), 16 (8.6%), and 16 (9.2%), respectively when stored under

evaporative cooling conditions.

Percentage marketability (PM)

The interaction effect among cultivars, maturity stages and storage environment significantly ($P < 0.05$) affected PM of tomatoes (Table 2). Marglobe harvested at light-red stage had lower PM value. Except in Marglobe harvested at light-red stage, both cultivars harvested at

the different maturity stages retained about 90% more fruits PM up to 14 days in the cooler. Also, 28% of Roma VF and 18% of Marglobe harvested at mature-green stage and stored under evaporative cooling conditions were marketable even at the end of the storage period. The visual appearance and PM of tomato fruit stored in the evaporative cooling conditions was found to be better. Tomatoes stored in the evaporative cooler remained fresh, shiny and of superior colour for a reasonable period. Hence, PM increased by two-fold when stored under evaporative cooling conditions.

Conclusion

The change in the sugar content of tomatoes during storage was found to be affected by cultivars and maturity stages at harvest and storage environment. Roma VF maintained higher concentration of sugar towards the end of storage compared to the concentration of this sugar in Marglobe variety. The reducing and total sugar of both tomato cultivars were maintained better when stored under evaporative cooling system. Since sugar is the substrates in the respiration process; the presence of higher concentration of sugars in tomatoes stored in the cooler was an indication of lowered respiration, and resulted in longer shelf life. Moreover, the highest percentage of the marketable fruits was maintained in tomatoes harvested at green mature stage. After 16 days of storage under ambient conditions, Roma VF had more marketable tomatoes harvested at green mature, turning and lighter maturity stages. The results therefore showed that maintaining lower temperature and higher relative humidity during storage combined with selecting cultivars having long shelf life and proper maturity stage could maintain fruit quality in terms of sugar content, weight loss and percentage marketability for relatively longer period. The data also showed that multi-layer evaporative cooling systems have a very large potential to propitiate thermal comfort and can still be used as an alternative to conventional systems in many tropical regions, saving energy and protecting the environment.

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