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Postharvest quality and bioactive properties of tomatoes (*Solanum lycopersicum*) stored in a low-cost and energy-free evaporative cooling system

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ABSTRACT

The aim of this study was to investigate the effect of low cost evaporative cooling system on the quality of two tomato cultivars, namely, 9065 jam and round tomatoes. Both the tomato cultivars were harvested from a smallholder farmer's field at Umsinga and stored for 20 days in one of the three storage conditions namely; cold room (CR), room temperature (RT) and evaporative cooling system (ECS) and sampling done every 5 days. The tomato samples were laid out as a factorial design with four replications. Results obtained proved that the storage conditions and storage period had a significant effect ($p < 0.05$) on the lycopene content (LC), antioxidants, total phenolic content (TPC) and ascorbic acid (AA) of the tomato samples. A decreasing trend with storage time was observed for antioxidants and TPC for both the cultivars whilst there was an increasing trend of AA and lycopene content on both the cultivars stored in the different storage conditions. Ascorbic acid was highest in samples stored in RT (0.173 mg/100g for round tomatoes; 0.172 mg/100g for 9065 jam tomatoes), second highest in samples stored under ECS (0.16 mg/100g for round; 0.17 mg/100g for 9065 jam) and lowest in samples inside the CR (0.11 mg/100g; 0.12 mg/100g for 9065 jam). Lycopene content was highest in samples stored in RT (45.31 mg/100g for round tomatoes; 52.9 mg/100g for 9065 jam tomatoes) second highest in samples stored under ECS (32.46 mg/100g for round tomatoes; 42.98 mg/100g for 9065 jam tomatoes) and lowest in samples inside the CR (14.16 mg/100g for round tomatoes; 8.79 mg/100g for 9065 jam tomatoes). Total phenolic content was highest in samples stored in CR (0.17 mg/100g GAE for round tomatoes; 0.19 mg/100g GAE for 9065 jam tomatoes) second highest in samples stored under ECS (0.124 mg/100g GAE for round tomatoes; 0.126 mg/100g GAE for 9065 jam tomatoes) and lowest in samples inside the RT (0.11 mg/100g GAE for round tomatoes; 0.12 mg/100g GAE for 9065 jam tomatoes). Antioxidant activities were highest in samples stored in CR (2.05 mg/100g for round tomatoes; 2.03 mg/100g for 9065 jam tomatoes), followed by samples stored under ECS (1.82 mg/100g for round tomatoes; 1.96 mg/100g for 9065 jam tomatoes) and lowest in samples inside the RT (1.02 mg/100g for round tomatoes; 1.07 mg/100 g for 9065 jam tomatoes). The correlation relationship among cultivars was positive and PCA proved that the cultivars were similar. Although CR provided the best storage condition for the investigated parameters, the results provided sufficient evidence that ECS can be the best method to increase shelf life in rural communities due to its association with cost reduction.

1. Introduction

Tomato (*Solanum lycopersicum*) is one of the most scientifically investigated horticultural produce because of its commercial importance (Correia et al., 2015). It is considered the main supplier of several phytonutrients and providing an important role in human health (Tigist et al., 2013). However, tomatoes are inherently perishable which make them deteriorate fast during postharvest value chain. As means of

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counteracting such losses tomatoes are harvested as early mature green, however, mature green tomatoes cannot be stored at temperatures less than 10 °C as this causes chilling injuries on the fruit (Castro et al., 2005) and red mature tomatoes cannot be stored for more than 7 days under normal ambient conditions in summer (Znidarcic and Pozrl, 2006). According to Rajkumar and Mitali (2009) marketability of tomatoes is lost very quickly due to its quick colour change and spoilage during postharvest. This, however, makes proper postharvest handling and storage of tomatoes very important in order to ensure good quality maintenance, an extension of shelf life and to extend supply to the market.

The physical quality of horticultural products such as firmness, colour and size are affected by storage time and exposure to unsuitable postharvest temperatures (Cantwell et al., 2009; Pinheiro et al., 2009; Abiso et al., 2015). However, according to Serea et al. (2014), postharvest storage time and temperatures do not only affect physical and physiological properties of tomatoes but also influence biochemical and nutritional properties of the fruit such as ascorbic acid (AA), total phenolic content (TPC), lycopene content (LC) and antioxidant activities. Measuring chemical parameters is considered a way of assessing the nutritional quality of horticultural products. Hence, Duma et al. (2017) stated that different qualitative and quantitative changes of chemical composition take place during ripening of tomatoes and mostly influenced by temperatures. Temperature is an important environmental factor which is known to decrease and or increase processes occurring in a produce depending on the temperature it is exposed to. Hence, Tolesa and Workneh (2017) suggested that the correct way of preventing postharvest losses caused by the use of inappropriate temperatures from affecting tomatoes chemical properties is exposing the produce to its optimum cooling temperature requirements during postharvest. According to Munoz et al. (2017) storing any harvested fruit and vegetable is the best way to avoid easy deterioration, maintaining physicochemical properties and increasing the shelf life of the produce.

Postharvest storage conditions include methods such as refrigeration, hydro-cooling, vacuum cooling, room cooling, and evaporative cooling system (Xuan et al., 2012; Vala et al., 2014). The main goal of postharvest cooling treatments is to reduce the rate of respiration and transpiration (Falah et al., 2015). Other importance of cooling includes maintaining quality, decreasing susceptibility to ethylene damage, increasing shelf life and decreasing normal metabolism rate which is associated with consuming sugars, acids, vitamins and other constituents of the tomato fruit (Thompson et al., 2001). However, these cooling systems are not affordable to smallholder farmers. As a result, this leads to postharvest loses which is one of the reasons inhibiting the success of these farmers. In addition, these resource-constrained farmers cannot afford the high cost of electricity or they do not have access to electricity at all (Nkolisa et al., 2018). Therefore, there is a need to find alternative ways to reduce postharvest losses and increase shelf life of the horticultural perishable produce for smallholder farmers to improve their profits and alleviate the problems associated with food insecurity in these rural communities.

Evaporative cooling systems have been developed which cater to the needs of these resource-constrained farmers. Evaporative cooling system is known to be a cost-effective and efficient technology for reducing temperature, increasing relative humidity and also increasing the shelf life of horticultural produce (Lal Basediya et al., 2013). Thus, it may be suitable for rural communities because it provides cooling without the need for power source (Chinenye, 2011). However, little is known about its cooling efficiency and postharvest performance of tomatoes stored in the evaporative cooling system. Thus this manuscript is the continuation of the work which was reported by Nkolisa et al. (2018).

Therefore, the aim of this study was to evaluate the effect of low cost evaporative cooling system compared to cold storage and room temperature on TPC, AA, lycopene content and antioxidant activity of two tomato cultivars, “9065” jam and round.

2. Materials and methods

2.1. Experimental site

The study was conducted at Nhlesi in Umsinga which is located under the UMzinyathi District in KwaZulu-Natal province, South Africa (28°45′56.45″ S, 30°33′42.37″ E) and at the University of KwaZulu-Natal (UKZN); Pietermaritzburg Campus, (29°37′S 30°84′E).

2.2. Treatments and experimental design

A total of 1000 tomato fruit samples (‘9065’ Jam tomatoes and round tomatoes) were harvested from a smallholder farmers field at Umsinga (28°45′56.45″ S, 30°33′42.37″ E) and transported in a well-ventilated vehicle to the postharvest research laboratory of the University of KwaZulu-Natal, Pietermaritzburg. From the harvested samples, 500 tomatoes were ‘9065’ jam cultivar and 500 were round. Mature green tomatoes of uniform size and free from blemishes were selected, washed with cold tap water to remove field heat and dirt. Then after, from the 1000 fruit that were harvested, only 648 were used for the experiment. The 648 tomato fruit were divided equally and segregated by assigning them to one of three postharvest storage treatments; namely evaporative cooling system (ECS), cold room (CR) and room temperature (RT). The sample fruit were neatly packed in display boxes for each treatment and laid out as a $2 \times 3 \times 5$ factorial design, whereby 2 cultivars were assigned to 3 storage treatments and sampled at 5 days' interval. For each cultivar, the design was a factorial arrangement with four replicates of 27 sample fruit per replicate. The day after harvest, two-thirds of the sample fruit were taken for storage at Umsinga under the evaporative cooling system and room temperature and the remaining fruit were stored in a cold room with the delivery air of 12 °C at UKZN.

2.3. Temperature and relative humidity (RH)

The temperature and RH varied between 17.2 to 19.8 °C and 79.8 and 83.9 % for ECS during the storage period, respectively. For RT the temperature and RH ranged between 19.3 to 23.0 °C and 55.6–63.6 % during the storage period respectively. Whereas, in CR the temperature and RH varied between 10.9 to 11.2 °C and 91.4–93.5 %, respectively during the duration of the experiment (Nkolisa et al., 2018).

2.4. Sampling

Fruit sampling was done on a 5-day interval for 20 days. Samples were collected from each storage treatments and taken to the UKZN Postharvest Research Laboratory for analysis until the last day of the experiment.

2.5. Data collection

2.5.1. Ascorbic acid

Ascorbic acid extraction was done following a method described by Di Matteo et al. (2010) with slight modifications, where a fresh sample was used instead of a dry sample. Briefly, each of the tomato fresh samples (1 g) were extracted by 20 mL of 3 % (w/v) metaphosphoric acid followed by shaking at 300 rpm for 30 minutes using a shaker (IKA® KS 130 control shaker, IKA® work INC., USA) and then the extract centrifuged at 4000 rpm for 10 minutes in a 4 °C centrifuge (Sorvall RC- 5C Plus Superspeed Centrifuge, Ramsey, MN 55303 United States). The ascorbic acid content was determined using a method of 2, 6 dichlorophenolindophenol (DCPIP) as described by Kampfenkel et al. (1995). Briefly, 1 mL of each sample extract was added into 3 mL of 0.2 mM DCPIP and measured immediately after mixing for 15 seconds using a UV spectrophotometer (UV- 1800, Shimadzu Scientific Instruments INC., Columbia, USA) at 515 nm. The ascorbic acid concentration on tomatoes was expressed in mg 100 g^{-1} fresh weight according to the standard

curve A_{525} = 3.6593 x μmol AsA (R^2 = 0.9982).

2.5.2. Lycopene content

Lycopene content was determined according to a method previously described by Fish et al. (2002). Briefly, 0.5 g fresh weight (FW) of each fruit sample was weighed using a calibrated weighing balance and placed inside different test tubes. 5 mL of butylated hydroxytoluene (BHT)-acetone solution (0.05% w/v), 5 mL of ethanol and 10 mL of hexane were added to the sample fruit on test tubes. The solvents were at a ratio of 2:1:1 making up a total volume of 20 mL. The test tubes were kept on ice in a cooler box and each test tube covered with aluminum foil for light protection at room temperature.

The solution was then shaken using a shaker (IKA® KS 130 control shaker, IKA® work INC., USA) for 15 minutes. After shaking, 3 mL of distilled water was added to the solution to make a final volume of 23 mL and then the solution further shaken for 5 minutes. The solution was then placed at room temperature for 5 minutes to allow the separation of hexane phases. The absorbance was measured at 503 nm using a UV-1800 Spectrophotometer (Shimadzu Scientific Instruments INC., Columbia, USA) against a hexane blank because hexane forms the upper layer of the solvents and the mixed samples are 50% hexane by volume. Lycopene (mg/kg fresh weight) was then calculated using Eq. (1) described by Suwanaruang (2016).

$$\text{Lycopene content} = \text{Abs}_{(503\ \text{nm})} \times 137.4 \quad (1)$$

where 137.4, was the lycopene constant coefficient and $\text{Abs}_{(503\ \text{nm})}$, was the absorbance of each sample fruit read at 503 nm.

2.5.3. Total phenolic content

From each tomato sample, 1 g of fresh weight was extracted with 10 mL of 80% methanol (80:20, v/v) and heated in an oven at 40 °C for 24 hours according to an extraction method previously explained by Singleton et al. (1999) with minor modifications, where a fresh sample was used instead of a dried sample.

Total phenolic contents in tomato fruit were determined by the Folin-Ciocalteau (FC) reagent procedure as determined by Singleton et al. (1965). Briefly, a 0.1 mL of the crude extract for each fruit sample was mixed with 0.5 mL FC reagent along with 1.5 mL of 7% sodium carbonate solution. Distilled water was added to make a final solution volume of 10 mL. The mixture was heated in an oven at 40 °C for 2 hours, and the absorbance was then recorded at 750 nm using a UV-VIS Spectrophotometer (Varioskan Flash Multimode Reader, Thermo Fisher Scientific, USA). The final results were expressed in mg of Gallic acid equivalent to 100 g of fresh weight of fruit sample.

2.5.4. Antioxidant activities

From each tomato sample, 1 g of fresh weight was extracted with 10 mL of 80% methanol (80:20, v/v) and heated in an oven at 40 °C for 24 hours according to an extraction method previously explained by Singleton et al. (1999) with minor modifications, where a fresh sample was used instead of a dried sample. Scavenging effect of 2, 2-diphenyl-1--picrylhydrazyl (DPPH) radical was determined using a method described by Brand-Williams et al. (1995) with slight modifications, whereby a fresh sample was used instead of dried sample. Before testing of antioxidant capacity on tomatoes, DPPH solution was freshly prepared by dissolving 0.025 g of DPPH in 100% (v/v) methanol. From the prepared extract, 5μL of an aliquot from each sample fruit was added in a cuvette containing 3 mL of the freshly prepared DPPH. The solution was then thoroughly mixed using a pipette tip and allowed to stand for 15 minutes to react at room temperature. The absorbance was measured at 515 nm wavelength using a UV-1800 Spectrophotometer (Shimadzu Scientific Instruments INC., Columbia, USA) against a blank of methanol without DPPH.

2.6. Data analysis

The collected data was analyzed using Genstat® version 17. Statistically, significant differences between the treatments were determined by analysis of variance (ANOVA) with a GenStat® 18th Edition (VSN International), under 5% levels of significance. The means were separated using Duncan's multiple ranges. Data was also subjected to multivariate statistical analyses, principal component analysis (PCA) using Unscrambler® (Version 10.3, Camo Software, AS, Norway).

3. Results and discussion

3.1. Ascorbic acid

The effect of different storage conditions on ascorbic acid of '9065' jam tomatoes and round tomatoes is shown in Table 1. Significant differences ($p < 0.001$) were observed in AA content with RT having the lowest, followed by ECS and RT. However, there were no differences found in AA content between the cultivars in storage × cultivar interaction. The increasing trend in AA content with time was observed in both cultivars and in all storage conditions. The observed increase in AA content was similar to the findings of Ajayi and Oderinde (2013) who also reported an increase in AA content in tomatoes with an increase in storage period when they were subjected in three post-harvest treatments. These treatments comprised of fruit without preservatives, used as the control, fruit preserved with groundnut oil and fruit preserved with salt. However, no differences ($p > 0.05$) were found in RT and ECS treatments between the cultivars from day 0 to day 20. Small variability was observed only in CR between day 5 and day 10. These results may suggest that the studied cultivars accumulate a similar level of AA content. In addition, the average values indicated that AA content was significantly lower under CR storage than ECS and RT, respectively.

Table 1
The interaction effect of storage condition and cultivars on the ascorbic acid content of tomatoes during 20 days of storage.

Ascorbic acid (mg 100 g^{-1})								
Storage periods (days)								
Storage condition	Cultivar	0	5	10	15	20	Storage × cultivar	Mean
CR	9065 Jam	0.03 (±0.002)^{a}	0.08 (±0.005)^{b}	0.11 (±0.004)^{cd}	0.11 (±0.005)^{de}	0.12 (±0.003)^{ef}	0.09^{a}	0.09^{a}
	Round	0.03 (±0.003)^{a}	0.07 (±0.005)^{b}	0.09 (±0.003)^{bc}	0.11 (±0.003)^{de}	0.12 (±0.003)^{ef}	0.08^{a}	
RT	9065 Jam	0.03 (±0.002)^{a}	0.15 (±0.005)^{ghij}	0.16 (±0.003)^{hijk}	0.16 (±0.003)^{hijk}	0.17 (±0.003)^{k}	1.13^{cd}	0.13^{c}
	Round	0.04 (±0.002)^{a}	0.15 (±0.001)^{ghij}	0.16 (±0.001)^{hijk}	0.17 (±0.003)^{ijk}	0.17 (±0.004)^{k}	1.13^{d}	
ECS	9065 Jam	0.03 (±0.001)^{a}	0.13 (±0.007)^{efg}	0.14 (±0.003)^{fgh}	0.15 (±0.002)^{ghi}	0.17 (±0.011)^{jk}	0.12^{bc}	0.12^{b}
	Round	0.04 (±0.003)^{a}	0.14 (±0.002)^{fgh}	0.14 (±0.006)^{fghi}	0.15 (±0.002)^{ghi}	0.16 (±0.004)^{hijk}	0.13^{cd}	

$p_s < 0.001$, LSD = 0.003.
$p_{c\times s} < 0.05$, LSD = 0.005.
$p_{c\times s\times d} < 0.05$, LSD = 0.011.
Note: Numbers with different letters within and across the column are statistical different at p < 0.05. CR = cold room; RT = room temperature, ECS = evaporative cooling system, s = storage, c = cultivar and d = days.

Room temperature storage is associated with short shelf life compared to tomatoes stored under controlled environments because of the faster development of quality attributes that reduce the shelf life (Hossain and Gottschalk, 2009). Thus, the obtained results where AA content was lower under CR support findings of Samira et al. (2013) who explained that constant low temperatures retard aging through reduced respiration rate and other metabolic processes on selected produce. Vinha et al. (2013) alluded that, high levels of acidity on tomatoes is responsible for the stability of AA content during storage. For this study, the observations of Vinha et al. (2013) could be true for samples stored at CR which remained green throughout the experiment compared with those stored at RT and under an ECS.

According to Yoshida et al. (1994), high temperatures are known to increase enzymatic catalysis and lead to the biochemical breakdown of compounds in fruit and vegetables. This usually makes the selected product lose its quality faster and have a short shelf life. For this study samples stored at RT ripened faster and as a result, were fully red at the end of the experiment whilst those in the CR were still mature green. Samples inside the ECS were mixed, some remained mature green and some were red. This therefore clearly indicates that samples that were stored in RT were more affected; they increased more followed by sample fruit stored inside the ECS, while samples inside the cold room were the lowest.

3.2. Lycopene content

Table 2 displays the effect of cultivars and storage conditions in the lycopene content of tomato samples during the 20 days of storage period. The lycopene content of '9065' jam tomatoes and round tomatoes which were harvested at the mature green stage and stored for 20 days in the CR, ECS and RT ranged between 2.3 and 52.9 mg $100g^{-1}$ of fresh tomato. The highest lycopene content was found on '9065' jam tomato stored at RT. These findings are in agreement with findings of Vinha et al. (2013) who reported that lycopene contents on tomatoes stored at RT are usually high because the temperature is not regulated to optimum requirement levels as the stored produce. Also, the obtained lycopene range values are in correspondence with the finding of Brandt et al. (2006) who reported lycopene values of 1–55 mg $100g^{-1}$ of fresh tomato. In this particular study, the temperatures ranged between 19 and 32 °C (Nkolisa et al., 2018) and the lycopene content was determined at each maturity stage and the results were calculated from average data of two years of experiment.

In this study, the general trend observed during the storage of tomatoes for lycopene content was an increasing trend (Table 2). Similar results were also reported by Sood et al. (2011) who stated that increase in lycopene content on mature green tomatoes is a result of ripening of tomatoes and the samples changing to their red colour. Lycopene content is responsible for the development of red colour in tomatoes (Nair and Lilwani, 2015). From day 0 to day 15 on both the cultivars, there was no significant difference ($p > 0.05$) on the tomato samples stored in a CR. As a result, during sampling, especially at day 15 and day 20 it was easy to identify tomato fruit physically, which were stored inside the CR from those stored in an ECS and at RT. These obtained results support findings of Samira et al. (2013) who explained that low temperatures retard aging through reduced respiration rate and other undesirable metabolic changes.

Sample fruit in an evaporative cooler showed 16% lower lycopene content during the storage period compared to sample fruit stored in RT (Table 2). Hence, it was observed that there was a significant difference ($p < 0.05$) on '9065' jam tomatoes stored at RT with those inside the ECS from day 10 till the last day of the experiment. Whilst, for round tomatoes, a significant difference ($p < 0.05$) existed among tomato samples stored at RT and ECS on day 15 and day 20. It is hypothesized that the observed highest lycopene content on samples at RT was due to higher temperatures which existed in this storage facility compared to the other storage facilities. These findings are in line with those of Tadesse et al. (2015) who explained that at high temperatures the rate of ripening process which is associated with increasing of lycopene content in tomatoes increases. The interaction among cultivar, storage condition and storage period on the lycopene content of tomato fruit was significantly different ($p < 0.05$) (Table 2). Generally, as storage days increased, lycopene content on all samples stored in the different storage conditions increased. It was observed that CR was the best storage method for decreasing the ripening rate of the tomato samples. The evaporative cooler performed better compared to RT temperature which caused the highest ripening rate and fast colour changes on the tomatoes.

3.3. Total phenolic content

The interaction effect among tomato cultivar, storage condition and storage period proved that there was a significant difference ($p < 0.05$) in TPC of the sample fruit (Table 3). Total phenolic content on the sample fruit ranges between 0.31 mg $100g^{-1}$ GAE and 0.19 mg $100g^{-1}$ GAE. A general trend of decrease in phenolic content on the tomato samples was observed as the storage period advanced. The obtained decreasing trend on phenolic content of the samples corresponded to findings of Duma et al. (2017) who explained that on mature green tomatoes, the decrease in the levels of phenolic content of tomatoes is as a result of the rate of ripening, the binding of phenols to proteins and the changes in chemical structure of the sample fruit.

On the first sampling time (day 0), there was no significant difference ($p < 0.05$) between '9065 jam tomatoes and round tomatoes. From the second sampling day, changes were beginning to appear among the tomatoes depending on the treatment a certain tomato was applied and or stored. Samples stored in the CR had the highest phenolic content and followed by the samples stored in an evaporative cooling system. It was

Table 2
The interaction effect of storage condition and cultivars on the lycopene content of tomatoes during 20 days of storage.

Lycopene content (mg 100 g^{-1})								
Storage periods (days)								
Storage condition	Cultivar	0	5	10	15	20	Storage × cultivar	Mean
CR	9065 Jam	3.05 (±0.131)^{ab}	4.10 (±0.223)^{abc}	5.33 (±0.279)^{abcde}	7.40 (±0.271)^{cdef}	8.79 (±0.140)^{efg}	5.73^{a}	5.91^{a}
	Round	2.33 (±0.099)^{a}	2.87 (±0.159)^{ab}	4.01 (±0.254)^{abc}	7.13 (±0.299)^{cdef}	14.2 (±0.962)^{i}	6.10^{a}	
RT	9065 Jam	3.10 (±0.108)^{ab}	7.98 (±0.399)^{defg}	11.26 (±1.033)^{ghi}	31.9 (±2.423)^{k}	52.9 (±2.693)^{m}	21.4^{e}	19.7^{b}
	Round	2.30 (±0.094)^{a}	7.45 (±0.273)^{cdef}	12.82 (±0.210)^{hi}	21.9 (±1.375)^{j}	45.3 (±3.135)^{l}	17.9^{d}	
ECS	9065 Jam	3.03 (±0.104)^{ab}	5.45 (±0.488)^{abcde}	6.56 (±0.329)^{bcdef}	19.9 (±1.176)^{j}	43.0 (±2.375)^{l}	21.4^{c}	14.2^{c}
	Round	2.25 (±0.094)^{a}	4.97 (±0.243)^{abcd}	9.70 (±0.362)^{fgh}	14.5 (±0.863)^{i}	32.5 (±1.861)^{k}	12.8^{b}	

$p_s < 0.001$, LSD = 1.00.
$p_{c\times s} < 0.001$, LSD = 1.42.
$p_{c\times s\times d} < 0.001$, LSD = 3.17.
Note: Numbers with different letters within and across the column are statistical different at p < 0.05. CR = cold room; RT = room temperature, ECS = evaporative cooling system, s = storage, c = cultivar and d = days.

Table 3
The interaction effect of storage condition and cultivars on the total phenolic content of tomatoes during 20 days of storage.

Total phenolic content (mg 100 g^{-1})								
Storage periods (days)								
Storage condition	Cultivar	0	5	10	15	20	Storage × cultivar	Mean
CR	9065 Jam	0.34 (±0.008)^{l}	0.32 (±0.011)^{kl}	0.28 (±0.006)^{ijk}	0.21 (±0.005)^{defg}	0.19 (±0.002)^{cde}	0.91^{a}	0.21^{a}
	Round	0.33 (±0.011)^{l}	0.31 (±0.016)^{jkl}	0.23 (±0.011)^{efgh}	0.21 (±0.008)^{def}	0.17 (±0.009)^{bcd}	0.22^{b}	
RT	9065 Jam	0.32 (±0.017)^{kl}	0.2 (±0.007)^{de}	0.17 (±0.014)^{bcd}	0.15 (±0.009)^{abc}	0.13 (±0.008)^{ab}	0.27^{c}	0.26^{b}
	Round	0.31 (±0.009)^{jkl}	0.26 (±0.013)^{fghi}	0.23 (±0.011)^{efgh}	0.19 (±0.045)^{de}	0.12 (±0.009)^{a}	0.25^{c}	
ECS	9065 Jam	0.33 (±0.017)^{kl}	0.27 (±0.015)^{hij}	0.21 (±0.039)^{de}	0.15 (±0.004)^{abc}	0.12 (±0.003)^{ab}	0.21^{ab}	0.21^{a}
	Round	0.34 (±0.016)^{l}	0.26 (±0.015)^{ghi}	0.17 (±0.007)^{bcd}	0.15 (±0.002)^{abc}	0.12 (±0.003)^{a}	0.20^{ab}	

$p_s < 0.001$, LSD = 0.013.
$p_{c\times s} = 0.001$, LSD = 0.018.
$p_{c\times s\times d} = 0.07$, LSD = 0.041.
Note: Numbers with different letters within and across the column are statistical different at $p < 0.05$. CR = cold room; RT = room temperature, ECS = evaporative cooling system, s = storage, c = cultivar and d = days.

also interesting to note that there was no significant difference ($p < 0.05$) on phenolic content on fruit samples between the cultivars in an ECS and at RT on the last day of the experiment. The observed low values of TPC on samples at CR could be an indication of lower respiration and metabolic rates occurring in this storage condition (Laurie and Klein, 1999). This, therefore, means that the highest values of TPC in samples stored at RT are due to high metabolic rates due to high temperatures in this storage condition. It was also hypothesized that RT had the highest temperatures compared to ECS and RT. These findings, correspond with those of Vinha et al. (2013) who explained that when tomatoes are stored at temperatures of 25 °C and more, exposed of rate metabolic processes and the ripening rate which therefore lead to decrease in levels of soluble phenolic compounds. Moldovan et al. (2016) agreed with findings of Vinha et al. (2013) by stating that, exposing a harvested tomato to high temperatures as it requires will lead to decrease in the levels of phenolic content.

The interaction between cultivars and the storage period was significant ($p < 0.05$). The results proved that the overall phenolic content of tomatoes was well maintained inside the CR. The ECS performed better than RT but at the end, there was no significant difference ($p < 0.05$) among tomato samples at RT and ECS for both cultivars.

3.4. Antioxidants activities

The changes in the antioxidant activity of tomatoes during storage times are due to the ripening process. As storage advances, antioxidant activities in tomato samples decreased (Table 4). The results showed a significant difference ($p < 0.05$) among '9065' jam and round tomatoes in antioxidant activities during 20 days of storage.

Antioxidant capacity of fruit is usually related to all the chemical properties of tomatoes investigated in this study which are lycopene content, phenolic compound and ascorbic acid (Odriozola-Serrano et al., 2008; Vinha et al., 2013). This is explained more following findings of Viet (2015) who explained that tomatoes are considered one of the fruit with high antioxidant activity because it contains compounds with high biological activity such as ascorbic acid, phenolic compound and lycopene content. Viet (2015) further stated that antioxidant capacity reflects the amount of lycopene, ascorbic acid and phenolic compounds. Although Odriozola-Serrano et al. (2008), Vinha et al. (2013) and Viet (2015) stated that antioxidant capacity of fruit relates to all biologically active compounds including lycopene, ascorbic acid and phenolics, the quantity of antioxidant capacity depends on the extraction method used. In this study, antioxidant capacity was determined on samples extracted using 80% methanol, the same solvent used to extract phenolics.

In this study, it is hypothesized that samples stored under RT had the lowest antioxidant capacity because they were ripening faster than the order samples stored inside the CR and under ECS. Also, it was observed that sample fruit inside RT, had the highest lycopene content, highest ascorbic acid and the lowest phenolic content and since these are related to antioxidant capacity they could have led to the lowest value obtained for both round and '9065' jam tomatoes on samples inside the RT.

Findings from this study correspond with findings of Vunnam et al. (2014) who distinguished that antioxidants capacity found on tomatoes decrease with time under storage conditions during postharvest mostly faster in produce exposed to high temperatures. In this study, this could be the result of the lowest antioxidants decrease in sample fruit stored under CR as inside these storage temperatures were the lowest (12 °C).

The decrease in antioxidant capacity observed during storage was mainly because the methanolic method used to extract and determine antioxidants activity was similar to the method used to extract phenolics. Therefore, the antioxidant determined herewith was that of phenolic compounds, not ascorbic acid and lycopene. This was also confirmed by

Table 4
The interaction effect of storage condition and cultivars on the antioxidant activities of tomatoes during 20 days of storage.

Antioxidants (mg/100 g) Storage periods (days)								
Storage condition	Cultivar	0	5	10	15	20	Storage × cultivar	Mean
CR	9065 Jam	2.92 (±0.013)^{p}	2.76 (±0.019)^{o}	2.57 (±0.018)^{lmn}	2.39 (±0.021)^{hij}	2.03 (±0.024)^{d}	2.53d	2.45c
	Round	2.65 (±0.016)^{mno}	2.55 (±0.016)^{lm}	2.38 (±0.015)^{ghi}	2.27 (±0.018)^{efg}	2.03 (±0.024)^{d}	2.37c	
RT	9065 Jam	2.90 (±0.011)^{p}	2.57 (±0.018)^{lmn}	2.35 (±0.012)^{fghi}	1.74 (±0.060)^{b}	1.08 (±0.037)^{a}	2.13a	2.11a
	Round	2.68 (±0.017)^{no}	2.43 (±0.026)^{ijk}	2.56 (±0.020)^{ef}	2.06 (±0.025)^{d}	1.05 (±0.129)^{a}	2.09a	
ECS	9065 Jam	2.93 (±0.012)^{p}	2.69 (±0.019)^{o}	2.49 (±0.024)^{jkl}	2.29 (±0.023)^{fgh}	1.97 (±0.058)^{d}	2.47d	2.39b
	Round	2.68 (±0.017)^{o}	2.51 (±0.014)^{kl}	2.29 (±0.010)^{fgh}	2.18 (±0.019)^{e}	1.84 (±0.057)^{c}	2.30b	

$p_s < 0.001$, LSD = 0.003.
$p_{c\times s} < 0.001$, LSD = 0.043.
$p_{c\times s\times d} < 0.001$, LSD = 0.096.
Note: Numbers with different letters within and across the column are statistical different at $p < 0.05$. CR = cold room; RT = room temperature, ECS = evaporative cooling system, s = storage, c = cultivar and d = days.

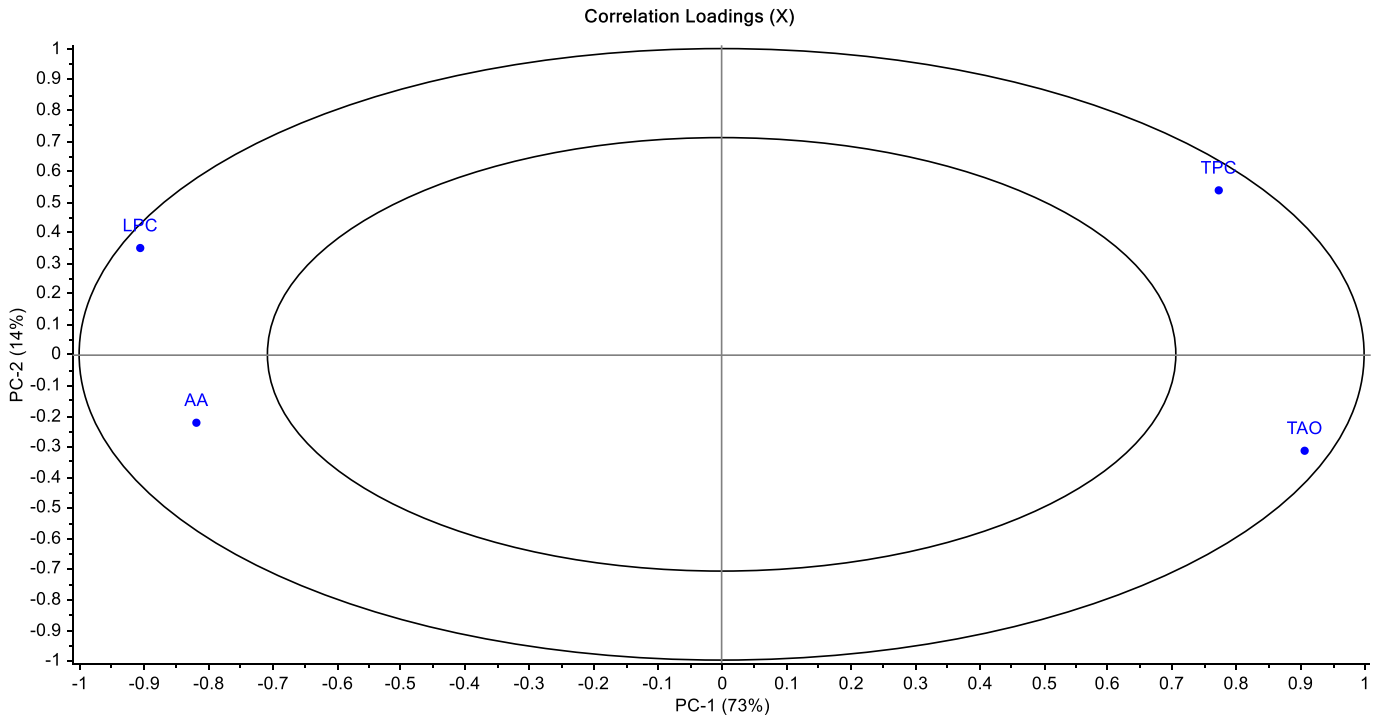

Fig. 1. Principal component analysis (PCA) for the first two principal components (PCs) showing the variation in biochemical compounds of tomatoes stored in cold room, evaporative cooling system and room temperature.

the PCA loadings plot in Fig. 1, which showed a strong correlation between total phenolic content and total antioxidant capacity. Sample fruit stored inside the ECS and RT were changing as a result of daily weather temperatures. However, samples stored in the ECS decreased better in antioxidant capacities compared to those inside RT. Differences on the rate of decrease between the two tomato cultivars could be explained according to findings of Ali et al. (2017) who explained that changes in antioxidants activities in different produce and cultivars depend on fruit type and generic appearance of the produce.

3.5. *The principal component analysis (PCA) based correlation*

The PCA for the first two PC (Fig. 1) showed variation in biochemical changes in tomato samples stored in different storage conditions. The first two principal components explained 87% of the total variability, PC1 explained 73% of the variance and PC2 explained 14% of the variance. It was observed that AA was more associated with LPC whereas, TPC was more associated with TAO. The distribution of clusters showed a slight variation between CR, ECS and RT. Clear separation of clusters was

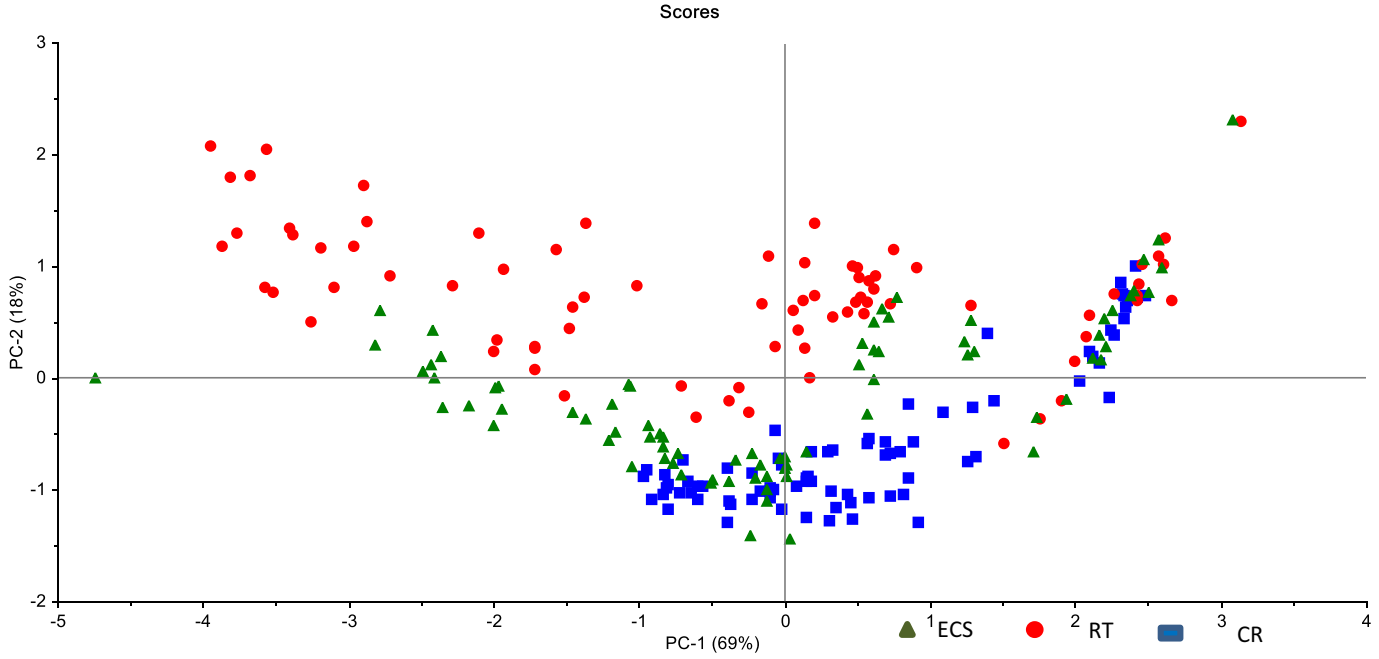

Fig. 2. Principal component analysis (PCA) similarity map for the first two principal components (PCs) showing variation in biochemical compounds occurring in '9065' jam tomato samples stored in different storage conditions. ECS, Evaporative cooling system; RT, Room temperature and CR, Cold room.

observed between CR and RT with ECS in between them in biochemical compounds of '9065' jam tomato samples (Fig. 2). This was explained by 87% of the first two principal components, PC1 explained 69% of the variance while PC2 explained 18% of the variance. Similar trends were observed in jam tomato samples (Fig. 3) with PCA for the first two PC explaining 87% of the total variability, PC1 explained 73% of the variance, whereas PC2 explained 14% of the variance. Lastly, '9065' jam tomato and round tomato biochemical changes were 100% correlated (Fig. 4). This indicates that the studied cultivars are affected by the similar type of environmental conditions.

4. Conclusion

In this study, for both cultivars, antioxidants and phenolic compounds decreased whilst ascorbic acid and lycopene content increased with increase in storage time. As expected, sample tomatoes stored inside the cold room performed best in terms of maintaining biochemical properties of '9065' jam and round tomatoes. The cold room had the lowest

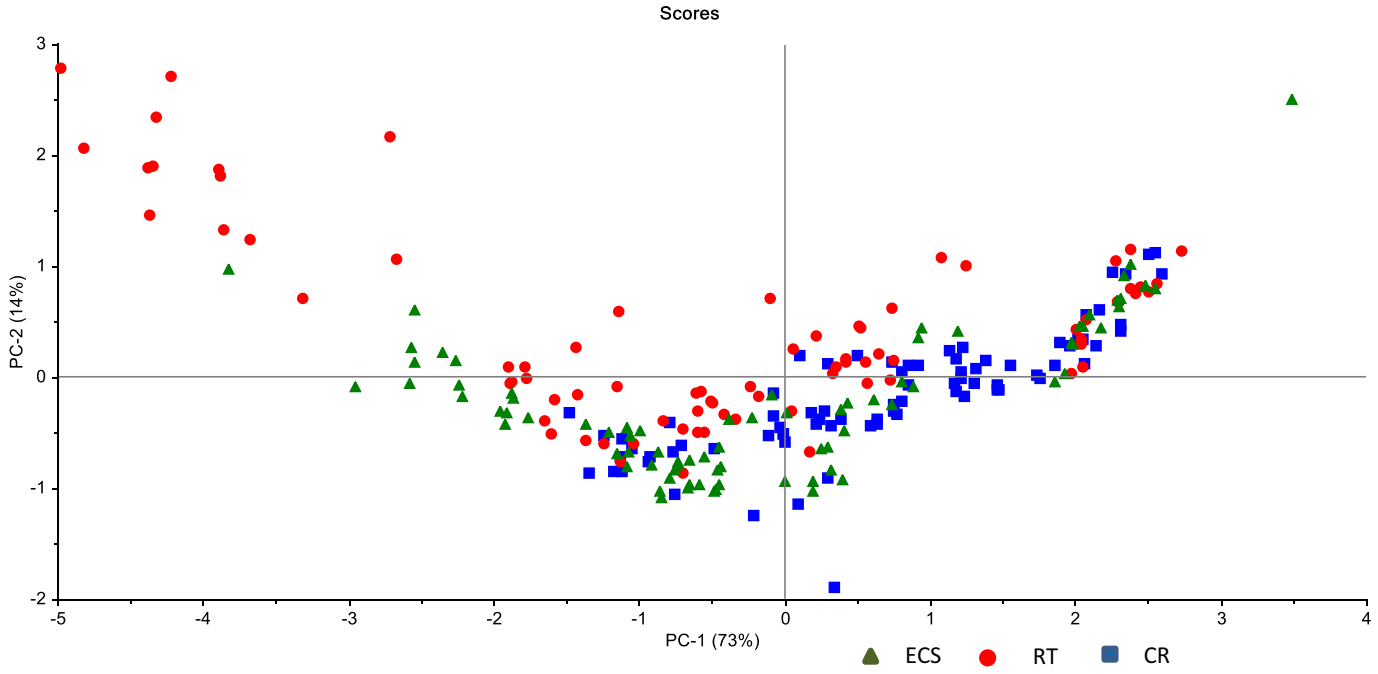

Fig. 3. Principal component analysis (PCA) similarity map for the first two principal components (PCs) showing variation in biochemical compounds occurring in round jam tomato samples stored in different storage conditions. ECS, Evaporative cooling system; RT, Room temperature and CR, Cold room.

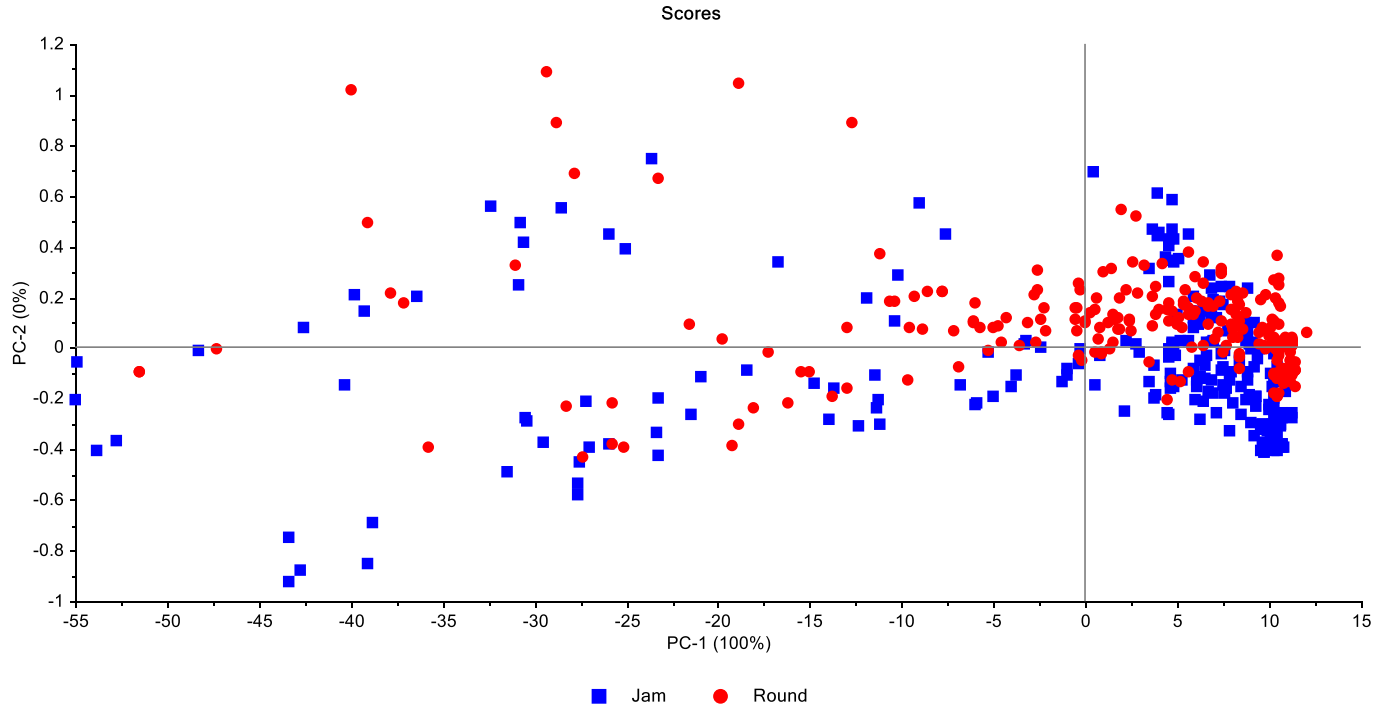

Fig. 4. Principal component analysis (PCA) similarity map for the first two principal components (PCs) showing variation in biochemical compounds occurring in '9065' jam tomato samples and round tomatoes stored in different storage conditions.

temperatures of 12 °C which led to the samples stored in the cold room to remain green throughout the experiment. Temperature changes inside the evaporative cooler and in room temperatures caused both the cultivars to reach a red colour at the end of the experiment. Tomatoes stored in the cold room had the lowest lycopene content and ascorbic acid and the highest antioxidants and phenolic content. Whilst evaporative cooler had the lowest lycopene content and AA and highest phenolic compounds and antioxidants compared to room temperature. Sample fruit stored in the evaporative cooling system were better and ripened slower than those stored at room temperature. Therefore, it also appeared that the best method of cooling was the cold room, followed by evaporative cooler and lastly storage at room temperature. Correlation proved a positive relationship between the parameters. According to the principal component analysis, the tomato cultivars are similar and the biochemical parameters of the sample tomatoes are statistically the same.

Declarations

Author contribution statement

N. Nkolisa: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

L. S. Magwaza: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

T. S. Workneh: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

A. Chimphango: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

N. J. Sithole: Analyzed and interpreted the data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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