Influence of storage environment, maturity stage and pre-storage disinfection treatments on tomato fruit quality during winter in KwaZulu-Natal, South Africa

G. N. Tolesa¹ · T. S. Workneh¹

Received: 27 December 2016 / Accepted: 18 July 2017 / Published online: 8 August 2017
© Association of Food Scientists & Technologists (India) 2017

Abstract The aim of this study was to explore influence of evaporative cooling (EC), pre-storage disinfection treatments and maturity stage at harvest on postharvest quality of tomato fruit. The tomato samples (*Lycopersicon esculentum* Mill. cv. Nemonetta) were harvested, stored for 28 days and data were collected every seven days. The pH, total titratable acidity (TTA), total soluble solids (TSS), firmness, colour, weight loss (PWL) and marketability percentage were analysed. The temperature difference between ambient storage and EC at the fan varied between 4 and 7 °C, the relative humidity (RH) varied between 31 and 86%, while at different locations inside the EC it varied between 2–3 °C and 5–8%, respectively. Maturity had significant influence on the overall quality of tomatoes. The pH value of green, pink and red tomato was 4.86 and 5.03. The TTA content, the TSS content significantly affected over the 14 days of storage. TSS:TA was found to be in the range of 7.8–33.9. The EC storage shows a higher firmness and hue angle, when compared to the ambient conditions stored tomatoes. Compared to ambient storage, EC storage reduced the PWL by 7–10% over 30 days, while ambient storage took 15 days. EC storage and pre-storage treatments improved the shelf-life and marketability of tomatoes. However, variation in temperature and RH inside EC could affect the storability of the produce.

Keywords Evaporative cooler · Pre-storage disinfection treatments · Relative humidity distribution · Temperature distribution · Tomato quality

Introduction

Fresh commodities should be available in good quality to meet consumer needs and hence an appropriate precooling and optimum desirable microclimate inside storage facilities and packaging are required (Thompson 2004). Cooling is employed to reduce chemical, biochemical and microbial changes, as well as respiration and water loss. Hence, this prolongs the shelf-life and enables the quality to be maintained (Kader 1985). Maintaining an optimum cooling temperature and relative humidity (RH) is very crucial to reduce postharvest losses. Different methods have been applied for the cooling fresh commodities, including mechanical refrigeration, hydro-cooling, natural convective cooling, vacuum cooling, room cooling, forced air cooling and evaporative cooling (Xuan et al. 2012). Mechanical refrigeration is the most commonly applied technology, but it is expensive and requires a high initial investment cost and is associated with environmental impacts through direct and indirect greenhouse gas emissions (Tassou et al. 2010). On the contrary, evaporative cooler (EC) was reported to have a lower costs in terms of installation and low energy requirements to run a fan and water pump, and hence it was reported to be affordable for small-scale farmers operating in arid and semi-arid regions (Workneh 2010). For EC to be effective, the atmospheric air conditions should have a lower RH (65%) (Thompson 2004). Several researchers reported that three basic methods of EC have been developed, including direct evaporative cooling (DEC), indirect evaporative cooling (IEC)

✉ G. N. Tolesa
getachewneme@yahoo.com

¹ Bioresources Engineering Discipline, School of Engineering, University of KwaZulu-Natal, Private Bag X01, Scottsville, Carbis Road, Pietermaritzburg 3209, South Africa

and semi-indirect evaporative cooling (SIEC) (Basediya et al. 2013). Several EC designs have been reported to be efficient for fruit and vegetable storage and preservation (Roy and Pal 1994). The designs vary from a grass straw house to high technology designs, such as a wet wall, roof, charcoal, coconut straw, rice husk, cellulose pad, jute curtain, pot-in-pot EC and zero-energy EC (Liberty et al. 2013). Therefore, it can be easily constructed from locally-available materials and is affordable for small-scale farmers.

For every 10 °C temperature fluctuation, the respiration rate changes by two-to four-fold (Watada et al. 1996) and the temperature is found to be the single most important factor that affects the shelf-life of fresh produce. Hence, optimal temperature management, which is attainable by using an EC system, is the most important operation for small-scale producers (Liberty et al. 2013). Moreover, RH influences water loss and decay development, triggers physiological disorders and affects the ripening processes of fresh produce (Kader 1985). Therefore, a RH of between 85 and 95% was recommended for fruit and 90–98% for vegetables (Kader 1985), which is attainable by EC. Temperature, RH, and ventilation management maintain the quality and longer shelf-life of fresh produce (Liberty et al. 2013). Optimum storage temperatures for different tomato maturity stages are reported to be 12–20 °C and 7–10 °C, respectively, for the green and pink mature stage, within a period of 4–7 days (Liberty et al. 2013). Optimum storage RH was reported to be 85–90% for a shelf-life one to three weeks (Chinenye et al. 2013). Even though EC reduces the temperature and RH, it is limited only for the pre-cooling of produce, with the main aim of removing the field heat. Therefore, several researchers recommended integrating postharvest treatments and the EC storage environment for best performance in shelf-life extension and maintaining the quality (Fallik et al. 1996). Some pre-storage treatments, including anolyte water and chlorinated water disinfection (Workneh et al. 2003), as well as dipping in hot water can be applied to fruit and vegetables as a pre-storage treatment for shelf-life extension (Fallik et al. 1996). However, there is not much information available for the integration of these treatments with the EC storage environment system.

The quality indices that influence consumer acceptance and market success were reported to be colour, size, shape, texture, flavour, total soluble solids (TSS), titratable acidity and physiological weight loss (Barrett et al. 2010). TSS varies from 3 to 15%, which is dependent on tomato variety and size (Beckles 2012). The authors reported that temperature has an influence on the tomato maturity stage, the texture and colour uniformity during postharvest handling. Hence, the main objectives of this study are to determine the temperature and RH distribution inside the

EC chamber, as well as to investigate the cumulative effects of maturity stage, storage conditions, storage period, and pre-storage treatments on the quality and shelf-life of tomatoes.

Materials and methods

Site description

The study was carried out at the Ukulinga Research Farm, Pietermaritzburg, South Africa, with a latitude of −29.668, a longitude of 30.406 and an altitude of 808.

Sample tomato production and preparation three maturity stages of tomato samples (green, pink and red) (*Lycopersicon esculentum* Mill. cr. Nemonetta), produced by the ZZ2 Farm, Limpopo, South Africa, were used for the study.

Evaporative cooler

A 4-ton capacity experimental scale insulated multi-pad evaporative cooler (EC), with one indirect heat exchanger and three direct pads, was established at the Ukulinga Research Farm of the University of KwaZulu-Natal, South Africa. The dimensions of the EC is a length of 6 m, a width of 4 m and a height of 2.4 m and 60 mm thick. An axial fan (OW354), with a blade size 340 mm (H)* 340 mm (W)* 260 mm (Φ) was used to drive air into the EC storage chamber.

Experimental design

The experimental design consists of four factors, including three tomato maturity stages (green, pink and red), four treatments (AW, HotH₂O, Cl₂, and Control), two storage conditions (ambient and EC) and five storage periods with five replications. Five fruits per sample were used for the experiment.

Disinfection pre-storage treatments

Different pre-storage treatments, including anolyte (AW), chlorination (Cl₂) water and hot water (HotH₂O), were applied to the sample. Sample tomatoes were dipped into an AW solution for 5 min (Workneh et al. 2003) and air-dried, before being stored. The hot water treatment was done by dipping the sample into hot water at 42.5 °C for 30 min (Itoh 2003). Chlorine disinfection was done by dipping samples into a solution containing 100 µg ml^{−1} total chlorine (Cl₂) for 20 min, which was prepared by dissolving standard grade sodium hypochlorite (5% NaOCl) in tap water (Workneh et al. 2011). The control

samples were dipped into cold water for 20 min. Five tomato fruits were randomly picked for the quality indices analysis every seven days for the 28 days of storage period. The measurements were replicated five times.

Temperature and relative humidity measurements

Temperature and RH were recorded at different locations inside the cooler. Hobo data loggers (HOBO Prov2 Part No. U23-001 series) were used to record the temperature and RH. The speed of Fan two was kept constant [$(U_x = 0.75, V_y = 1.32 \text{ and } W_z = 1.20 \text{ (m/s)})$]. The ambient air data was collected from ARC-AWS weather station, which is located at the Ukulinga Research Farm.

pH value

Five tomato samples from each maturity stage were taken and blended into a homogeneous pulp. This was then filtered, using Whatman filter paper No.1, and 25 ml of the filtrate was then used to measure pH values with a pH meter (Orion Star, Model 210, Thermo Scientific Pty), according to the procedure used by AOAC (1995).

Total titratable acidity

A 25 ml filtrate of the pulped tomato was taken for total titratable acidity (TTA) determination and was titrated with 0.1 N NaOH, using a phenolphthalein indicator. The TTA content was calculated, using the following equation (AOAC 1995):

$$\%TA = \frac{ml\ NaOH\ used * N * meq}{ml\ of\ tomato\ juice} * 100 \quad (1)$$

where N = normality of NaOH, meq = milliequivalents of citric acid, which is 0064.

Total soluble solids the total soluble solid (TSS) content was determined, using a digital handheld refractometer (Pocket Refractometer, PAL-3, Japan). The tomato sample was pulped and filtered by Whatman filter paper No.1. The filtrate was used for the analysis (AOAC 1995).

Total soluble solids to total titratable acidity ratio

The TSS to TTA ratio of tomato slurry was calculated, using the following equation (Moneruzzaman et al. 2008):

$$TSS : TARatio = \frac{\%TSS\ Content\ of\ FruitPulp}{\%TA\ of\ of\ the\ Fruit\ Pulp} \quad (2)$$

Firmness

The fruit firmness was determined by using the Intron Universal Testing Machine (Model No. 3345) with a 7.5 mm penetration depth, a $3.00\ mm\ s^{-1}$ speed, a 50 N maximum force and a 2 mm diameter probe, according to the procedure used by Pinheiro et al. (2013). Five fruits from each category of tomatoes, subjected to different treatments, were used for the analysis.

Colour

Tomato skin colour was measured along the waist diameter, using the digital Minolta Chromatic 400 method of the CIELAB colour space, according to the procedures of Batu (2004). The instrument was calibrated against a white standard tile before each colour reading. The hue (h°) value was measured and recorded.

Physiological weight loss

The physiological weight loss (PWL) was determined gravimetrically for change of weight of the samples every seven days of the storage period and converted to a percentage of the initial weight. The cumulative PWL (%) was expressed as a percentage with respect to storage period (Tefera et al. 2007).

$$\%Weight\ loss = \frac{Weight_{(t=0)} - Weight_{(t=t)}}{Weight_{(t=0)}} * 100\% \quad (3)$$

Percentage marketability

The marketability of the tomatoes was accessed subjectively, according to Mohammed et al. (1999). The visible shrivelling, smoothness, mould growth and shininess of the tomatoes were considered. The number of sound fruits was counted and the percentage was calculated with respect to the initial sample number every seven days over the 28 days period.

Data analysis

The data was subjected to a factorial analysis of variance (ANOVA). Duncan's multiple mean comparisons operated by the Least Significant Difference test (L.S.D.) was used to separate means. GenStat Version 17 was used for statistical analysis. The fresh produce kept in a multi-pad evaporative cooler and ambient storage environment for a 28-day period.

Results and discussion

Temperature and relative humidity

The recorded ambient temperature ranged between 13 and 23 °C, while the temperature inside the EC varied between 11 and 18 °C. Although the experiment was conducted in winter, a comprehensive lower temperature was achieved inside the EC storage chamber, due to the evaporative cooling effect resulting from the multi-pad cooling systems.

The daily ambient RH and the relative humidity of air inside the EC varied from 16–67.8% to 69.3–90.4%, respectively. The increase in RH was due to the humidification effect of the inlet air being forced through the direct cooling pads. Fresh commodities require low temperatures during storage. The maintenance of high RH is also important for keeping the freshness and for the reduction of moisture loss (Thompson 2004). The data presented in this result display evidence demonstrating that the application of multi-pad EC reasonably reduces the inside temperature and increases the RH, which are both suitable for prolonging the shelf-life of fresh fruit and vegetables.

The maximum hourly temperature of the ambient air temperature difference was found between 12 am and 5 pm, which is in agreement with the report of Anyanwu (2004). Moreover, the maximum temperature difference between the outside and inside EC was attained during the same periods. These periods of the day are the time during which cooling is important for fruit and vegetables in order to maintain freshness (Anyanwu 2004). This implies that the evaporative cooling technology is highly suitable for fresh produce pre-cooling and for short-term storage in arid and semi-arid regions (Workneh 2010).

The ambient hourly RH was found to be very low at midday and towards the afternoon, while the RH inside EC was found to be high throughout the day. A low RH means that the air is dry, hence removing much of the moisture from the wet surface of the fresh produce (Awolè et al. 2011). This implies that storage at ambient environmental conditions, from the midday to the late evening, will significantly influence the quality fresh produce. On the other hand, the RH inside the EC was relatively high during the daytime, due to humidification and is suitable for extending the shelf-life of fruit and vegetables (Thompson 2004). Low RH and high ambient dry bulb temperature are recommended for the effectiveness of the EC (Workneh 2010). High temperatures and low RH were attained between 12 am to 5 pm.

The state of the ambient temperature and RH were found to be 22.8 °C and 31%, respectively. The difference in temperature between the ambient and inside EC was found to be 7.6 °C, while the RH increased by 55% during the hottest day.

The air temperature and RH at different locations inside the EC were found to be 15.2 °C and 86%, respectively (Fig. 1). The result indicates that there were temperature variations between different sensor locations inside the EC (Fig. 2). The temperature depression between the ambient and the EC at the fan location varied between 4 and 7 °C in this study, 4–13 °C reported by Chinenye et al. (2013) and 5 °C found by Getinet et al. (2008) during the hottest day of the storage periods. It is evident from the data obtained in this study that the RH was increased by 55%, when compared to the ambient air relative humidity. Getinet et al. (2008) reported that the RH was increased by 18%. The differences between the inlet and exit air temperatures and the relative humidity varied between 2–3 °C and

Fig. 1 a Psychrometric chart showing the evaporative cooling process during the daytime. **a** is the ambient air condition (22.8 °C, 31% of RH); **b** is the air condition after fan 2 (15.2 °C, 86% of RH); **c** is the change in temperature (7.6 °C) and RH (55%)

Fig. 2 Temperature or RH distributions inside EC: where AMB is the ambient, Temperature-RH sensors: position-1 (P1) is next to inlet fan, position-2 (P2) is right hand corner of inlet side, position-3 (P3) is left hand corner of the inlet face side, position-4 (P4) is 2 m from the fan along symmetry line hung at 1.5 m, position-5 (P5) is 4 m

from the fan along symmetry line hung at 1.5 m, position-6 (P6) is 6 m from the fan along symmetry line hung at 1.5 m, position-7 (P7) is at the exit hole1, position-8 (P8) is at exit hole3, position-9 (P9) is at 3 m from the inlet wall side top corner opposite to the door, and position-10 (P10) is at 3 m from the inlet wall side top of the door

5–8%, respectively. The coldest air was recorded near the inlet next to the axial fan, while the higher temperature was at the air exit of the EC storage. The difference in environmental conditions, with respect to the location inside the cooler chamber, might indicate their influence on the quality of fresh produce stored inside EC. Maintaining a uniform air distribution and the conditions inside the cooler chamber is preferable for keeping the proper physiology, quality and shelf-life extension of fresh produce throughout the cooler chamber space. Hence, more advanced studies might be required, using modelling tools such as Ansys for CFD.

pH value

The pH value is one of the most essential processing features of tomatoes, hence remaining the main factor for the fruit industry (Moneruzzaman et al. 2008). The pH value of tomatoes harvested at the green, pink and red mature stages was found to be 4.88, 5.05 and 4.96, respectively (Table 1). The maturity stage had a significance ($p \leq 0.001$) influence in pH values of tomato samples. The pH value of sample tomatoes increased with the storage period, which was in agreement with the findings of Moneruzzaman et al. (2008). This increase might be attributed to the enzymatic breakdown of pectin during the storage period. Both ambient and EC storage conditions had significant ($p \leq 0.05$) influence on the pH value. Pre-storage

disinfection treatments and their interactions had a highly significant ($p \leq 0.001$) effect on the pH values of tomatoes. The slight increase in pH value in the maturity stage might be due to respiration, ripening and physiological changes, which might lead to a high susceptibility to deterioration. Moreover, tomato samples dipped in chlorinated water showed the lowest pH value. The control tomato samples and tomatoes subjected to hot water treatment had a relatively medium effect on the changes in pH value. Anolyte water disinfection exhibited the highest pH value, but, Workneh et al. (2003) reported that it had no effect on the pH value of fresh carrots.

The effect of two-way interactions of all the maturity stage, storage condition, storage period and pre-storage disinfection treatments exhibited a highly significant ($p \leq 0.001$) influence on the pH value. The physiological changes of fruit components might contribute to the fluctuations in the pH value observed for all maturity stages of tomatoes (Pila et al. 2010).

Total titratable acidity content

TTA content is one of quality indices directly related to the tomato processing industry. The TTA content of tomatoes was reported to be directly proportional to the ripening of tomatoes (Gautier et al. 2008). It was suggested that a TTA of 0.35–0.55% was recommended to be suitable for the tomato processing industry (Gould 1992). The TTA of

Table 1 Changes in pH, total titratable acidity (TTA) (%), total soluble solids (TSS) (%), TSS:TA ratio, of tomato fruits subjected to four treatments (anolyte water, chlorinated water, hot water and control), three maturity stages (*green*, *pink* and *red*) and two storage conditions [room temperature (RT) and evaporative cooling environment (EC)] and stored for 28-days of storage period

Treatment	pH content					Total titratable acidity (%)				
	Day 1	Day 7	Day 14	Day 21	Day 28	Day 1	Day 7	Day 14	Day 21	Day 28
<i>Evaporative cooler</i>										
G, anolyte water	4.84 ^{uv}	4.85 ^v	4.57 ^c	5.24 ^{zq}	4.78 ^{qr}	0.50 ^c	0.42 ^j	0.33 ^h	0.33 ^g	0.27 ^d
G, Cl ₂ water	4.84 ^{uv}	4.70 ^m	4.87 ^{vw}	5.05 ^{zk}	3.47 ^a	0.50 ^c	0.42 ^j	0.30 ^d	0.30 ^d	0.29 ^f
G, hot water	4.84 ^{uv}	5.58 ^{zt}	4.77 ^{op}	5.13 ^{zo}	4.89 ^x	0.50 ^c	0.41 ⁱ	0.30 ^d	0.30 ^d	0.32 ⁱ
G, control	4.84 ^{uv}	5.87 ^{zv}	4.53 ^b	4.83 ^u	4.83 ^u	0.50 ^c	0.41 ⁱ	0.35 ^j	0.35 ^j	0.43 ^m
P, anolyte	5.10 ^{zm}	5.09 ^{zm}	4.78 ^{qr}	5.87 ^{zv}	5.59 ^{zt}	0.43 ^b	0.39 ^h	0.33 ^h	0.33 ^g	0.35 ^k
P, Cl ₂ water	5.10 ^{zm}	4.85 ^v	4.62 ^e	5.10 ^{zm}	4.68 ⁱ	0.44 ^b	0.38	0.32 ^g	0.32 ^f	0.27 ^d
P, hot water	5.10 ^{zm}	5.02 ^{zi}	4.69 ^{ij}	5.07 ^{zk}	4.96 ^{ze}	0.44 ^b	0.35 ^d	0.29 ^c	0.29 ^c	0.28 ^e
P, control	5.10 ^{zm}	5.53 ^{zt}	4.70	5.10 ^{zm}	—	0.44 ^b	0.39 ^h	0.34 ⁱ	0.34 ⁱ	—
R, anolyte	5.05 ^{zk}	4.92 ^{yz}	4.84 ^{uv}	5.24 ^{zq}	4.73 ⁿ	0.38 ^a	0.37 ^f	0.34 ⁱ	0.34 ⁱ	0.29 ^f
R, Cl ₂ water	5.05 ^{zk}	4.77 ^{op}	4.69 ^k	5.10 ^{zm}	—	0.38 ^a	0.31 ^b	0.30 ^d	0.30 ^d	—
R, hot water	5.05 ^{zk}	5.17 ^{zp}	4.86 ^v	5.26 ^{zq}	4.97 ^{zf}	0.38 ^a	0.25 ^a	0.27 ^a	0.27 ^a	0.30 ^g
R, control	5.05 ^{zk}	5.12 ^{zn}	4.94 ^{za}	4.99 ^{zg}	4.88 ^w	0.38 ^a	0.36 ^c	0.32 ^g	0.32 ^f	0.36 ^l
<i>Room temperature</i>										
G, anolyte	4.85 ^v	4.83 ^u	4.83 ^u	5.00 ^{zh}	5.02 ^{zi}	0.50 ^c	0.33 ^d	0.31 ^f	0.31 ^e	0.31 ^h
G, Cl ₂ water	4.84 ^v	4.74 ⁿ	4.66 ^g	5.01 ^{zi}	4.81 ^s	0.50 ^c	0.39 ^h	0.31 ^f	0.31 ^e	0.24 ^a
G, hot water	4.85 ^v	5.24 ^{zq}	4.73 ⁿ	5.50 ^{zs}	4.89 ^x	0.50 ^c	0.43	0.31 ^f	0.31 ^e	0.26 ^c
G, control	4.84 ^v	4.90 ^{xy}	4.58 ^d	4.94 ^{zb}	4.94 ^{zb}	0.50 ^c	0.39 ^h	0.30 ^d	0.30 ^d	0.31 ^h
P, anolyte	5.04 ^{zj}	5.09 ^{zm}	4.78 ^{qr}	5.87 ^{zv}	—	0.43 ^b	0.39 ^h	0.33 ^h	0.33 ^g	—
P, Cl ₂ water	5.04 ^{zj}	4.91 ^y	4.91 ^y	5.03 ^{zi}	—	0.43 ^b	0.34 ^d	0.32 ^g	0.32 ^f	—
P, hot water	5.04 ^{zj}	4.67 ^h	4.79 ^r	5.32 ^{zr}	—	0.43 ^b	0.43 ^k	0.28 ^b	0.28 ^b	—
P, control	5.04 ^{zj}	4.91 ^y	4.93 ^z	5.08 ^{zl}	—	0.43 ^b	0.41 ⁱ	0.30 ^d	0.30 ^d	—
R, anolyte	5.00 ^{zh}	4.78 ^{qr}	4.85 ^v	6.10 ^{zw}	—	0.38 ^a	0.38 ^g	0.33 ^h	0.33 ^g	—
R, Cl ₂ water	5.00 ^{zh}	5.27 ^{zq}	4.85 ^v	4.95 ^{zc}	—	0.38 ^a	0.31 ^b	0.28 ^b	0.28 ^b	—
R, hot water	5.00 ^{zh}	4.85 ^v	4.71 ^{mn}	5.28 ^{zr}	—	0.38 ^a	0.32 ^c	0.28 ^b	0.28 ^b	—
R, control	5.00 ^{zh}	4.76 ^o	4.85 ^v	5.08 ^{zl}	4.81 ^s	0.38 ^a	0.32 ^c	0.29 ^c	0.29 ^c	0.29 ^f
<i>Significant level (P)</i>										
Storages (A)	<0.05	—	—	—	—	<0.001	—	—	—	—
Maturity (B)	<0.001	—	—	—	—	<0.001	—	—	—	—
Disinfection (C)	<0.001	—	—	—	—	<0.001	—	—	—	—
Storage period (D)	<0.001	—	—	—	—	<0.001	—	—	—	—
A × B	<0.001	—	—	—	—	<0.001	—	—	—	—
A × C	<0.001	—	—	—	—	<0.001	—	—	—	—
A × D	<0.001	—	—	—	—	<0.001	—	—	—	—
B × C	<0.001	—	—	—	—	—	—	—	—	—
B × D	<0.001	—	—	—	—	<0.001	—	—	—	—
C × D	<0.001	—	—	—	—	<0.001	—	—	—	—
A × B × C	<0.001	—	—	—	—	<0.001	—	—	—	—
A × B × D	<0.001	—	—	—	—	<0.001	—	—	—	—
A × C × D	<0.001	—	—	—	—	<0.001	—	—	—	—
B × C × D	<0.001	—	—	—	—	<0.001	—	—	—	—
A × B × C × D	<0.001	—	—	—	—	<0.001	—	—	—	—
LSD _{0.05} = 0.0907, CV (%) = 1.5, SE = 0.0730						LSD _{0.05} = 0.018, CV (%) = 4.3, SE = 0.0146				

Table 1 continued

Treatment	Total soluble solid (%)					TTA:TSS				
	Day 1	Day 7	Day 14	Day 21	Day 28	Day 1	Day 7	Day 14	Day 21	Day 28
<i>Evaporative cooler</i>										
G, anolyte water	3.88 ^b	5.24 ^r	4.00 ^f	4.00 ^p	3.42 ^d	7.68 ^a	12.38 ^l	12.01 ^l	12.01 ^l	12.85 ⁱ
G, Cl ₂ water	3.98 ^c	3.44 ^e	3.66 ^l	3.660 ^k	3.30 ^b	7.88 ^c	8.23 ^b	12.11 ^l	12.11 ^l	11.63 ^c
G, hot water	3.98 ^c	4.12 ⁿ	3.64 ^k	3.64 ^j	3.96 ^g	7.88 ^c	10.12 ^e	11.98 ^l	11.98 ^l	12.47 ^g
G, control	3.98 ^c	4.00 ^m	3.96 ^f	3.96 ^p	3.86 ^g	7.88 ^c	9.76 ^d	11.47 ⁱ	11.47 ⁱ	9.08 ^a
P, anolyte	3.70 ^a	3.30 ^c	3.42 ^f	3.42 ^f	4.44 ^j	8.74 ^f	8.54 ^b	10.27 ^c	10.27 ^c	15.24 ^q
P, Cl ₂ water	3.72 ^a	4.48 ^p	3.74 ⁿ	3.74 ^m	3.35 ^c	8.54 ^e	11.75 ^j	11.87 ^k	11.87 ^k	13.66 ^m
P, hot water	3.72 ^a	3.76 ^j	4.00 ^r	4.00 ^p	3.92 ^g	8.54 ^e	10.81 ^g	13.83 ^q	13.83 ^r	14.20 ⁿ
P, control	3.72 ^a	4.26 ^o	3.44 ^f	3.44 ^f	—	8.54 ^e	10.90 ^h	10.13 ^b	10.13 ^b	—
R, anolyte	3.92 ^b	3.74 ⁱ	3.56 ⁱ	3.56 ^h	3.50 ^e	10.27 ^h	10.09 ^e	10.53 ^e	10.53 ^e	12.11 ^f
R, Cl ₂ water	3.92 ^b	3.40 ^d	3.54 ^h	3.54 ^h	—	10.27 ^h	10.89 ^h	11.75 ^j	11.75 ^j	—
R, hot water	3.92 ^b	3.78 ^j	3.70 ^m	3.70 ^l	3.96 ^g	10.27 ^h	12.83 ^m	13.92 ^q	13.92 ^r	11.86 ^d
R, control	3.92 ^b	3.48 ^f	3.50 ^g	3.50 ^g	3.92 ^g	10.27 ^h	9.78 ^d	11.04 ^h	11.04 ^h	9.06 ^a
<i>Room temperature</i>										
G, anolyte	3.88 ^b	4.02 ^m	3.20 ^b	3.20 ^b	4.14 ^h	7.74 ^b	12.33 ^l	10.21 ^b	10.21 ^b	13.19 ^k
G, Cl ₂ water	3.88 ^b	3.94 ^l	3.78 ^o	3.78 ⁿ	3.22 ^a	7.74 ^b	10.17 ^f	12.20 ^m	12.20 ^m	13.44 ^l
G, hot water	3.88 ^b	3.48 ^f	3.36 ^e	3.36 ^e	3.42 ^d	7.74 ^b	8.12 ^b	10.93 ^g	10.93 ^g	13.35 ^l
G, control	3.98 ^c	3.40 ^d	3.82 ^q	3.82 ^o	3.92 ^g	7.94 ^d	8.63 ^b	12.66 ^o	12.66 ^p	12.71 ^h
P, anolyte	3.70 ^a	3.30 ^c	3.42 ^f	3.42 ^f	—	8.74 ^f	8.54 ^b	10.27 ^c	10.27 ^c	—
P, Cl ₂ water	3.70 ^a	3.58 ^g	3.32 ^d	3.32 ^d	—	8.74 ^f	10.38 ^f	10.45 ^d	10.45 ^d	—
P, hot water	3.70 ^a	4.94 ^q	3.60 ^j	3.60 ⁱ	—	8.74 ^f	11.46 ⁱ	12.91 ^p	12.91 ^q	—
P, control	3.70 ^a	3.86 ^k	3.26 ^c	3.26 ^c	—	8.74 ^f	9.36 ^c	10.77 ^f	10.77 ^f	—
R, anolyte	3.82 ^b	3.68 ^h	3.12 ^a	3.12 ^a	—	10.06 ^g	9.63 ^d	9.46 ^a	9.46 ^a	—
R, Cl ₂ water	3.82 ^b	3.10 ^a	3.50 ^g	3.50 ^g	—	10.06 ^g	10.05 ^d	12.31 ⁿ	12.31 ⁿ	—
R, hot water	3.82 ^b	3.08 ^a	3.48 ^g	3.48 ^g	—	10.06 ^g	9.72 ^d	12.66 ^o	12.66 ^o	—
R, control	3.82 ^b	3.86 ^k	3.20 ^b	3.20 ^b	4.66 ^k	10.06 ^g	12.05 ^k	10.97 ^g	10.97 ^g	13.43 ^l
<i>Significant level (P)</i>										
Storages (A)	<0.001	—	—	—	—	<0.001	—	—	—	—
Maturity (B)	<0.001	—	—	—	—	<0.001	—	—	—	—
Disinfection (C)	<0.001	—	—	—	—	<0.001	—	—	—	—
Storage period (D)	<0.001	—	—	—	—	<0.001	—	—	—	—
A × B	<0.001	—	—	—	—	<0.05	—	—	—	—
A × C	<0.001	—	—	—	—	<0.001	—	—	—	—
A × D	<0.001	—	—	—	—	<0.001	—	—	—	—
B × C	<0.001	—	—	—	—	<0.001	—	—	—	—
B × D	<0.001	—	—	—	—	<0.001	—	—	—	—
C × D	<0.001	—	—	—	—	<0.001	—	—	—	—
A × B × C	<0.001	—	—	—	—	<0.001	—	—	—	—
A × B × D	<0.001	—	—	—	—	<0.001	—	—	—	—
A × C × D	<0.001	—	—	—	—	<0.001	—	—	—	—
B × C × D	<0.001	—	—	—	—	<0.001	—	—	—	—
A × B × C × D	<0.001	—	—	—	—	<0.001	—	—	—	—
LSD _{0.05} = 0.168, CV (%) = 3.6, SE = 0.135						LSD _{0.05} = 0.8842, CV (%) = 6.0, SE = 0.712				

The means separation was carried out by the Duncan's multiple range test ($p < 0.05$) and the column means with similar superscripted letter(s) are not significantly different

TTA:TSS, total titratable acidity to total soluble solid ration; A, storage environments; B, maturity stages; C disinfection treatments; D, storage period; G, green mature tomatoes; P, pink tomatoes and R, red tomatoes

tomatoes decreased from 0.51–0.3%, 0.44–0.3% to 0.38–0.3% over the 14 days of storage, respectively, for green, pink and red stages. The decrease was reported to be due to the metabolic activity of the fruit itself, which reduces the organic acids (Pila et al. 2010).

All individual factors, including maturity stage, storage conditions, storage period and pre-storage disinfection treatments, had a significant ($p \leq 0.001$) effect on the TTA content of the tomato samples (Table 1). The TTA content decreased with the ripening of tomatoes during the storage period, which is in agreement with the findings of Moneruzzaman et al. (2008). Hot water dipped samples exhibited the lowest TTA, followed by chlorinated and anolyte water that was treated while the control sample showed the largest TTA content.

All two-way interactions between the maturity stage, storage conditions, storage period, and disinfection treatments had a significant ($p \leq 0.001$) influence on the TTA content of the tomato samples. Compared to pink and red tomatoes, the green mature stage had the highest TTA content, when stored under ambient conditions or in an EC storage environment. The lowest TTA content of tomatoes was exhibited by red tomatoes over a three-week period, while the largest shown was by green and pink over a short period, which was in agreement with Pila et al. (2010). Compared to the other treatments, the largest TTA content was exhibited by the EC storage environment of tomato samples subjected to anolyte water disinfection. The result indicates that the combined effect of EC storage with anolyte water maintains the TTA content and that the TTA content decreases with storage period elongation (Pila et al. 2010).

The three-way interaction effects of the maturity stage, storage conditions, storage periods and pre-storage disinfection treatments had a significant ($p \leq 0.05$) effect on the changes in the TTA contents, which is in agreement with the findings of Moneruzzaman et al. (2008). Tomatoes harvested at the green and pink stages and stored in an EC environment throughout the storage period, showed the highest TTA content. Compared to ambient storage, the EC storage conditions maintained the higher TTA of tomato samples over the 14 days of the storage period. Anolyte and hot water dipped red tomatoes that were subjected to both outside and inside EC storage showed the lowest TTA content, whereas the highest TTA was shown by green tomatoes stored inside EC and subjected to all pre-storage disinfection treatments.

Total soluble solids content

Total soluble solid (TSS) content is the refractometric index that indicates the percentage total soluble solids in a solution (Beckles 2012) and it is one of tomato quality

indices. It is the sum of fruit acids, sugars and other soluble components of the fruit pulp and is inversely proportional to fruit's size (Beckles 2012). The TSS value from 5.5 to 8.5% is recommended to be suitable for the processing industry (Gould 1992).

All individual factors, including the maturity stages, storage conditions, storage period and pre-storage disinfection treatments, had a significant ($p \leq 0.001$) effect on the TSS content of tomatoes (Table 1). The TSS of tomatoes harvested at the green and pink mature stage increased from 3.9–4.2% to 3.7–4.5%, respectively, over a seven-day of storage period, followed by an increase over 14 days of storage, with a decreasing trend thereafter. Compared to tomatoes stored under ambient condition, the TSS was higher for tomatoes stored under EC storage, which was in agreement with the results reported by Getinet et al. (2008). The pre-storage disinfection treatment result proves that chlorination disinfection was the best of maintaining the TSS content, followed by anolyte and hot water dipping.

All the two-way interaction effects of the maturity stage, storage conditions, storage period and pre-storage disinfection treatments had a significant ($p \leq 0.001$) effect on the TSS content of tomatoes. Tomatoes harvested at the green maturity stage and stored inside an EC storage environment showed the lowest TSS content. This shows that EC storage qualifies in lowering the TSS, by reducing the physiological breakdown of the tomato constituents (Pila et al. 2010). The lowest TSS content was found in the tomatoes that were harvested at the pink and green stages and dipped in anolyte and chlorinated water. On the other hand, green and red tomatoes dipped in anolyte water, and pink tomatoes subjected to hot water, showed the highest TSS content. Moreover, the interaction effects of anolyte water and chlorinated dipped samples subjected to EC storage had the lowest TSS content, which could be a good combination.

All the three-way interactions between maturity stages, storage conditions, periods and pre-storage disinfection treatments had a significant ($p \leq 0.001$) effect on the TSS content of tomatoes. The EC storage environment maintained the low TSS content over two weeks of the storage period. Moreover, the lowest TSS content is shown by pink tomato samples that were dipped in anolyte or chlorinated water and stored in an EC environment. Low maturity stage tomatoes, combined with disinfection treatments and the EC environment, resulted in the lowest TSS content. Hence, the green maturity stage, a two-week storage period and an EC environment might be the best combination, to maintain the quality of tomatoes. Moreover, tomato samples dipped in anolyte water had the lowest TSS content over a two-week of storage period and stored in an EC environment.

Total soluble solids to total titratable acid ratio

The TSS to TTA ratio (TSS:TTA) is an important key indicator of the quality of fresh produce (Beckles 2012). The TSS:TA is highly dependent on the maturity stage and growth conditions (Kader et al. 1978). In this study, the TSS:TTA changed from 7.8–15.1, 6.7–27.3 to 8.8–33.9 for tomato samples harvested at the green, pink and red stages, respectively (Table 1). Several researchers reported that fruit size is dependent on the TSS:TTA (Kader et al. 1978). Thus, a TSS:TTA content of 3–5%, 5–7% and 9–15% was identified for large beefsteak, medium-sized and cherry tomatoes, respectively (Gautier et al. 2008). As a result, the tomato samples used for this study are considered to be beefsteak (large fruit sized) tomatoes.

Firmness

All individual factors, including the maturity stages, storage conditions, storage period and disinfection pre-storage treatments, had a significant ($p \leq 0.05$) effect on the changes in firmness (Fig. 3). Tomatoes harvested at the green maturity stage remained intact and were the firmest, followed by pink and red, respectively, which is in agreement with the report of Batu (2004). The tomatoes harvested at the green, pink and red maturity stages experienced a decrease in firmness from 29 to 10 N, 25 to 13 N, 20.5 to 10 N, respectively, over 21 days of the storage period. The decrease in firmness could be due to

the physiological breakdown of the fruit cell wall during ripening (Batu 2004). Batu (2004) reported that a firmness greater than 8.76 N was very firm and very marketable in supermarkets, hence, the result of this experiment is in agreement with the author's report. Moreover, the tomatoes stored inside an EC environment had higher firmness, compared to those stored under ambient conditions, which is in agreement with the report of Luna-Guevara et al. (2014). The result indicates that EC storage kept the fruit structure intact and firm, which might contribute to the maintenance of tomato quality. Moreover, the effects of hot water treatment indicated the lowest firmness, as reported by Luna-Guevara et al. (2014), while anolyte water and chlorinated disinfected tomatoes maintained higher firmness.

All the two-way interaction effects between the maturity stages, storage conditions, storage period and disinfection treatments, were found to be significant ($p \leq 0.05$) for the changes in the firmness of the tomatoes. Compared to red and pink mature stage tomatoes, the green mature tomatoes that were subjected to EC storage conditions showed the highest firmness (Fig. 3). The result indicates that a combination of less mature tomatoes and low temperature (EC) storage conditions gave the firmest tomatoes, which is in agreement with (Lana et al. 2005). Moreover, tomatoes harvested at the red maturity stage and subjected to all disinfection treatments show the lowest firmness, while the green tomatoes display the highest firmness. On the other hand, the interaction of EC storage and chlorinated water

Fig. 3 Changes in firmness (N) of tomatoes harvested at green (a), pink (b) and red (c) stage and subjected to pre-storage and storage environment treatments ($n = 5$). Where RT is room temperature, EC

is evaporative cooling, AW is anolyte water, HotH₂O is hot water, and Cl₂ is chlorinated water (colour figure online)

dipping maintained the firmness better than the other treatments.

All the three-way interaction effects among the maturity stages, storage conditions, storage period and disinfection treatments, were had a significant ($p \leq 0.05$) influence on the firmness of the tomatoes. Tomatoes harvested at the green maturity stage, subjected to both ambient and EC conditions, had the largest firmness throughout storage period, but the red stage experienced the lowest firmness. Moreover, the results indicated that the combination of red maturity stage tomatoes, ambient storage and hot water treatment aggravated the firmness loss. However, the less mature stage tomatoes, subjected to EC storage and chlorination disinfection or hot water treatment, maintained their firmness. Similarly, a combination of less mature tomatoes, subjected to short storage period and chlorinated or anolyte water disinfected, gave the highest firmness. However, Workneh et al. (2003) reported that dipping in anolyte water had no effect on the firmness of carrot.

Colour

Tomato colour is one of the most important factors that determines the consumer's acceptance and purchase. The higher hue angle of tomatoes indicates the lower physiological colour development. All individual factors, including maturity stage, storage period and disinfection treatments, had a significant ($p \leq 0.05$) influence on the changes in hue angle of the tomato fruit (Fig. 4). The hue

angle difference among the maturity stages could be acquired by the ripening of the fruit tissue. The hue angle was inversely proportional to the maturity stages, due to the ripening process (Viskelis et al. 2008). The effects of storage conditions on the changes in hue angle were not found to be significant ($p > 0.05$), which is in agreement with the report of Luna-Guevara et al. (2014). Compared to ambient storage, the EC storage environment slowed down the colour development of tomatoes harvested at three maturity stages. This indicates that the EC prolonged the shelf-life of the tomatoes by reducing physiological changes that lead to the colour development (Viskelis et al. 2008). A prolonged storage period highly affected the hue angle, which might be due to a breakdown of the components and lycopene development (Viskelis et al. 2008). In addition, hot water treatment maintained a high hue angle.

All the two-way interaction effects between the maturity stages, storage condition, storage periods and disinfection treatments, had a significant ($p \leq 0.05$) effect on the hue angle of the tomato samples. The tomato samples harvested at the green maturity stage experienced the largest hue angle, when stored under EC environment (Fig. 4). Hence, combination of less maturity stage and EC storage environment, it was found to be significant for maintaining quality and freshness. Moreover, tomatoes harvested at the green and pink maturity stage and subjected to a short storage period experienced the highest hue angle. A hue angle of 103° to 45° , 73° to 45° and 60° to 45° , respectively, was demonstrated for tomatoes harvested at the

Fig. 4 Changes in hue angle of tomatoes harvested at green (a), pink (b) and red (c) stage and subjected to pre-storage and storage environment treatments ($n = 5$). Where RT is room temperature, EC

is evaporative cooling, AW is anolyte water, HotH₂O is hot water, and Cl₂ is chlorinated water (colour figure online)

Fig. 5 Change in cumulative percentage of physiological weight loss of three tomatoes maturity stages [*Green* (G), *Pink* (P) and *Red* (R)] at ambient temperature (AMB) of 21 °C and evaporative cooler (EC) (colour figure online)

green, pink and red maturity stages, over a 21-day storage period. Similar to the report of Radzevičius et al. (2009), the hue angle of the external tomato colour approached 40° to 45° for different maturity stages over 21-day storage period. A combination of the green maturity stage with all disinfection treatments, gave the largest hue angle. In addition, the results indicate that a combination of EC storage environment and hot water treatment maintained the firmness of tomatoes. Moreover, the results indicate that a short storage period and hot water or chlorine disinfection maintained the quality of the tomatoes. The result showed that a combination of less ripe tomatoes and stored in an EC environment for short period, gave the best quality.

Physiological weight loss

The cumulative physiological weight loss (PWL) of tomatoes harvested at the green, pink and red maturity stages and subjected to either an ambient or EC storage environment, is shown in Fig. 5. The PWL of tomatoes

harvested at the red maturity stage and subjected to an ambient storage environment was 12% over 15 days period, while that for tomatoes stored inside EC was 9.6% over a 29-day storage period. The PWL of tomatoes harvested at the pink maturity stage and subjected to ambient storage was found to be 10.7% over 15-day period, while the stored under the EC lost 7.2% weight during a 29-day storage period. Furthermore, the PWL of tomatoes harvested at the green maturity stage and subjected to ambient storage was 10.6% over a 20-day period, while inside EC it was 7% over a 29-day period. This implies that EC maintains the water content of the tomatoes by lowering the physiological respiration and removal of water from the fruit surface. Researchers report that about 10% of PWL is acceptable as a threshold for the quality of fresh produce (Acedo 1997). Islam et al. (2012) reported that tomatoes storage inside a zero energy evaporative cooling chamber resulted in only 2.6% PWL, compared to ambient storage (5.4%). The shelf-life of tomatoes stored inside EC had been extended by at least 14 days, when compared to tomatoes stored in an ambient storage environment.

Fig. 6 Change in cumulative percentage of marketability of tomatoes at room temperature of 20–23 °C and evaporative cooler (EC), where RT is room temperature, AW is anolyte water, HotH₂O is hot water, and Cl₂ is chlorinated water

Moreover, the evaporative cooler can extend the shelf-life of carrots by three-week, compared to ambient storage (Babarinsa et al. 1997). The result shows that storage under an EC environment over 30 days seems to be good enough to keep the PWL below the threshold level (10%).

Marketability

The percentage of marketable tomato fruits decreased during the storage period (Fig. 6). The EC storage significantly ($p \leq 0.05$) improved the marketability of tomatoes harvested at all maturity stages (i.e. green, pink and red), in agreement to the report of Workneh et al. (2011). The control tomatoes dipped in hot water and stored in an ambient storage environment, showed a faster loss of marketability (80%) in the 14 days storage. However, tomato samples dipped in chlorinated water and stored under ambient conditions had a 40% loss in marketability. On the contrary, the control samples dipped in anolyte water displayed a small loss in marketability (10%) during the 14 days storage. Moreover, tomatoes dipped in anolyte and chlorinated water and stored in an EC environment had 80% marketability over the 21 days storage period. On the contrary, the tomatoes treated with hot water and stored inside the EC were found to have 50% less marketability over the 14 days of storage.

Conclusion

This study shows that an evaporative cooler decreases the air temperature, while increasing the RH considerably. The midday to the late afternoon of the day is the hottest and, hence, reducing the temperature of the produce is highly important. The air temperature difference between the ambient and the EC environment ranged between 4 and 7 °C, while the RH increased by 55%. The reduced temperature can retard the physiological change and the RH increase can keep the tomatoes fresh. No uniform distribution of air temperature and RH found between the inlet and exit of EC. Integration between maturity stages, EC, pre-storage disinfection treatments significantly contribute to the maintenance of tomato quality. The pH value, TSS and TSS:TA of the tomatoes increased. But, the TTA content showed a decline during the storage period of 14 days. All tomato samples experienced a decrease in firmness and hue angle over the storage period of 21 days. The EC storage maintained a higher firmness and hue angle, when compared to ambient condition. Tomatoes dipped in anolyte or chlorinated water and subjected to EC storage maintained the percentage of marketability by two-folds over a 21-days, when compared to tomatoes dipped in hot water and stored under similar conditions. Hence, the

EC storage with pre-storage disinfection treatments improved the marketability of the fruit and, hence, extended the shelf-life of tomatoes. Moreover, the EC maintained the PWL 7–10% over the 30-day storage period, while the ambient storage was maintained at 10–12% for 15 days. Hence, integrated approaches of storage conditions and pre-storage disinfection treatments are important for extending the shelf-life and quality maintenance of fresh produce. However, further modelling studies of the microclimate air dynamics might be of paramount important for the further modification of the design of the EC chamber, in order to attain further uniform air dynamics distribution.

Acknowledgements The Federal Ministry of Education of Ethiopia is gratefully acknowledged for its research grant support. The National Research Fund (NRF-TWAS) is also greatly acknowledged for its scholarship grant (Reference No. SFH150902141138). The host institute, the University of KwaZulu-Natal, is warmly acknowledged for its support. Moreover, the ZZ2 and the tomato Postharvest Innovation Programme project is acknowledged for the provision of tomato samples.

References

- Acedo ALJ (1997) Storage life of vegetables in simple evaporative coolers. *Trop Sci* 37:169–175
- Anyanwu EE (2004) Design and measured performance of a porous evaporative cooler for preservation of fruits and vegetables. *Energ Convers Manag* 45:2187–2195
- AOAC (1995) Official methods of analysis: association of official analytical chemists. AOAC, Virginia
- Awole S, Woldetsadik K, Workneh TS (2011) Yield and storability of green fruits from hot pepper cultivars (*Capsicum* spp.). *Afr J Biotechnol* 10:12662–12670
- Babarinsa FA, Williams JO, Osanu FC (1997) Storage of carrots in a brick wall cooler under semi-arid conditions. *Trop Sci* 37:21–27
- Barrett DM, Beaulieu JC, Shewfelt R (2010) Color, flavor, texture, and nutritional quality of fresh-cut fruits and vegetables: desirable levels, instrumental and sensory measurement, and the effects of processing. *Crit Rev Food Sci* 50:369–389
- Basediya A, Samuel DVK, Beera V (2013) Evaporative cooling system for storage of fruits and vegetables: a review. *J Food Sci Technol* 50:429–442
- Batu A (2004) Determination of acceptable firmness and colour values of tomatoes. *J Food Eng* 61:471–475
- Beckles DM (2012) Factors affecting the postharvest soluble solids and sugar content of tomato (*Solanum lycopersicum* L.) fruit. *Postharvest Biol Tec* 63:129–140
- Chinenye NM, Manuwa SI, Olukunle OJ, Oluwalana IB (2013) Development of an active evaporative cooling system for short-term storage of fruits and vegetable in a tropical climate. *Agric Eng Int: CIGR J* 15:307–313
- Fallik E, Grinberg S, Alkalai S, Lurie S (1996) The effectiveness of postharvest hot water dipping on the control of grey and black moulds in sweet red pepper (*Capsicum annuum*). *Plant Pathol* 45:644–649
- Gautier H, Diakou-Verdin V, Bénard C, Reich M, Buret M, Bourgaud F, Poëssel JL, Caris-Veyrat C, Génard M (2008) How does tomato quality (sugar, acid, and nutritional quality) vary with

- ripening stage, temperature, and irradiance? J Agr Food Chem 56:1241–1250
- Getinet H, Seyoum T, Woldetsadik K (2008) The effect of cultivar, maturity stage and storage environment on quality of tomatoes. J Food Eng 87:467–478
- Gould WA (1992) Tomato production, processing and technology. CTI Publications, Timonium
- Islam MP, Morimoto T, Hatou K (2012) Storage behavior of tomato inside a zero energy cool chamber. Agric Eng Int CIGR J 14:209–217
- Itoh K (2003) Combined effects of hot water treatment (HWT) and modified atmosphere packaging (MAP) on quality of tomatoes. Packag Technol Sci 16:171–178
- Kader AA (1985) Postharvest biology and technology: an overview. In: Kader AA et al (eds) Postharvest technology of horticultural crops, Special Publications 3310:15. University of California DANR, Oakland
- Kader AA, Stevens M, Albright M, Morris L (1978) Amino acid composition and flavor of fresh market tomatoes as influenced by fruit ripeness when harvested. J Am Soc Hort Sci 103:541–544
- Lana MM, Tijskens LMM, Van Kooten O (2005) Effects of storage temperature and fruit ripening on firmness of fresh cut tomatoes. Postharvest Biol Tec 35:87–95
- Liberty JT, Ugwuishiwua BO, Pukumab SA, Odo CE (2013) Principles and application of evaporative cooling systems for fruits and vegetables preservation. Int J Curr Eng Technol 3:1000–1006
- Luna-Guevara ML, Jiménez-González Ó, Luna-Guevara JJ, Hernández-Carranza P, Ochoa-Velasco CE (2014) Quality parameters and bioactive compounds of red tomatoes (*Solanum lycopersicum* L.) CV roma VF at different postharvest conditions. J Food Res 3:8–18
- Mohammed M, Wilson LA, Gomes PI (1999) Postharvest sensory and physiochemical attributes of processing and nonprocessing tomato cultivars. J Food Qual 22:167–182
- Moneruzzaman KM, Hossain ABMS, Sani W, Saifuddin M (2008) Effect of stages of maturity and ripening conditions on the biochemical characteristics of tomato. Am J Biochem Biotech 4:329–335
- Pila N, Gol NB, Rao TVR (2010) Effect of post harvest treatments on physicochemical characteristics and shelf life of tomato (*Lycopersicon esculentum* Mill.) fruits during storage. Am Euras J Agric Environ Sci 9:470–479
- Pinheiro J, Alegria C, Abreu M, Gonçalves EM, Silva CLM (2013) Kinetics of changes in the physical quality parameters of fresh tomato fruits (*Solanum lycopersicum*, cv. Zinac) during storage. J Food Eng 114:338–345
- Radzevičius A, Karkleliene R, Viškelis P, Bobinas C, Bobinaite R, Sakalauskiene S, Metspalu L (2009) Tomato (*Lycopersicon esculentum* Mill.) fruit quality and physiological parameters at different ripening stages of Lithuanian cultivars. Agron Res 7:712–718
- Roy SK, Pal RK (1994) A low-cost cool chamber: an innovative technology for developing countries. In: Champ BR, Highley E, Johnson GI (eds) Postharvest handling of tropical fruits: ACIAR proceedings, vol 50. ACIAR, Canberra, pp 393–395
- Tassou SA, Lewis JS, Ge YT, Hadaway A, Chaer I (2010) A review of emerging technologies for food refrigeration applications. App Therm Eng 30:263–276
- Tefera A, Seyoum T, Woldetsadik K (2007) Effect of disinfection, packaging, and storage environment on the shelf life of mango. Biosyst Eng 96:201–212
- Thompson JF (2004) Pre-cooling and storage facilities. In: Gross KC, Wang CY, Saltveit M (eds) The commercial storage of fruits, vegetables, florist and nursery stocks. Agriculture handbook number 66. USDA, ARS, Washington
- Viskelis P, Jankauskiene J, Bobinaite R (2008) Content of carotenoids and physical properties of tomatoes harvested at different ripening stages. In: Foodbalt 3rd Z. Jelgava, Latvia, pp 166–170
- Watada AE, Ko NP, Minott DA (1996) Factors affecting quality of fresh-cut horticultural products. Postharvest Biol Tec 9:115–125
- Workneh TS (2010) Feasibility and economic evaluation of low-cost evaporative cooling system in fruit and vegetables storage. Afr J Food Agric Nutr Dev 10:2984–2997
- Workneh TS, Osthoff G, Pretorius J, Hugo C (2003) Comparison of anolyte and chlorinated water as a disinfecting dipping treatment for stored carrots. J Food Qual 26:463–474
- Workneh TS, Osthoff G, Steyn MS (2011) Influence of preharvest and postharvest treatments on stored tomato quality. Afr J Agric Res 6:2725–2736
- Xuan YM, Xiao F, Niu XF, Huang X, Wang SW (2012) Research and application of evaporative cooling in China: a review (I) research. Renew Sustain Energy Rev 16:3535–3546