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The Effects of a Low Cost Hydro Cooling System on the Postharvest Quality Characteristics of Selected Tropical Fruits and Vegetables

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Abstract

Quality of fresh produce getting to consumers is influenced by the postharvest handling practices. In developing countries, low cost hydrocooling system offers affordable means to curb postharvest loses of perishables. This study was undertaken to establish the effect of combining hydrocooling and low temperature storage on postharvest quality of perishables, specifically carrots, courgettes, tomatoes and African eggplants. Mature good quality produce were harvested and divided into four portions. Two portions were hydrocooled using chilled water (2 ± 1^0C) and change in temperature monitored. The other two were controls. Hydrocooled and control samples were stored at 10^0C and 20-25^0C at 95%relative humidity. Respiration rates, weight loss, soluble solids and titratable acidity changes were assessed at 2 days interval for 9 days. The percentage weight loss on day 9 was 1.83 %, 13.91 %, 8.09 %, 6.25 % and titratable acidity was 0.24%, 0.019%, 0.13%, in samples hydrocooled and stored at 10 ^{0} compared to 4.30%, 28.35%, 20.03%, 2.15%weight loss and 0.32%, 0.037%, 0.16%,titratable acidity in control for tomatoes, courgettes carrots and African eggplants, respectively. Respiration rates and soluble solids were higher in controls. Storage time had a significant effect ($P\leq0.05$) on produce quality.

INTRODUCTION

Fruits and vegetables constitute an important subsector in horticultural industry in Kenya (KARI 2012). Besides their economic importance, they constitute a major part of human nutrition (Hounsome et al. 2008). However, due to their high perishability, limited postharvest technologies in most of the developing countries and inadequate cold storage, huge postharvest losses are incurred (Kitinoja et al. 2011).

Temperature control plays an important role in preserving the quality of freshly harvested produce. Cool temperatures are essential in the preservation of flavour, texture, aroma volatiles, appearance and also in prolonging the shelf life and keeping quality of fresh produce (Teruel et al., 2004; Thorpe 2008). This is because low temperature slows down changes in physiological, chemical and physical composition of the produce (Khorshidi et al. 2010). Systems that facilitate fast cooling in fresh produce are important for rapid decrease in product temperature (Manganaris et al. 2007). Use of chilled water to cool the produce otherwise referred to as hydrocooling allows high heat transfer rates, resulting in shorter cooling time of produce.

According to Manganaris et al., (2007), water removes heat about fifteen times faster than air. Although hydrocooling offers faster cooling, there are differences in time required to cool different products to the target temperature. This is due to differences in products geometry, size and the thermal properties (Teruel et al. 2004). Despite the well-known benefits of hydrocooling on postharvest life of perishables, the technique has not been fully utilized in developing countries due to the fact that conventional custom made hydrocooling systems are usually expensive, and out of reach for most subsistence farmers (FAO 2014; Kitinoja 2010).

In order to reach out to a wide number of subsistence farmers it is imperative to assemble a hydrocooling system using locally available materials that are light in weight, flexible and which can easily be moved from one location to another as may be required.

The present study was undertaken with the aim of establishing the time required to cool specific fruits

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and vegetables to target temperatures using the low cost hydrocooling system designed and also assess its effects on postharvest characteristics in the selected produce.

MATERIALS AND METHODS

Sample collection

Tomatoes (*Lycopersicum esculentum*), carrots (*Daucus carota*) and African eggplant (*Solanum aethiopicum* L) were obtained from Juja with a Global Position System (GPS) coordinates of 1° 10' 60S , 37° 7' 0E and 1840M and courgettes (*Cucurbita pepo*) from Ngarariga Limuru, with a GPS coordinates of 1° 4' 60S, 36° 37' 0E and 2274M latitude, longitude and altitude, both locations within Kiambu county Kenya. The plants were grown under field conditions between August and December, 2014 with supplementary irrigation as required. Tomatoes were harvested at turning stage, 57 days from transplanting when the fruits showed about 30% change from green to yellow. Eggplants were harvested when the fruits were fully yellow, at 60 days from transplanting. The carrots were harvested 63 days after planting when the shoulder diameter was about $1\frac{1}{4}$inches while courgettes were harvested when their length was between 20 to 25centimetres. At the time of harvesting, the produce had attained physiological maturity andcommercially acceptable sizes. The samples were packed in cushioned crates, lined with moist paper towels to prevent moisture loss and immediately transported within three hours to the Postharvest laboratory, Department of Food Science and Technology at Jomo Kenyatta University of Agriculture and Technology, Nairobi Kenya.

The low cost hydrocooling setup

The cooling system consisted of: a jacketed water reservoir (144 cm× 30 cm×33 cm, capacity 144 litres), with water cooled using crushed ice to 2 ± 1^0C, a water pump (Pedrollo pkm 60®, Height 38±5 m and KW 0.37),with a head of 1.3meters of22 mm diameter polypropylene random copolymer pipe and two identical stainless steel showers placed in sequence at 0.94m apart. Water was circulated in the system at a flow rate of 25 ±3 liters per minute for the first shower and 18± 2.5 liters per minute for the second shower.

Temperature measurement during hydrocooling

The fresh produce samples were divided into two batches, one batch was hydrocooled while the other was the control. During hydrocooling, the produce was placed at 20± 5 cm from the shower head as illustrated in figure 1(a) and temperature monitored at the core of the produce in the middle of the plastic crate as shown in figure 1(b). Core temperature of three samples in a single run was measured during cooling by inserting temperature probes (calibrated to 0.1 ^{0}C) of a data logger with a USB interface into the produce using the principal of r4 and r3 for spherical and cylindrical products respectively (Teruel et al. 2004).

Cooling time is a parameter used to evaluate efficiency of cooling systems. In this study, with respect to the produce desired final temperatures and to avoid chilling injury, two terms half cooling time ($TAT\frac{1}{2}$) and seven eighth cooling time ($TAT\frac{7}{8}$) were considered (Teruel et al. 2004).

These were obtained using the formulae below:

$$TAT_{\frac{1}{2}} = \frac{Tp-Ta}{Ti-Ta} = 0.5 \qquad \text{i}$$

$$TAT_{\frac{7}{8}} = \frac{Tp-Ta}{Ti-Ta} = 0.125 \qquad \text{ii}$$

Where: Ti is the initial product temperature and Tp is product temperature during cooling and Ta is the temperature of cooling medium (Teruel et al. 2004).

Storage profile

Storage was done at two conditions. Hydrocooled (HC) and control (NC) samples were kept at low temperature cold (10^0C±1) (CR) for tomatoes, courgettes and eggplants and 7 ± 1^0Cfor carrots. In the second storage treatment both hydrocooled and control samples were kept at ambient temperature of about 25^0C±1(RT) and 95% ±2 relative humidity for 9 days. The fruit were sampled periodically at two days interval and then analysed for the parameters indicated below.

Analysis of physical, physiological and chemical parameters

Produce dimension and sphericity

Produce dimension (transverse and longitudinal diameters) were measured using a varnier scale, and sphericity calculated using the formula shown in Equation iii.

$$Sphericity = \frac{Transverse\ Diameter}{Longitudinal\ Diameter} \qquad \text{iii}$$

Weight loss

Weight loss was determined using a digital analytical balance (Shimadzu Libror AEG-220). Sampling was done at an interval of 2 days and the weights compared to their initial weights at the start of the experiment and expressed as a percentage (Luengwilai and Beckles 2013).

Respiration rate

The fruits were incubated in one liter containers for one hour at room temperature. A 1ml headspace gas sample was injected into a gas chromatograph (Model GC-8A, Shimadzu Corp., Kyoto, Japan), fitted with a thermal conductivity detector and a Porapak Q (Singh et al. 2013).

Total soluble solids and Total Titratable Acidity

The total soluble solid (TSS) was determined using a digital refractometer (Type PAL-1, Atago, Tokyo, Japan) and expressed as degrees brix (°B), while total titratable acidity (TTA) was determined by titration with 0.1N NaOH in presence of phenophthalein indicator and expressed as % citric acid (Sharma and Karki 2012; Yumbya et al., 2014).

Statistical Analysis

Data obtained from the experiment was presented as mean ± SE, computed in triplicates. It was statistically analysed using Genstat discovery edition 4, and means separated using Least Significant Difference (LSD) at P≤0.05.

RESULTS AND DISCUSSION

Product dimensions and sphericity

The fresh produce in this study were of different characteristic sizes and shapes. Carrots and courgettes had low sphericity values of 0.21 and 0.20 respectively, indicative of their cylindrical shapes as shown in Table 1. The tomatoes were spherical in shape while the African eggplants were obloid. Although both the courgettes and the carrots were similar in their cylindrical appearance and sphericity, produce volume was different. The mean volumes of the courgette and carrot fruits were 145.13 cm^3 and 82.78 cm^3 respectively.

Hydrocooling time

The recorded mean initial temperatures of produce at harvest was 20.7±0.6ºC, 21±0.9 ºC, 24±0.2 ºC and 22±0.4 ºC for tomatoes, carrots, courgettes and African eggplants respectively. Cooling time for all the produce varied proportionally with the produce volume, geometry and sphericity. Figure 2 shows the change in dimensionless cooling rate against time. Tomatoes which were more spherical, (sphericity 0.873±0.01) than the other produce, reached the half cooling time ($TAT_{1/2}$) at 10.25 ± 1 min, which was the longest time in the selected produce. African eggplants, carrots and courgettes attained the half cooling time ($TAT_{1/2}$) at 3.3±0.2, 2.1±0.2 and 4.9±0.3minutes respectively. Although the courgettes and carrots had almost equal sphericity, the courgettes took longer time to hydro cool to the target temperature of 10^0C.This can be attributed to their differences in volume, where carrots with larger volume required more time to reach the target temperature.

The time required to hydrocool a produce to target temperature was affected by produce sphericity and volume. Tomatoes which were more spherical took a longer time to cool to the target temperature of 10 ^{0}C, as compared to the cylindrical and oblate products. Similar results were obtained by (Teruel et al., 2004) when he hydrocooled green beans and acerola fruit. The individual produce size also determined the length of time required for the produce core temperature to reach the target temperature. This could be explained by the hot point phenomenon, where change in the core temperature of a product is a function of the surface area in contact with the cooling medium and volume of the product (Vigneault et al., 2000).

Weight loss

Weight loss in all the produce increased gradually over the storage time regardless of the treatment. The produce hydrocooled (HC) and stored at lower temperatures (CR) showed significantly lower weight loss throughout the storage period. On day 9, tomatoes, courgettes and carrots had a percentage weight loss of 1.83 %, 13.91 % and 8.09 % respectively. This was significantly different (P≤0.05) from the control which was not hydrocooled and subjected to ambient storage temperatures (NCRT), and those hydrocooled and stored at ambient conditions (HCRT). These two treatments, kept at room temperature had the highest percentage weight loss on day 9 as compared to the other treatments.

In tomatoes, the mean percentage weight loss for the control and those hydrocooled and kept at ambient temperature (HCRT) on day 9 was 4.30% and 4.43% while carrots were 20.03% and 20.45% and courgette 28.35% and 25.32% respectively; which were not significantly different (P≤0.05).

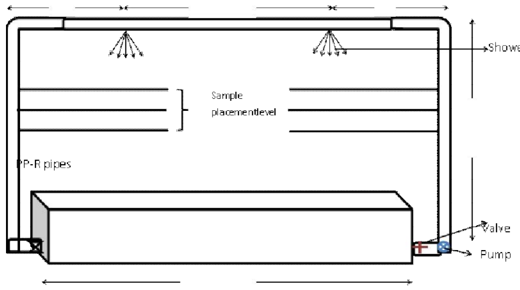
The African eggplants had the highest weight loss for hydro cooled samples and stored at low temperature as compared to the other treatments. These samples lost 6.25% of their initial weight as compared to 2.15% for the control (NC) stored at room temperature (RT) as shown in Tables 2-5.

Precooling and low storage temperatures have been used to manage weight loss in agricultural produce (Manganaris et al, 2007). Postharvest weight loss in tomato is a common serious problem during storage, attributed to loss of moisture and breakdown of carbohydrates during respiration. Precooling was found to decrease the rate of metabolism and as a result slowed down the degradation of surface materials hence resulting in lower weight loss as compared to the control (Reina et al., 1995). These findings are similar to those of Carvajal et al ,(2011) which examined various varieties of zucchini stored at different temperatures. Precooling, storage time and temperature affected weight loss in Zucchini.

The higher weight losses when precooled and stored at lower temperatures of 10^0C in African eggplant fruits can be attributed to the chilling injury symptoms that the fruit exhibited under this treatment. Fruits showed surface lesions, skin scalds and browning around the seeds which are typical chilling injury symptoms.

This phenomenon was previously reported by Luengwilai and Beckles, (2013) in tomato where high weight loss was observed in fruits that exhibited chilling injuries. Although the recommended storage temperature for the conventional eggplants is 10^0CConcello´n et al.,(2007), other factors such as environmental and soil factors prior to harvesting can affect the chilling injury sensitivity of produce (Sevillano et al., 2009).

Figure 1:
(a)System setup



(b) Temperature monitoring points

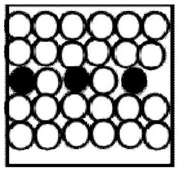


Figure 1(a) and (b): Elements comprising the shower type batch hydro-cooling system and temperature measuring points in a tray containing the fresh produce during hydro-cooling respectively.

Table 1: Produce dimensions sphericity and volume. Values presented are means ± standard error, n=80

Product	Transverse D (mm)	Longitudinal D (mm)	Sphericity (TD/LD)	Volume (Cm^3)
Tomatoes	44.93±1.35	51.67±1.75	0.87±0.01	74.97± 0.37
African eggplant	52.05±2.68	37.52±3.08	1.40 ± 0.04	85.66± 0.24
Courgettes	32.83 ± 0.58	167.92 ±2.47	0.20±0.01	145.13± 1.40
Carrots	27.80±0.53	132.89±3.32	0.21±0.01	82.78 ± 0.91

** Means ± standard error, in the same column with different subscript are significantly different (P≤ 0.05); n=5

Figure2: Dimensionless cooling time for courgettes, tomatoes, eggplants and carrots

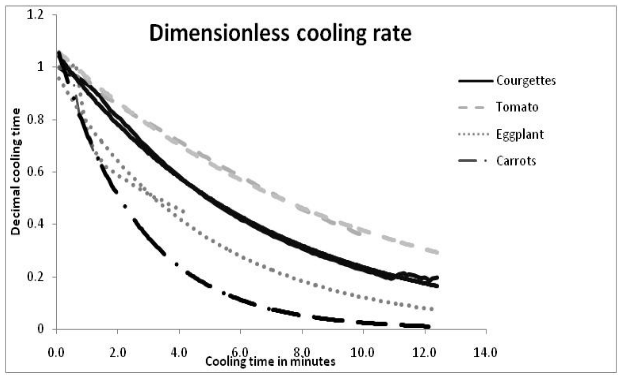


Table 2: Percentage weight loss in tomatoes during storage time

Treatment	Day 3	Day 5	Day 7	Day 9
HCCR	0.86±0.13$_a$	1.46±0.16$_a$	1.57±0.20$_a$	1.83±0.26$_a$
HCRT	2.00±0.27$_{ab}$	3.04±0.33$_b$	3.02±0.37$_b$	4.43±0.46$_{bc}$
NCCR	1.06±0.27$_a$	1.79±0.43$_a$	2.34±0.55$_{ab}$	3.35±0.76$_b$
NCRT	2.33±0.34$_{ab}$	3.15±0.38$_b$	3.22±0.45$_b$	4.30±0.68$_{bc}$
LSD 5%	**0.51**	**0.73**	**0.92**	**0.70**
Mean	**1.41**	**2.17**	**2.26**	**2.94**

** Means ± standard error, in the same column with different subscript are significantly different (P≤ 0.05); n=5

Table 3: Percentage weight loss in African eggplants

Treatment	Day 3	Day 5	Day 7	Day 9
HCCR	0.87±0.14$_{bc}$	3.60±0.29$_b$	4.96±0.57$_b$	6.25±0.39$_b$
HCRT	0.74±0.11$_b$	1.25±0.06$_a$	2.64±0.27$_a$	3.29±0.21$_a$
NCCR	1.17±0.13$_c$	3.06±0.25$_b$	3.55±0.27$_b$	4.74±0.59$_b$
NCRT	0.30±0.04$_a$	1.53±0.07$_a$	1.57±0.08$_a$	2.15±0.03$_a$
LSD 5%	**0.3698**	**0.6455**	**1.118**	**1.213**
Mean	**0.77**	**2.36**	**2.96**	**4.04**

** Means± standard error in the same column with different subscript are significantly different (P≤ 0.05); n=5.

Table 4: Percentage weight loss in courgettes

Treatment	Day 3	Day 5	Day 7	Day 9
HCCR	1.46±0.16$_a$	3.37±0.15$_a$	9.37±0.33$_a$	13.91±0.43$_a$
NCCR	2.75±0.28$_b$	8.69±0.26$_b$	20.58±0.53$_b$	25.32±0.40$_b$
HCRT	3.58±0.19$_c$	10.30±0.65$_c$	21.34±0.45$_b$	30.71±0.35$_d$
NCRT	5.72±0.24$_d$	13.15±0.92$_d$	23.78±0.60$_C$	28.35±0.31$_c$
LSD 5%	**0.762**	**1.466**	**1.383**	**1.156**
Mean	**3.11**	**8.88**	**18.77**	**24.57**

**Means± standard error; in the same column with different subscript are significantly different (P≤ 0.05) n=5.

Table 5: Percentage weight loss in carrots

Treatment	Day 3	Day 5	Day 7	Day 9
HCCR	1.32±0.19$_a$	3.13±0.39$_a$	4.53±0.54$_a$	8.09±0.42$_a$
HCRT	1.60±0.28$_{ab}$	10.51±0.49$_d$	14.26±0.76$_b$	20.45±0.68$_b$
NCCR	2.40±0.32$_c$	4.25±0.30$_{ab}$	5.56±0.43$_a$	10.01±0.62$_a$
NCRT	3.71±0.24$_d$	9.47±0.61$_c$	12.77±0.70$_b$	20.03±0.72$_b$
LSD 5%	**0.3735**	**1.123**	**1.970**	**1.987**
Mean	**2.06**	**5.85**	**7.72**	**12.47**

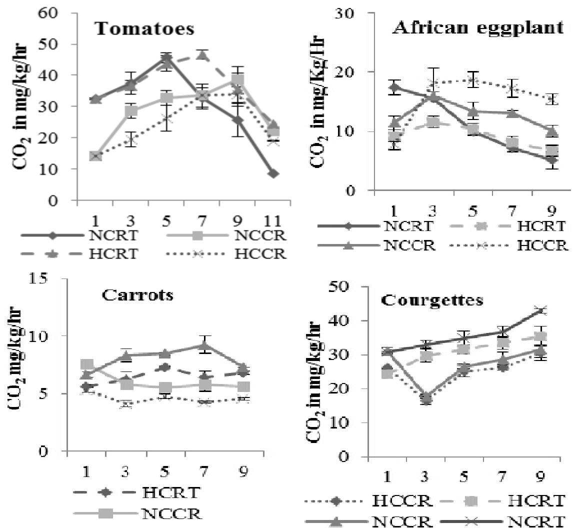
** Means± standard error in the same column with different subscript are significantly different (P≤ 0.05) n=5.

Respiration rates

The respiration rates were highly influenced by precooling and storage temperatures as shown in figure 3. In general, produce hydrocooled and stored at lower temperatures (HCCR) exhibited lower respiration rates throughout the storage period, except in the African eggplants. The tomatoes attained the climacteric peak of respiration on different days based on the storage temperature and precooling. The hydrocooled produce both stored under low temperature and room temperature attained respiratory peak on day 9 and 7 at with 33.8 mg/Kg/hr and 38.6mg/Kg/hr of carbon dioxide respectively. This respiration levels were lower than in the non hydrocooled control samples which attained their respiratory peaks on day 9 and 5 with 46.4mg/Kg/hr and 39.6 mg/Kg/hr of carbon dioxide. The other crops i.e. carrots, courgettes and African eggplants had no clear respiratory peak and showed lower respiration rates with lower storage temperatures, for both the hydrocooled and the control. The African eggplants exhibited a different pattern in this study. It exhibited highest respiration rates throughout the storage period, when hydrocooled and stored at low temperature. On day 9, the respiration rates were 15.06mg/Kg/hr carbon dioxide and 5.06 mg/Kg/hr carbon dioxide in hydrocooled and stored at low temperature and the control respectively.

Progressive increase in respiration rate during storage is a common phenomenon in perishable produce as a result of ripening related processes in climacteric fruits and spoilage development in non-climacteric fruits (Stephen and James 2010). Respiration rate is slowed down by low temperature storage in most commodities, but in chill sensitive produce, lower temperatures sufficient to cause chill injury will increase the respiration rates (Luengwilai and Beckles 2013). This phenomenon was similarly observed in the African eggplant fruits used in this study. In tomatoes, respiration increased progressively throughout storage, reaching climacteric peaks on different days based on treatments. The non hydrocooled tomatoes stored at room temperature reached the maximum peak earliest on day 5. The non-hydrocooled and the hydrocooled tomatoes in low temperature storage attained climacteric maximum on day 9. Respiration rates however declined in the fruits kept in the cold room after the 9th day. The decline occurring after the climacteric peak is a result of senescence beginning to set in. The results were not different from those obtained by Khanal and Uprety (2014) in potatoes, where those kept at low temperatures showed lower respiration rates than those kept at higher temperatures. Lower respiration rates are desirable in perishable produce because respiration rate determines the postharvest life and quality (Wu et al., 2014).

Figure 3: Respiration rates in produce over storage time. Vertical bars represent standard errors and n=3

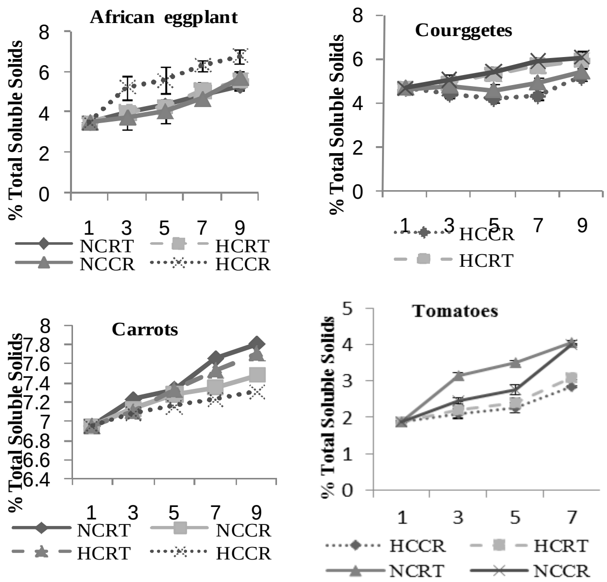


Total soluble solids

The total soluble solids (TSS) increased during storage for all the treatments in all produce as shown in**Figure**. Precooling had a significant effect ($P \leq 0.05$) in slowing the increase in TSS in all the vegetables except the African eggplant, where TSS was highest in samples hydrocooled and kept at low temperature than the other treatments. On day 9, TSS in courgettes in hydrocooled and stored at lower temperature had increased from 4.67% to 5.17% compared to the control which was not hydrocooled and had been kept at room temperature attaining 6.07%. Carrots and tomatoes showed a similar trend, with TSS in produce hydrocooled and stored at low temperature attaining 2.85% and 6.6 on day 9 respectively, which was significantly different ($P \leq 0.05$) from controls which had 4.05% and 7.55% respectively.

The increase in TSS during storage is attributed to the breakdown of starch into sugars or the hydrolysis of cell wall polysaccharides during ripening in climacteric fruits i.e. the tomatoes. The lower TSS with pre-cooling could be due to slowing down of metabolic activities. The slower rate of TSS increase in produce hydrocooled and kept at low temperature is due to the effect of precooling which reduced field heat from fruits, restricting respiratory activities and inhibited water loss. A similar phenomenon was reported by Makwana et al. (2014) when mangoes were hydrocooled using water at 8^0C for eight hours and stored at 8^0C. In the carrots, courgettes and African eggplants which do not ripen off the plant, TSS buildup during storage is due to the produce weight loss, resulting from moisture loss. Positive correlation between weight loss and TSS similarly observed in this study has been reported by Hailu et al.,(2008) in stored carrots stored at 1^0C.

Figure4: Total Soluble solid contents during storage. Vertical bars represent standard errors and n=3



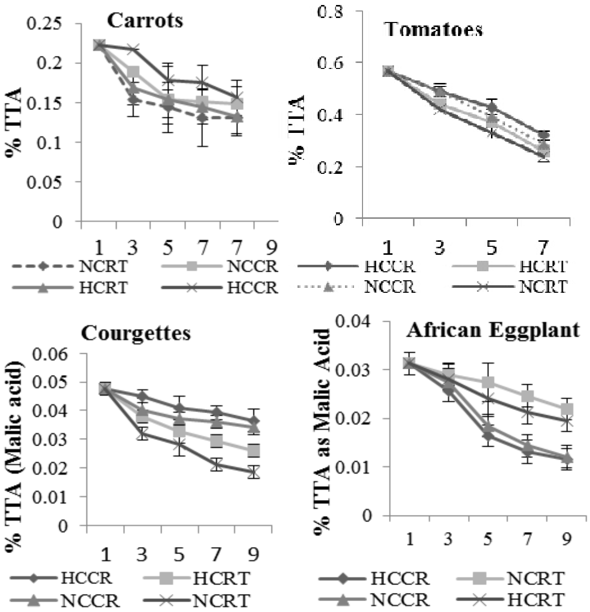
Titratable Acidity

The acidity declined during storage for all the treatments in all the produce during storage as shown in Figure 5. Faster decline in acidity was however observed in control produce stored at room temperature (NCRT) reaching 0.13% from 0.22% on day 9 for in carrots. The produce that were hydrocooled and stored at low temperature (HCCR) showed a gradual slow decline in the acidity attaining 0.15% on day 9. This was significantly different ($P \leq 0.05$) from the control.

The tomato acidity declined from 0.57% to 0.24% and 0.32% for the control and those hydrocooled and stored at low temperature (HCCR) respectively. This was a typical acidity reduction over storage time, associated with ripening. This findingswere similar to the results obtained by (Shahi et al. 2012) where fully ripe tomatoes had TTA of 0.31% expressed as citric acid.

The African eggplant fruits were however an exception. Although acidity declined during storage, rapid decline was observed in both the control and the hydrocooled fruits stored at low temperatures. The TTA for hydrocooled produce in low storage temperature and the control fruit at ambient storage was 0.01% and 0.02% on day 9 respectively. Decline in titratable acidity during storage of perishable produce is related to metabolic processes occurring in them. During respiration, organic acids are utilized as substrates of respiration. Decline in acidity is attributed to ripening, where (Žnidarčič and Požrl 2006) showed that the amount of organic declined as they are a substrate of respiration.

Figure 5: Titratable acidity of produce during storage. Vertical bars represent standard errors and n=3



CONCLUSION

Combining low storage temperature and hydrocooling has a positive effect on the postharvest quality of carrots, courgettes and tomatoes. Precooling of perishables to target temperature without further low temperature storage is only effective for 3 days in these produce. For produce that will stay on the shelves for more than 3 days, the findings in this study indicate that a further cold storage is necessary. Although the produce subjected to both precooling and low temperature storage were superior in quality, there was no significant statistical difference in their quality with those subjected to low temperature storage without prior precooling. Although the recommended storage temperature for the conventional eggplants is 10 °C, this may not be applicable to the African eggplant. The data obtained for African eggplant indicates that either hydrocooling or low temperature storage (10°C) or both may have a negative effect on the quality and postharvest life. It further underscores the need for proper precooling procedure for the specific type of produce. The findings of this study create an emphasis on importance of low temperature storage of produce, and that precooling without further cold storage is only effective for a short period of time.

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