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Effect of Calcium Chloride and Hydrocooling on Postharvest Quality of Selected Vegetables

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Abstract

Precooling and postharvest application of calcium chloride ($CaCl_2$) on produce has positive effects in maintaining the produce quality during storage. However, there is variation in the response of the produce to different $CaCl_2$ concentrations. As a result, there is need to establish optimal concentrations of calcium chloride that can extend postharvest life of targeted produce. Fresh good quality produce (tomatoes, carrots, courgettes and African eggplants) of uniform size and maturity were harvested and sampled into four portions. One was a control, hydrocooled with water only at 2±1 ^{0}C and the others were hydrocooled with water containing $CaCl_2$ at 0.5%, 1.0% and 1.5%. After hydrocooling, tomatoes, African eggplants and courgettes were stored at 10 ^{0}C, while carrots were stored at 7 ^{0}C, all at 95% constant relative humidity, and sampled every two days for quality assessment. Weight loss, chilling injury, vitamin c and β-carotene loss were reduced by application of calcium chloride. Titratable acidity decrease and increase in total soluble solids and specific sugars was also slowed by application of $CaCl_2$.

Keywords: ascorbic acid, beta carotene, calcium chloride, chilling injury, decay incidence

1. Introduction

Horticultural produce have contributed significantly to Kenya's economy, attracting good returns thus leading to increased production (Muthoka & Ogutu, 2014). However, to maximize profits from the increased production, which is usually accompanied by huge postharvest losses, there is need to develop proper postharvest handling practices (Dhillon & Kaur, 2013). This includes precooling of produce to eliminate the field heat and respiratory heat, thus delaying deterioration (Senthilkumar et al., 2015).

Surface treatment of produce has been shown to delay physiological decay and stabilize surface of produce, thus delay overall degradation (Akhtar et al., 2010). Hydrocooling of fresh produce is designed to precool the produce, remove soil, pesticide residues and microbes that cause quality loss. In addition, hydrocooling aids in removal of cell exudates that may further support microbial growth in the perishable produce (Gil et al., 2009).

Various sanitizers have been used in the past in hydrocooling and packing operations. Chlorine in water has been used during hydro-cooling and in disinfection of pack house, packaging and transport facilities. Hydrogen peroxide (food grade) has also been used as a disinfectant at concentrations of 0.5% or less, and is effective in inhibiting development of postharvest decay caused by a number of fungi (Acedo, 2010). Although there are many sanitizers available, the cost of acquisition and their suitability for application in the food industry poses a challenge on their use. Other substances used include Organic and inorganic salts which must be of the Generally Regarded as Safe category(GRAS) (Youssef et al., 2012).

Calcium chloride has been used previously on various produce including apples, mangoes, loquat and strawberries (Souza et al., 1999; Akhtar et al., 2010; Hussain et al., 2012; Dhillon & Kaur, 2013b), showing positive results in maintaining postharvest quality of the produce.

In order to determine the effect of hydrocooling using the low cost hydrocooling system and addition of calcium chloride, it is important to initially select the perishable commodities that are of global importance in terms of

nutrition and economy. In the current study, tomatoes were selected based on the economic importance of tomato value chain in the country (ERA-MOALF 2015), while carrots and courgettes were selected due to their production levels and potential for income generation (ERA-MOALF 2010). African eggplant, a traditionally important vegetable was studied in this context as there is little information on their postharvest management practices(Kitinoja et al., 2011; Msogoya et al., 2014).

This study was undertaken with the objective of establishing the optimum concentration of calcium chloride to be applied on the selected produce and also evaluate the effect of these concentrations on microbial quality of produce.

2. Materials and Methods

The produce were harvested at their commercial maturities, characteristic for each product, and sorted for uniformity in size and stage of maturity, and also to eliminate the injured, diseased and deformed produce before proceeding with the experiment.

2.1 Hydrocooling of Selected Perishables

Upon harvest, the experiment was laid out in the laboratory in a completely randomized design. Produce hydrocooling was done using a shower type hydrocooling system with chilled water as described by (Chepngeno et al., 2015). In this study, the chilled water (2±1 ^{0} C) contained $CaCl_2$ at 0 % w/w, 0.5 % w/w, 1.0 % w/w and 1.5 % w/w. Storage was done at 10 ^{0} C for 15 days in tomatoes, courgettes and African eggplants at 10 ^{0} C and carrots at 7 ^{0} C, for 9 days. Physical, chemical and microbiological assessments were then done at two days interval.

2.2 Physical Measurements

i. Weight loss

Weight loss in fruits was measured gravimetrically on individual fruits as described by (Juan et al., 2007), where individual fruits were placed in trays, kept at respective temperature regimes with a constant relative humidity of 95% and weights of five fruits per treatment taken at intervals of two days. The percentage weight loss in the fruits was determined as a function of the original sample weight using the equation below:

$$\%\,\boldsymbol{weight\ loss} = \left(\frac{\boldsymbol{Initial\ sample\ weight - Current\ sample\ weight}}{\boldsymbol{Initial\ sample\ weight}}\right) \times \mathbf{100}\% \quad (1)$$

ii. Colour

Produce external colour was evaluated objectively using a Chroma colour meter (CR-300, Minolta Japan) (Hernandez-Munoz et al., 2008). Four readings were taken from each fruit at 90 ^{0} interval using five fruits from each treatment and measurements done in triplicate. CIELAB output readings were obtained and used to obtain the Hue angle, as shown.

$$\boldsymbol{Hue\ Angle} = \boldsymbol{tan^{-1}}\left(\frac{\boldsymbol{b^*}}{\boldsymbol{a^*}}\right) \quad (2)$$

iii. Decay Incidence/ spoilage/ Chilling injury

The storage rot or chilling injury incidence from produce subjected to the treatments was determined as the percentage (count) of the sample with decay from total proportion.

$$\%\boldsymbol{Decay\ Incidence} = \left(\frac{\boldsymbol{Number\ of\ decayed\ samples\ in\ a\ treatment}}{\boldsymbol{Total\ number\ stored\ in\ a\ treatment}}\right) \times \mathbf{100} \quad (3)$$

2.3 Physiological

i. Respiration rates

Respiration rate measurement was done by taking produce of known weight in jars of known volume whose covers were fitted with a self -sealing rubber septum for gas sampling and incubated at room temperature for one hour. Headspace gas was drawn using airtight syringe and injected into the gas chromatograms (Model GC-8A Shimadzu Corp., Kyoto, Japan) fitted with thermal conductivity detector. Rate of carbon dioxide production was calculated as mg CO_2/Kg/hr at standard atmospheric pressure.

2.4 Chemical

i. Beta carotene

Beta carotene content was analyzed using open column chromatography and UV spectrophotometer. Extraction was done using acetone and petroleum ether as described by (Delia B Rodriguez-Amaya & Kimura, 2004)**.**The extract was then evaporated to dryness at 40 ^{0}C on a rotary vacuum evaporator (RE 100 BIBY with a water bath). The residue was dissolved in petroleum ether and the sample introduced into the chromatographic column packed with silica, and eluted with petroleum ether. Absorbance was read at 440 nm in a UV-Vis spectrophotometer (Shimadzu model UV – 1601 PC, Kyoto, Japan). Beta carotene content was then calculated using a freshly prepared beta carotene standard calibration curve.

ii. Total soluble solids (TSS) and titratable acidity (TTA)

The total soluble solid (TSS) content was determined using a digital refractometer (Model PAL-S, Atago, Tokyo, Japan) and expressed as degrees brix (°B). Total titratable acidity was determined by titrating a known volume of the juice against 0.1N sodium hydroxide with phenolphthalein indicator.

iii. Specific Soluble sugar content determination

Soluble sugar content (glucose, fructose and sucrose) was determined using the method described by (Sánchez-Mata et al., 2002), with a few modifications where 10 g of the solid sample was weighed and homogenized before being transferred quantitatively to a conical flask. 50 ml of 96% alcohol was added and refluxed at 100 ^{0} C for 1 hour. The samples were then stirred and the slurry filtered. This was then evaporated in a rotary evaporator at 60 ^{0} C to dryness, and then 10ml of distilled water was added to the dried sample and shaken to dissolve the extract. From the solution, 2 ml of the sample was drawn and 8 ml of acetonitrile added. The solution was then filtered using membrane filter. The sample was then injected into the HPLC with NH2P-50E column 10 Pkm pressure and 1ml/min flow rate and Refractive index detector and the quantity of specific sugars determined using freshly prepared standard sugar concentration curve.

iv. Vitamin C

Vitamin C was determined using the method described by (Mamun et al., 2012) with a few modifications. About 10 g of sample was weighed and extracted with 0.8% metaphosphoric acid. This was made to 20 mL of juice. The juice was centrifuged at 10000 rpm (Kokusan H-200 Tokyo Japan), at 4 ^{0}C for 15 minutes. The supernatant was filtered and diluted with 10 mL of 0.8% metaphosphoric acid. This was passed through 0.45 µ filter and 20 µL injected into the HPLC machine. HPLC analysis was done using C18-4D column and Shimadzu UV-VIS detector. The mobile phase was 0.8% metaphosphoric acid, at 1.2 mL/min flow rate and wavelength of 266.0 nm.

2.5 Microbiological Assays

i. Total plate count

Fruits of known weight from treatments above were washed in sterile distilled water using a shaker, with fruit to distilled water ratio as 1:9. The wash water was then further diluted using peptone water, up to 10^5 and plated in triplicate on total plate count agar prepared as per manufacturer's instructions and incubated at 25^{0}C for 24 hours (Monaghan et al., 2009).

ii. Total yeast and mould

Fruits of known weight from treatments above were washed in sterile distilled water using a shaker, with fruit to distilled water ratio as 1:9. The wash water was then further diluted using peptone water, up to 10^5 and plated in triplicate on potato dextrose agar prepared as per manufacturer's instructions and incubated at 25 ^{0}C for 24 hours (Badosa et al*.,* 2008).

2.6 Data Analysis

Data obtained from the experiment was analyzed for variance (ANOVA) using Genstat discovery edition 4, in a randomized complete block design (RCBD) in replicates so as to establish the effect of calcium chloride concentrations and also the storage time in days on the measured parameters.

3. Results and Discussion

3.1 Weight Loss

Weight loss in all the produce hydrocooled with the calcium chloride solutions at 0%, 0.5%, 1.0% and 1.5% increased gradually over the storage time regardless of the treatment as shown in Figure 1. Weight loss was

influenced by both the storage time and the $CaCl_2$ concentration used. The difference between the various $CaCl_2$ concentrations was significantly different ($P \leq 0.05$). The produce responded differently to the calcium chloride solutions. Tomatoes hydrocooled with water containing 1% $CaCl_2$ showed the least weight loss, attaining 1.30% loss in day 9, which was remarkably the lowest, for all treatments. Carrots showed higher weight losses when hydrocooled with water containing $CaCl_2$, attaining 9.9% weight loss at 0.5% $CaCl_2$ with the control, water only (0% $CaCl_2$) only attained a weight loss if 9.0%. Courgettes showed decreasing weight loss with increasing $CaCl_2$, concentration. The least weight loss was obtained in the 1.5% $CaCl_2$, with 4.42% in day 9 as compared to 0% $CaCl_2$ whose weight loss was 8%. African eggplants showed less percentage weight loss at 1% $CaCl_2$, with 4.75 %. This was significantly lower than in fruits hydrocooled with water only. Increasing $CaCl_2$ concentration to 1.5% resulted in higher weight loss again, reaching 6.04 % on day 9. The occurrence of higher weight loss at higher salt concentrations is attributed to existence of difference in water potential during hydrocooling. Similar findings were found in tamarillo fruits treated with various $CaCl_2$ concentration deeps by Pinzón-Gómez et al., (2014).

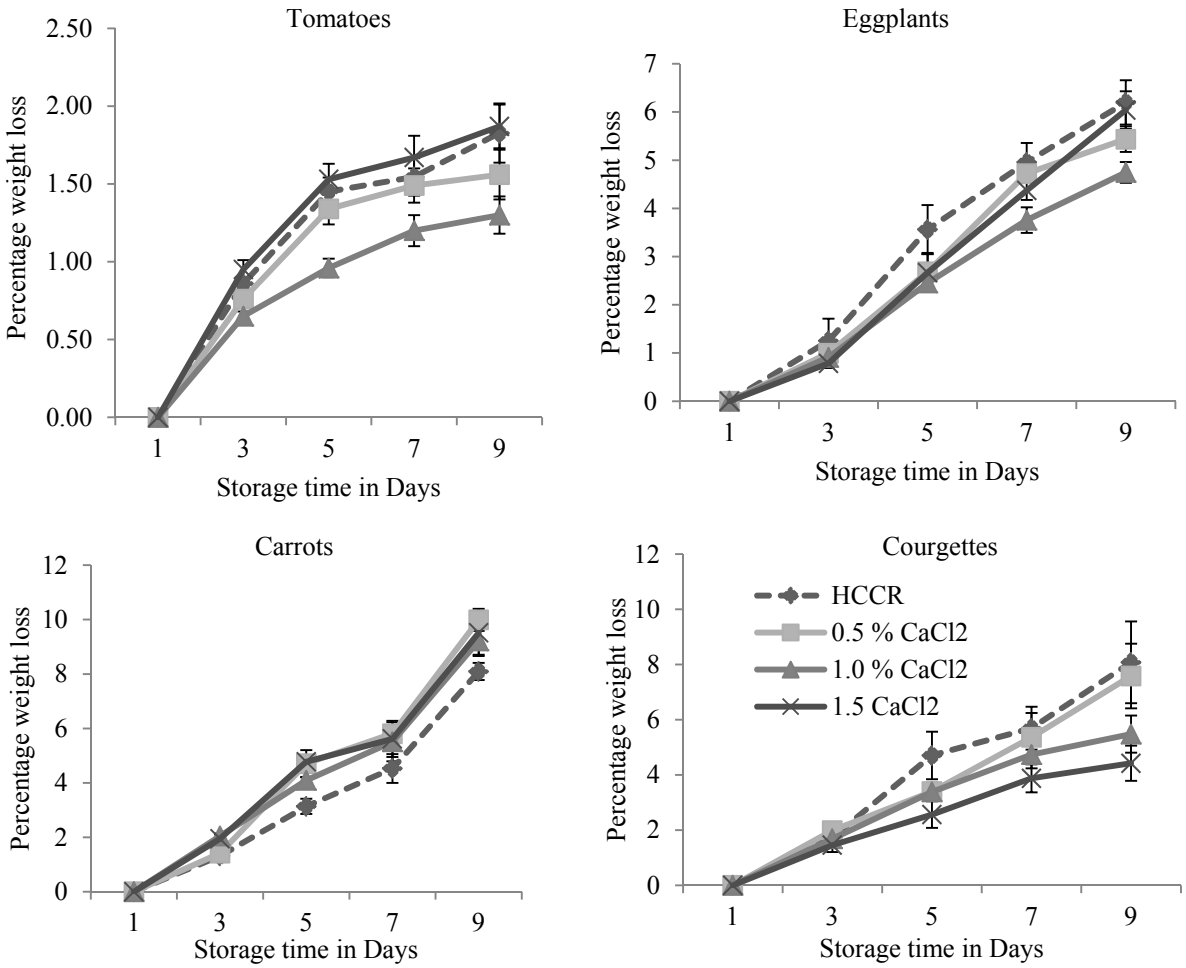

Figure 1. Percentage weight loss in vegetables when hydrocooled with water containing calcium chloride. Percentage weight loss in vegetables was calculated as a function of the initial weight. 5 fruits were monitored throughout the study period. Data is presented as means ±SE. Calcium chloride concentrations in the hydrocooling water was 0% (HCCR), 0.5%, 1.0% and 1.5%

3.2 Respiration Rates

Respiration rates in produce were influenced by both the calcium chloride content in water and storage time. A significant difference ($P \leq 0.05$) was observed between 0%, 0.5%, 1.0% and 1.5% $CaCl_2$. Effect of the various concentrations of $CaCl_2$ on produce respiration is as shown in Figure 2. Addition of calcium chloride to the hydrocooling water significantly reduced respiration rates ($P \leq 0.05$) in tomatoes, African eggplants and

courgettes, while increasing respiration rates in carrots.

Tomatoes treated with 1% $CaCl_2$ showed lower rates of respiration, throughout the storage period. In courgettes and African eggplants, the least respiration rates were observed in 1.5% $CaCl_2$. Carrots showed no positive response with addition of calcium chloride; instead the respiration rates increased with increasing calcium chloride concentration.

Calcium is associated with ripening in fruits and sufficient amounts have been shown to reduce transpiration rates and consequently the respiration rates. High levels of calcium in cell walls have also been found to reduce activity of fruit softening enzymes (Pinzón-Gómez et al., 2014).

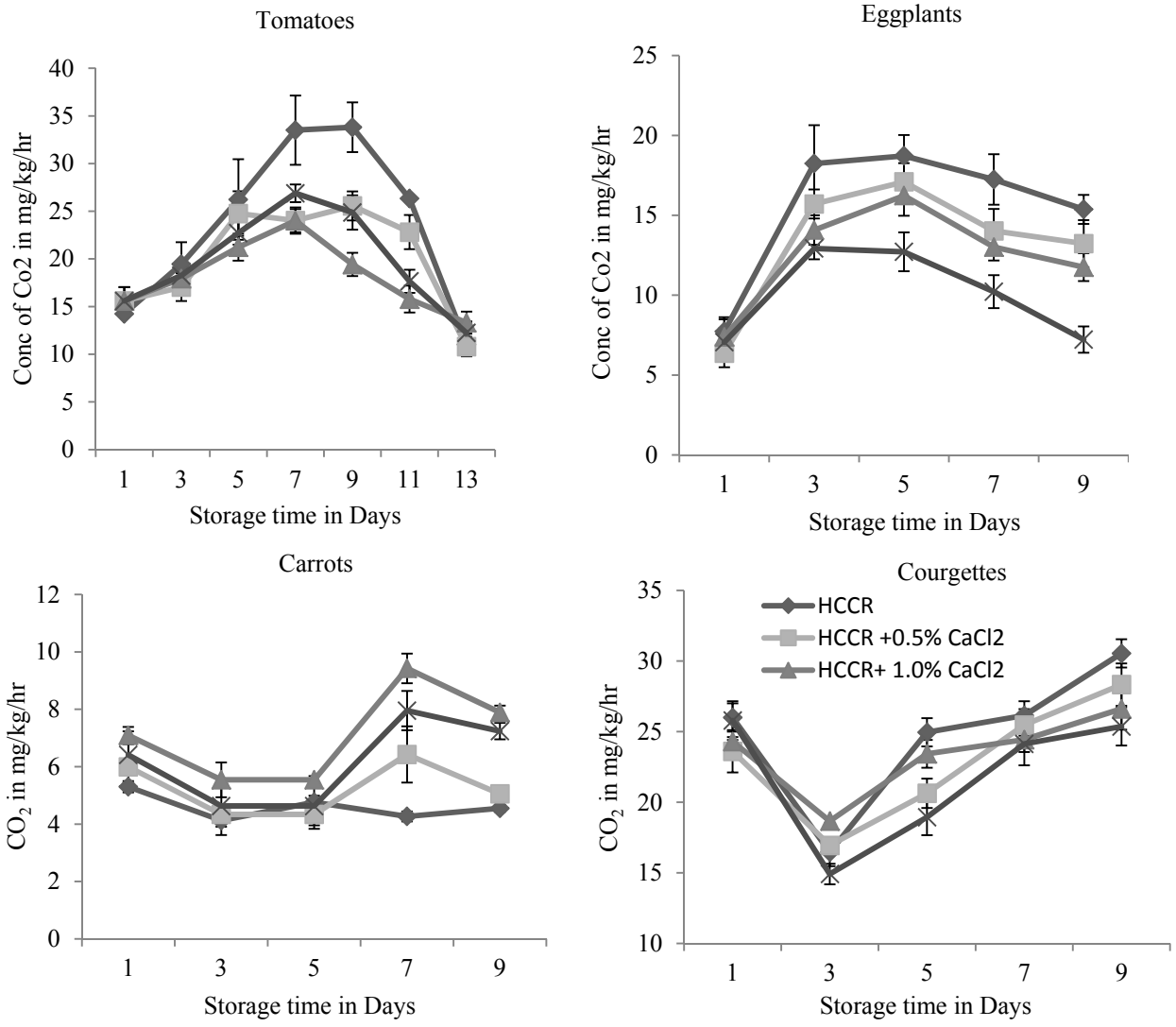

Figure 2. The Respiration rates in vegetables during storage. Data is presented as means ±SE. Calcium chloride concentrations in the hydrocooling water was 0% (HCCR), 0.5%, 1.0% and 1.5%

3.3 Titratable Acidity

Titratable acidity in all the produce declined over the storage period as shown in Figure 3. In tomatoes, %TTA declined from 0.6 % to range between 0.4 % and 0.28% after 9 days. The least titratable acidity loss during storage of produce occurred in tomatoes at 1% $CaCl_2$, attaining 0.4% TTA. Courgettes and African eggplants showed the least decline in acidity at 1.5% $CaCl_2$ concentration in the hydrocooling water, declining from 0.05% to 0.04 % and 0.03% to 0.01% respectively. Carrots had the highest decline in acidity at 1.5% $CaCl_2$.

Interaction between storage time and $CaCl_2$ concentration applied was observed. These were significantly different ($P \leq 0.05$). A negative correlation was observed between TSS and TTA in the produce.

Since $CaCl_2$ was observed to lower respiration rates, it therefore resulted in reduced rate of utilization of organic acids as substrate for respiration in the produce and delayed ripening of tomatoes Mahajan and Dhatt (2004). These correlation has previously been seen in tomatoes and mangoes (Rathore et al., 2007; Senevirathna & Daundasekera, 2010).

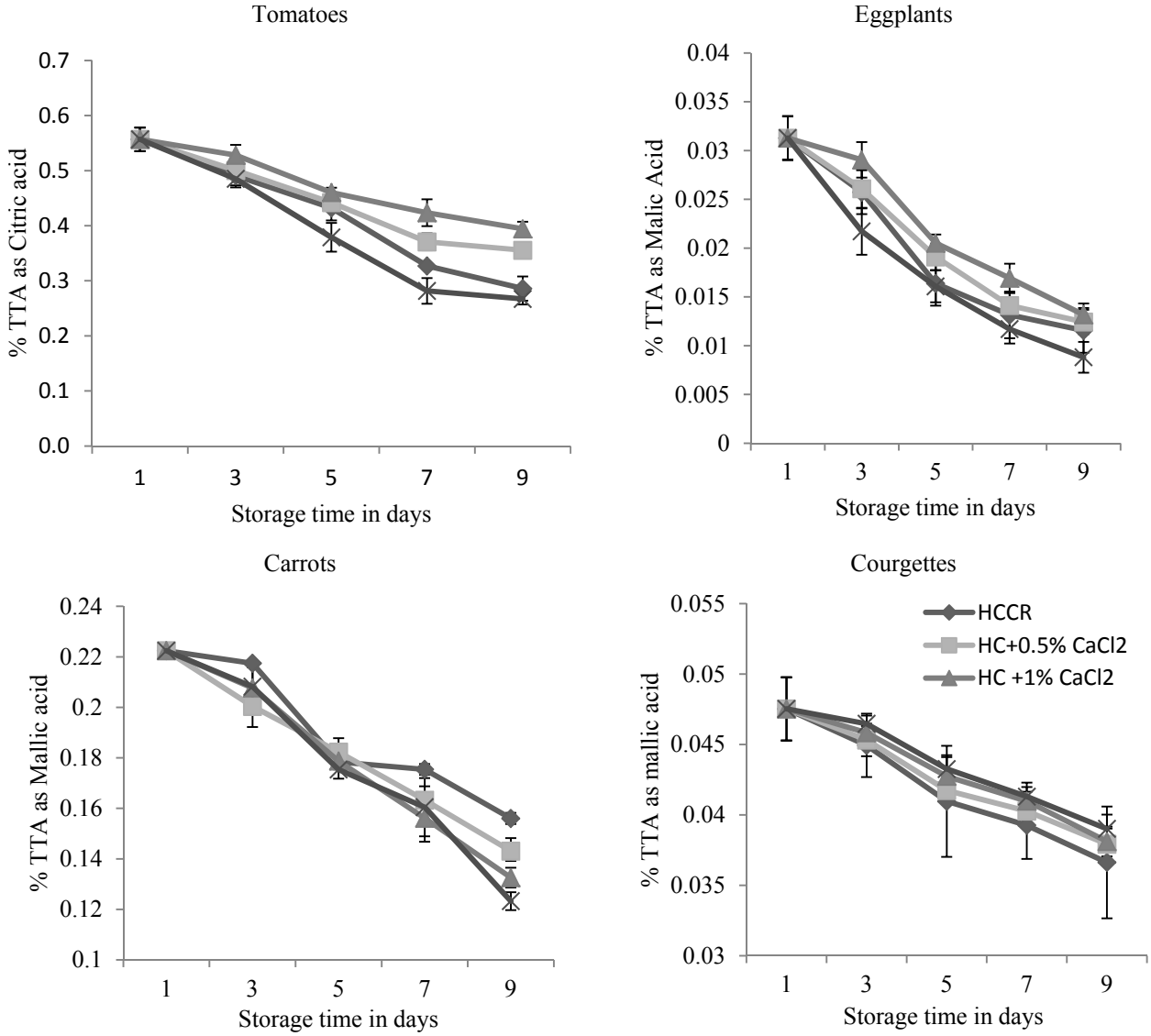

Figure 3. % TTA as affected by $CaCl_2$ application and storage time. Data is presented as means ±SE. Calcium chloride concentrations in the hydrocooling water was 0% (HCCR), 0.5%, 1.0% and 1.5%

3.4 Total Soluble Solids

The change in soluble solid content in the produce during the study period is shown in Figure 4. By the end of the storage period, TSS in $CaCl_2$ treated samples was lower than the control (water only) in tomatoes, courgettes and eggplants, although at differing concentrations. In tomatoes, the least TSS of 2.6% on day 9 was recorded in produce hydrocooled with 1.0% $CaCl_2$. Courgettes and African eggplants had the least TSS in 1.5% $CaCl_2$ treated samples with 4.7% and 6.4% respectively. Carrots had the least TSS in 0% $CaCl_2$ on day 9; with TSS increasing with increasing $CaCl_2$ concentrations in the water.

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 (Azene et al., 2014 and Youssef et al., 2012) and bananas (Khanbarad et al., 2012). However, the increase in TSS that occurs in non-climacteric produce may be associated with water loss (Hailu et al., 2008), or increased metabolic reactions due to invasion

by microbes or chilling injury (Khanbarad et al., 2012). 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 ^{0}C for eight hours and stored at 8 ^{0}C. In the carrots, courgettes and African eggplants which are non-climacteric commodities, TSS build-up 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 and in strawberries by Hernandez-Munoz et al. (2008).

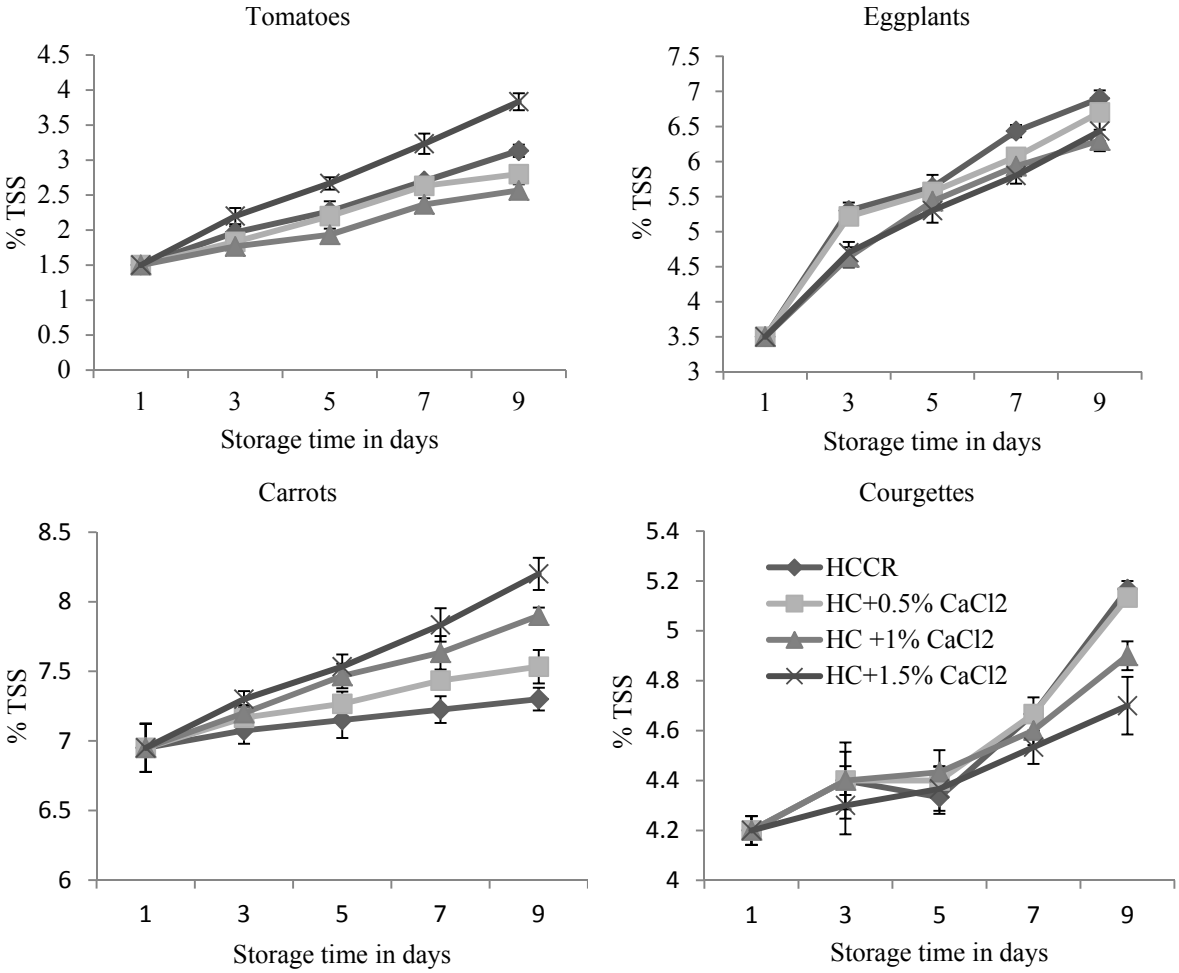

Figure 4. Total soluble solid content as influenced by various $CaCl_2$ concentrations during storage. Data is presented as means ±SE. Calcium chloride concentrations in the hydrocooling water was 0% (HCCR), 0.5%, 1.0% and 1.5%.

3.5 Specific Sugar Composition

The change in specific sugar composition in all the produce was significantly ($P \leq 0.05$) affected by the storage time. Longer storage time resulted in greater deviation in the sugar composition from those of fresh samples. As shown below in Figure 5, glucose and fructose increased during storage in all produce, while sucrose declined.

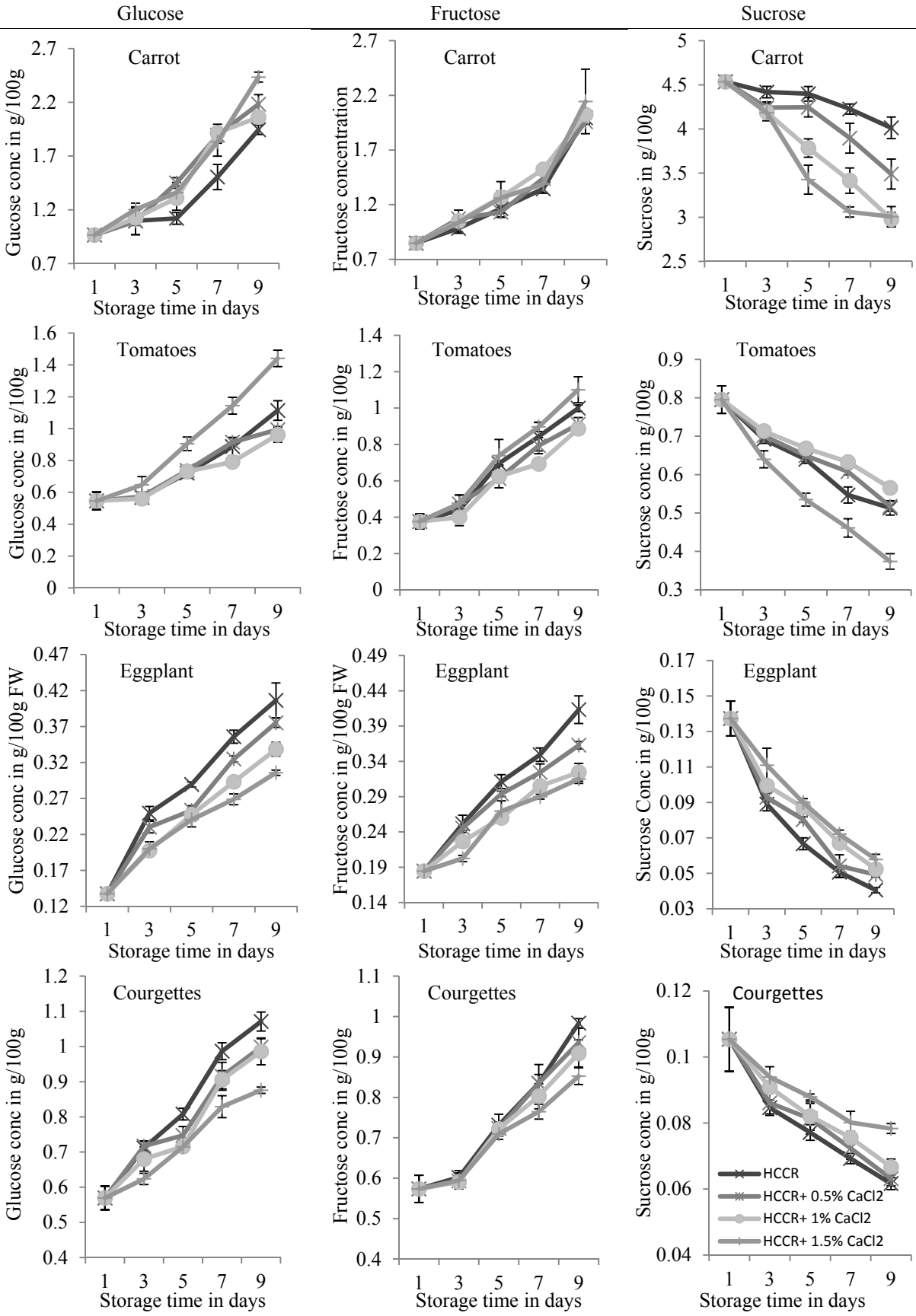

Figure 5. Specific sugar composition in vegetables during storage. Data is presented as means ±SE. Calcium chloride concentrations in the hydrocooling water was 0% (HCCR), 0.5%, 1.0% and 1.5%

In the $CaCl_2$ treatments, glucose and fructose increased in all produce during the storage period. At the start of the experiment, tomatoes had initial sugar content at 0.55 mg/100g, 0.38 mg/100g and 0.80 mg/100g for glucose, fructose and sucrose respectively. This increased to 1.44 mg/100g and 1.1 mg/100g in glucose and fructose under 1.5% $CaCl_2$ treatment. The least changes in sugar composition occurred at 1% $CaCl_2$ in tomatoes. This was significantly different ($P \leq 0.05$) from the control and 1.5% $CaCl_2$. Similar trends were observed for African eggplant, courgettes and carrots with least change in sugar content at 1.5% $CaCl_2$ in courgettes and African eggplants, being significantly different ($P \leq 0.05$) from control while carrots responded best to 0% $CaCl_2$.

The existing positive correlation observed between respiration rates, weight loss and soluble solid contents was similar to the findings of Irfan et al., (2013) in fig fruits. This shows that $CaCl_2$ treatment can be used in maintenance of postharvest quality. Similar correlations have been observed in strawberries by Chen et al. (2011) with $CaCl_2$ concentrations. He attributed the higher specific sugar change in produce at higher $CaCl_2$ to existence of phytotoxicity (Pinzón-Gómez et al., 2014).

3.6 Beta-carotene

Beta carotene in produce under study was significantly affected by storage time and concentration of $CaCl_2$ applied. The produce response to treatments is as shown in Figure 6. In carrots, courgettes and African eggplants, Beta carotene content decreased gradually during storage for all treatments. β-carotene in carrots declined from 3.93 mg/100g to 3.13, mg/100g in the control in day 9. It also declined to 3.12 mg/100g, 3.21 mg/100g and 3.08 mg/100g for 0.5%, 1.0% and 1.5% $CaCl_2$ respectively.

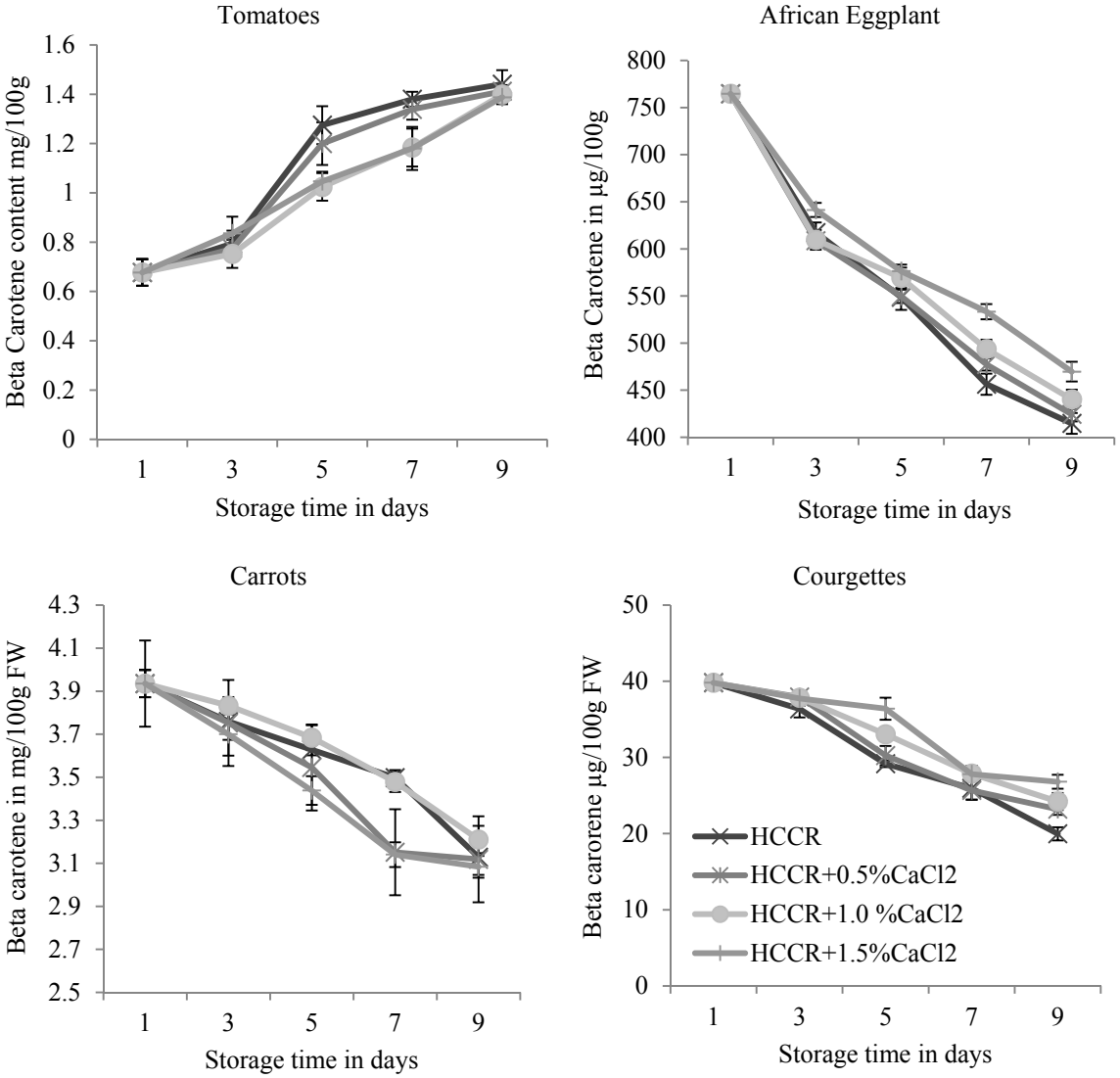

Figure 6. Beta carotene content as affected by $CaCl_2$ during storage. Data is presented as means ±SE. Calcium chloride concentrations in the hydrocooling water was 0% (HCCR), 0.5%, 1.0% and 1.5%

Beta carotene in tomatoes increased throughout the storage period, from 0.67 mg/100g to 1.38 mg/100g, 1.39 mg/100g, 1.25 mg/100g and 1.29 mg/100g for 0%, 0.5%, 1.0% and 1.5% $CaCl_2$ respectively, which were not statistically different ($P \leq 0.05$).

In courgettes the decline was from 40 µg/100g to 19.97 µg/100g, 21.43 µg/100g, 24.46 µg/100g and 26.37 µg/100g and whereas African eggplants declined from 763µg/100g to 436 µg/100g, 424 µg/100g, 440 µg/100g and 469 µg/100g for 0%, 0.5%, 1.0% and 1.5% $CaCl_2$ respectively, which were also not statistically different ($P \leq 0.05$).

This increase in beta carotene can be attributed to the unmasking of the carotenoids following chlorophyll degradation during ripening of tomatoes. Similar findings have been observed in produce such as mangoes and passion fruits (Makwana et al., 2014; Yumbya et al., 2014).

Effects of $CaCl_2$ on beta carotene followed the trend in titratable acidity. This was however not statistically different from the samples hydrocooled with portable water only during the period of this study. These findings are similar to those of (Negi & Roy, 2000) who found that longer storage time resulted in higher loss of beta carotene content accompanied by progression of senescence (Msogoya et al., 2014).

3.7 Vitamin C

The ascorbic acid quantity in the produce was significantly affected by storage time and precooling treatment. A decline in ascorbic acid was observed in all produce under study in all treatments as shown below in Figure 7.

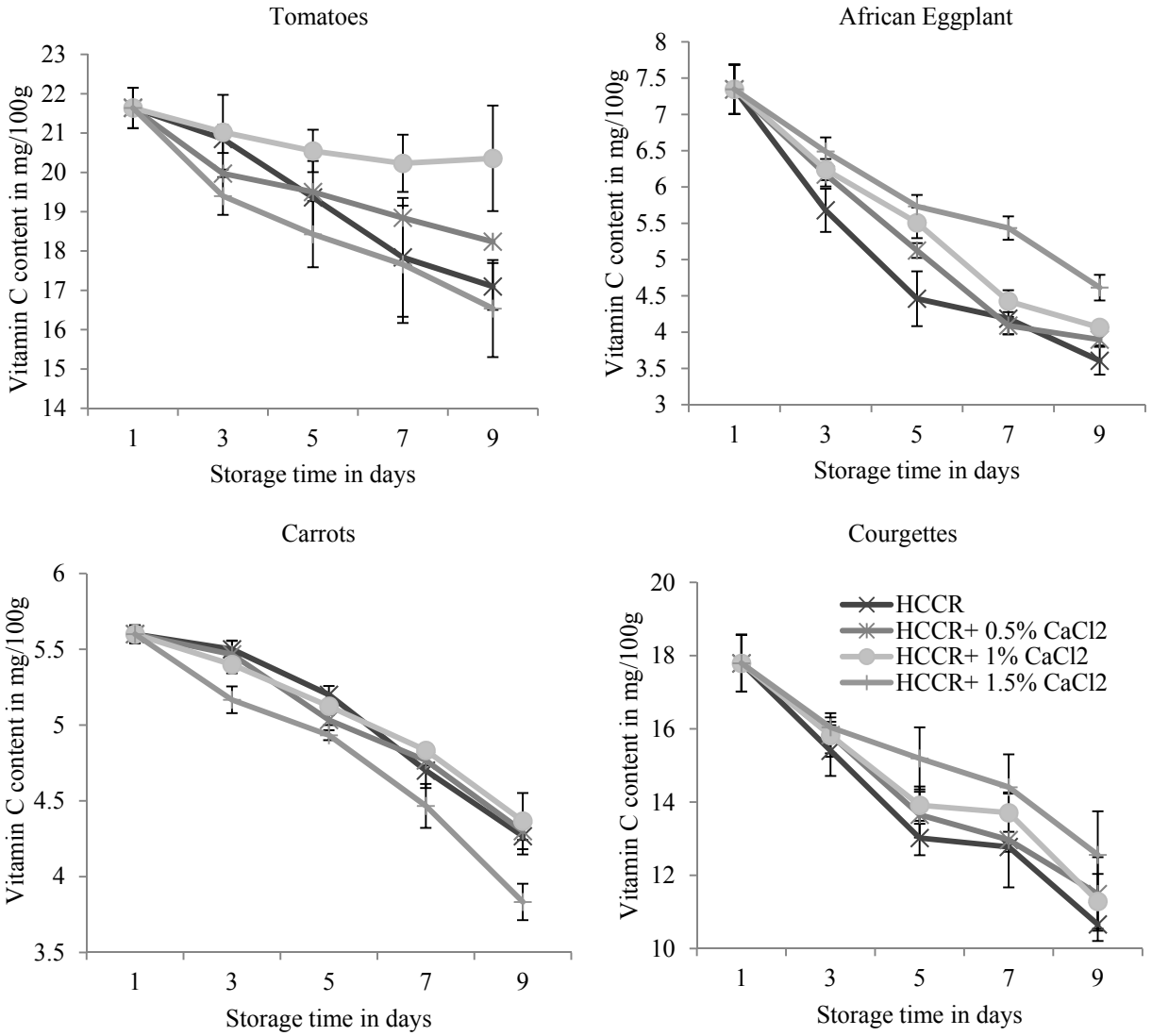

Figure 7. Vitamin C content in produce treated with $CaCl_2$ during storage. Data is presented as means ±SE. Calcium chloride concentrations in the hydrocooling water was 0% (HCCR), 0.5%, 1.0% and 1.5%

Use of calcium chloride in the hydrocooling water resulted in slower rate of loss of Vitamin C in courgettes and eggplants both at 1.5% (w/v) and tomatoes at 1 % w/v. In carrots, no positive effect was obtained at all the concentrations tested. The change was however significantly high at 1.5% $CaCl_2$, implying that the osmotic pressure existing between the wash water and the internal carrot composition may have resulted in higher oxidation of ascorbic acid, utilized in respiration together with other organic acids present.

Vitamin C retention was highest in carrots hydrocooled with 1.0 % $CaCl_2$ declining from 5.6 mg/100 g to 4.36 mg/100 g on day 9. This was however not significantly different ($P \leq 0.05$) from those hydrocooled with pure water with 0.5% $CaCl_2$, both kept at 7^0C.

In tomatoes, the Vitamin C content declined from 21.63 mg/100g at the start of the experiment, reaching the lowest of 16.53 mg/100g in in 1.5% $CaCl_2$ by the 9^{th} day. Similar findings were observed by (Moneruzzaman et al., 2008) in tomatoes, where decline was observed during ripening of tomatoes.

Eggplants had an initial vitamin C content of 7.3 mg/100 g which declined under the control experiment to 3.6 mg/100g by the 9^{th} day. Although this was lower than the findings of (Eze & Kanu, 2014), who reported vitamin C content of 14mg/100g, in African eggplants, Msogoya et al., (2014) observed similar trends for fruits under the control, where at harvest; vitamin C was at 8.08 mg/100g which declined to 4.84 mg/100g upon storage. The difference here could be due harvesting stages Eze and Kanu (2014) used unripe fruits while Msogoya et al., (2014) termed fruits used as at harvesting stage 2.

Ascorbic acid is a highly sensitive nutrient, commonly used as a quality indicator (Babu et al., 2015). The decline in vitamin C has been observed in other vegetables such as broccoli Carvalho and Clemente (2004), capsicum Rahman et al. (2015) and in tomatoes (Žnidarčič & Požrl, 2006). The decrease is due to natural degradation Carvalho and Clemente (2004) a product of oxidation and enzyme catalysts activity present in the fruits (Žnidarčič & Požrl, 2006).

3.8 Colour

Hue angles in the produce also declined over the storage time as shown in Figure 8. Hue angles in tomatoes declined by 15.2%, 12.33 %, 10.2% and 14.4% for 0%, 0.5%, 1.0% and 1.5% $CaCl_2$ respectively in tomatoes by the end of the 9 day study period.

A significant decline in L* values was observed in the African eggplant fruits. The decline ranged between 10.7% for 0% and 3.1% for 1% $CaCl_2$. The declined appeared to accompany development of surface lesions in the produce which was attributed to chilling injury in the produce. Although a change in hue angles was also observed to decline, it followed the severity of skin lesions. The decline was between 14.7% and 6.8% for 0% and 1% $CaCl_2$ respectively. These were significantly different ($P \leq 0.05$).

Courgettes on the other hand showed no significant change ($P \leq 0.05$) in hue angle during storage, with change only occurring in the L* values over storage time. L* values declined progressively during storage, with the greatest decline occurring in 0.5% treatment with 3.03%. This was not statistically different ($P \leq 0.05$) from control and those of 1% and 1.5% $CaCl_2$ respectively.

Similar findings were observed by Apai et al. (2007) on the peel of longan fruits; Tripathi et al. (2013) in apple fruits and Senevirathna and Daundasekera (2010) reported that 4% $CaCl_2$ had delayed colour development in tomato fruits although it was not significantly different from those of untreated fruits. These results further underscore the findings in this study where 1.0 % $CaCl_2$ showed the least colour change at the end of the storage period.

Calcium chloride has been shown to have an effect in ethylene production, where it suppresses its synthesis Ishaq et al. (2009), thereby delaying its role in unmasking the yellow and red carotenoids in climacteric fruits such as tomatoes (Pinzón-Gómez et al., 2014). This could possibly explain the cause of reduced colour change in tomatoes.

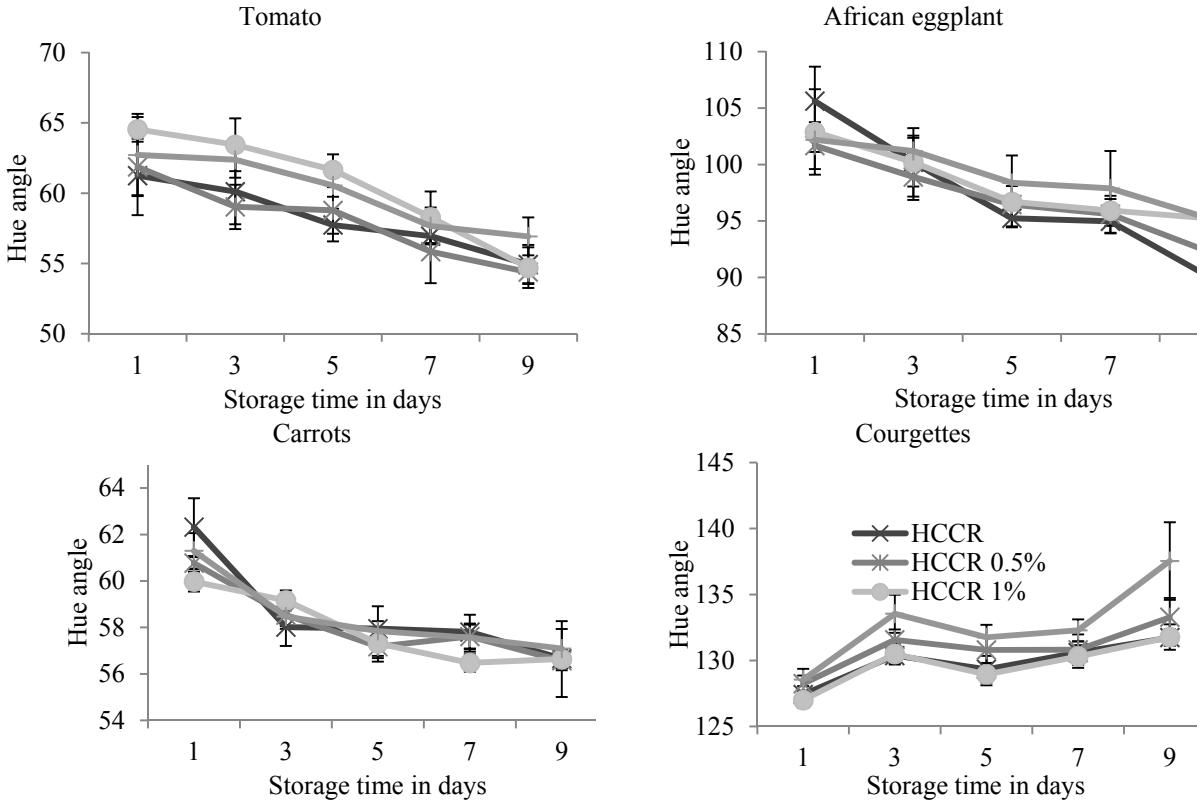

Figure 8. Hue angle changes in vegetables during storage. 5 fruits were monitored throughout the study period Data is presented as means ±SE. Calcium chloride concentrations in the hydrocooling water was 0% (HCCR), 0.5%, 1.0% and 1.5%

3.9 Decay Incidence

The decay incidence in all the vegetables increased gradually in all produce as shown in Figure 9 the optimum levels to delay this deteriorations in the concentrations studied were 1.0%, 1.5 %, 0% and 1.5% for tomatoes, eggplants, carrots and courgettes respectively Application of calcium chloride delayed the onset of deterioration in all produce, by between 3 to 7 days, although the products responded optimally to different concentrations.

The percentage deterioration due to shriveling of fruits ranged between 19.3% and 33 % in tomatoes, with 0% $CaCl_2$ at 32.8% while 1.0% $CaCl_2$ was 19.3% after 15 days of storage African eggplants deterioration characterized by development of surface lesions and browning around the seeds ranged between 26.7% when hydrocooled with water containing 1.5% $CaCl_2$ and 48.7% at 0% $CaCl_2$, at 9 days after storage. Carrots at the end of 9 day storage period, the proportion of deteriorated produce due to re-sprouting and development of dark coloration at the tips was between 7.4% at 0 % $CaCl_2$ and 14.3% at 1.0% $CaCl_2$. Deterioration in courgettes characterized by surface pitting and development of pinched ends ranged between 22.0% in 1.5% $CaCl_2$ and 26.3 % at 0.0% $CaCl_2$.

Produce spoilage and deterioration is a function of degradation of the cell wall (Franco et al., 2006). Application of a substance that delays any form of cell disintegration has been found to extend the postharvest life of produce.Calcium chloride has previously been reported to delay onset of deterioration in pear fruits (Sugar & Basile, 2011). This is attributed to calcium's interaction with the cell walls components resulting in maintenance of the cell integrity, Akhtar et al. (2010) for a long period of time (Babu et al., 2015) thus resulting in improved postharvest life. Calcium ions have been observed to form bridges with peptic molecules of the middle lamella. As a result, better cell cohesion is maintained leading to better PH quality of produce (Franco et al., 2006).

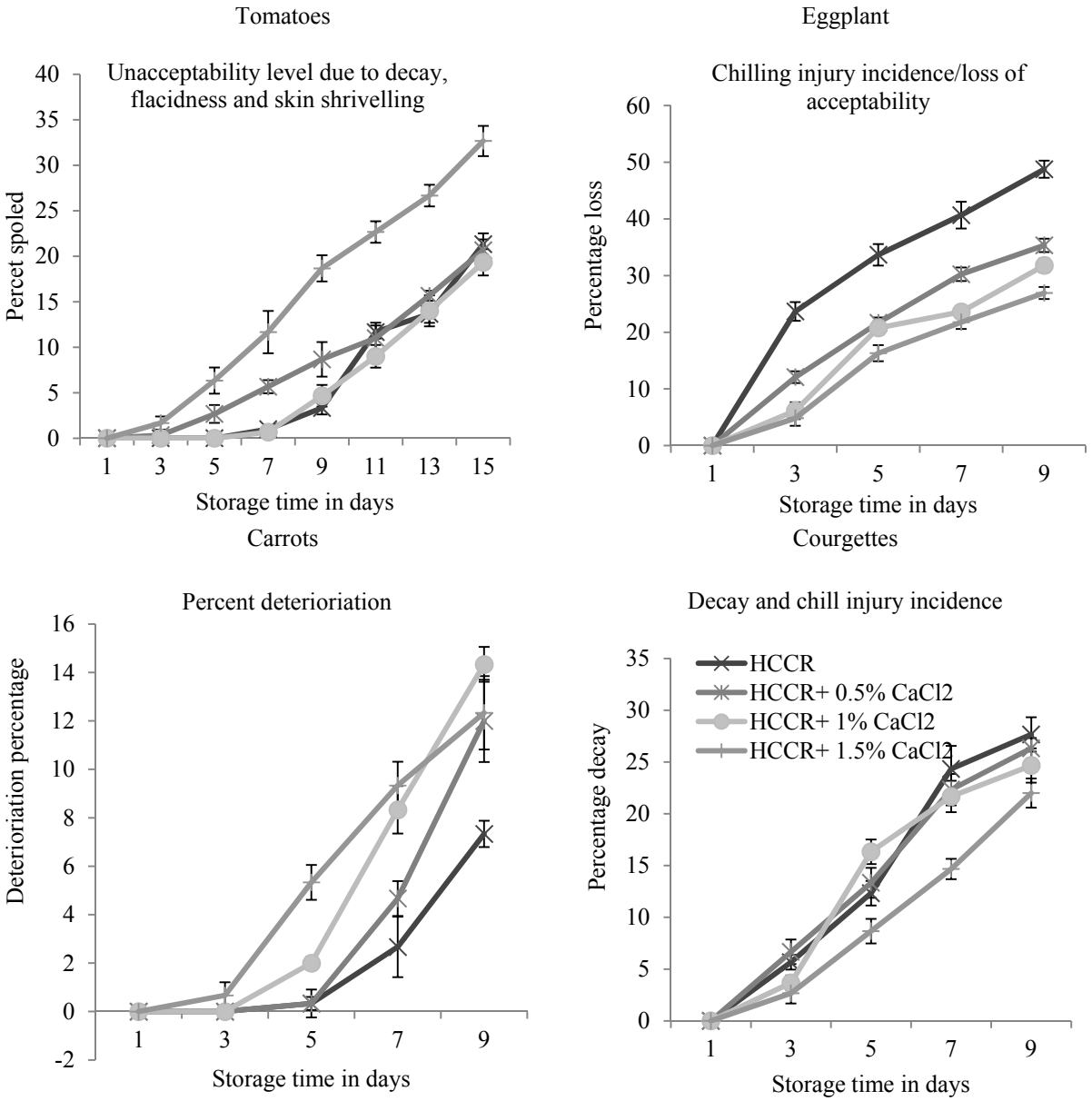

Figure 9. Spoilage incidences in produce during storage. Data is presented as means ±SE. Calcium chloride concentrations in the hydrocooling water was 0% (HCCR), 0.5%, 1.0% and 1.5%

3.10 Microbial Load

The microbial quality of the fresh produce varied significantly between the produce. Carrots had the highest microbial population both for yeast and mold and in total plate count. Hydrocooling the produce generally reduced the initial microbial loads, although it did not completely eliminate the microbes from the produce. The hydrocooling of the produce with various concentrations of $CaCl_2$ yielded results with significant difference at ($P \leq 0.05$). Microbial populations generally increased over the storage period as shown below in Figure 10 for TPC and Figure 11 for yeast and molds. After washing, TPC together with the yeast and mold increased over storage time, although the increase was slow and gradual. The slow growth in population can be attributed to the low storage temperatures of produce. Least microbial growth in all produce occurred in 1.5% $CaCl_2$.

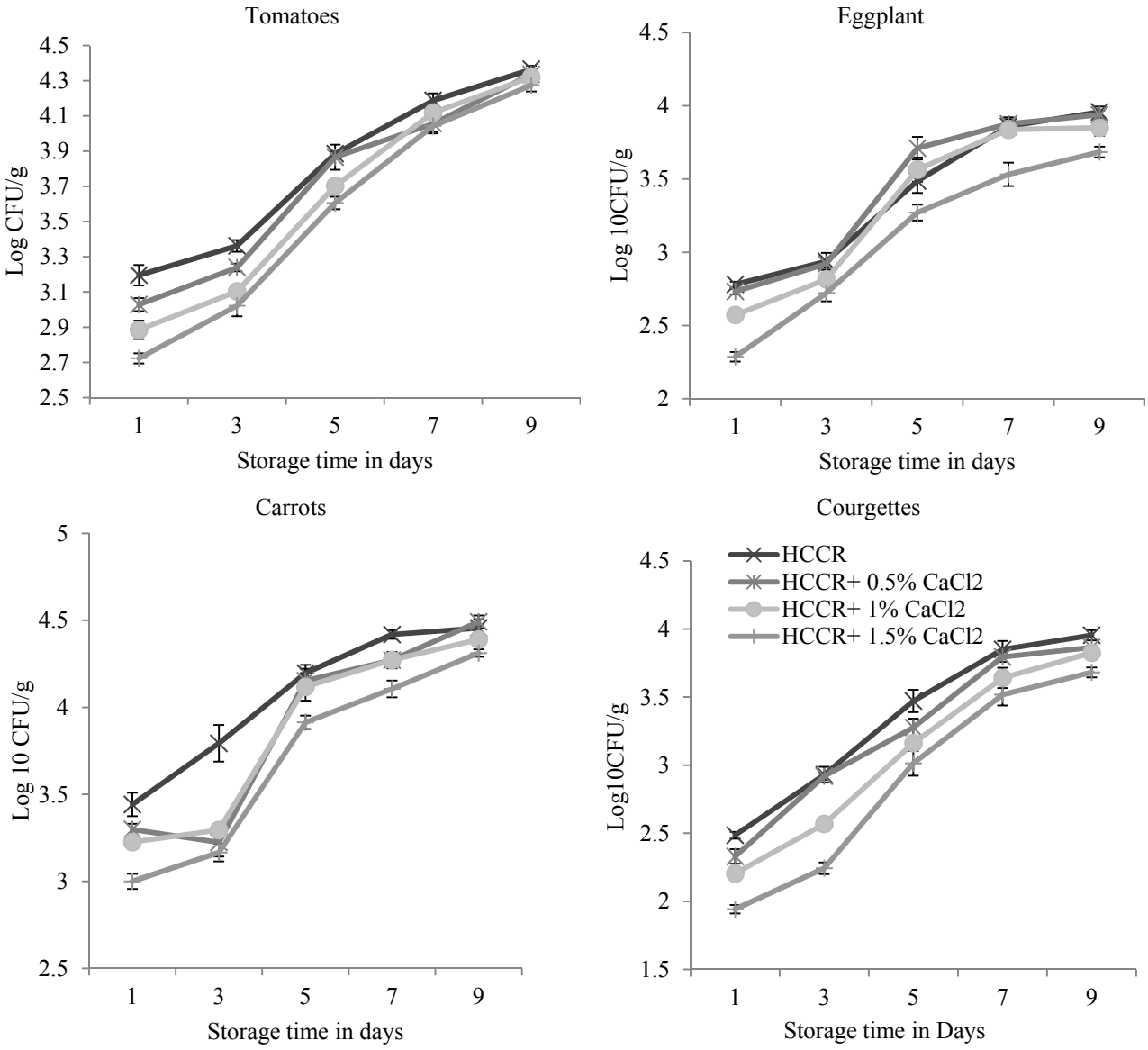

Figure 10. Total plate count in vegetables during storage. Data is presented as means ±SE. Calcium chloride concentrations in the hydrocooling water was 0% (HCCR), 0.5%, 1.0% and 1.5%

This can be attributed to osmolysis occurring in produce due to high salt concentration. Microbial infestation often leads to decay, becoming a major cause of food spoilage (Artés & Gómez, 2006). Abadias et al. (2008) indicated that it is almost impossible to eliminate microbes from fresh vegetables completely because the concentrations required to achieve this may be harmful to the product or consumer. However, upon storage, microbial populations increased on the surface of the produce regardless of the pretreatment applied. The microbes showed a typical logarithmic increase, which can be attributed to cell multiplication. Similar findings of high microbial loads have previously been reported in carrots in Spain by Abadias et al. (2008) when freshly cut and whole fruits and vegetables were sampled.

Due to their versatile nature, microbes grow on several surfaces, exhibiting different characteristics. However, low temperatures in which the fresh produce are kept have been shown to delay or retard their growth, thus delaying the overall quality deterioration as they limit the number of pathogens that can grow on the substrate (Pla et al., 2008).

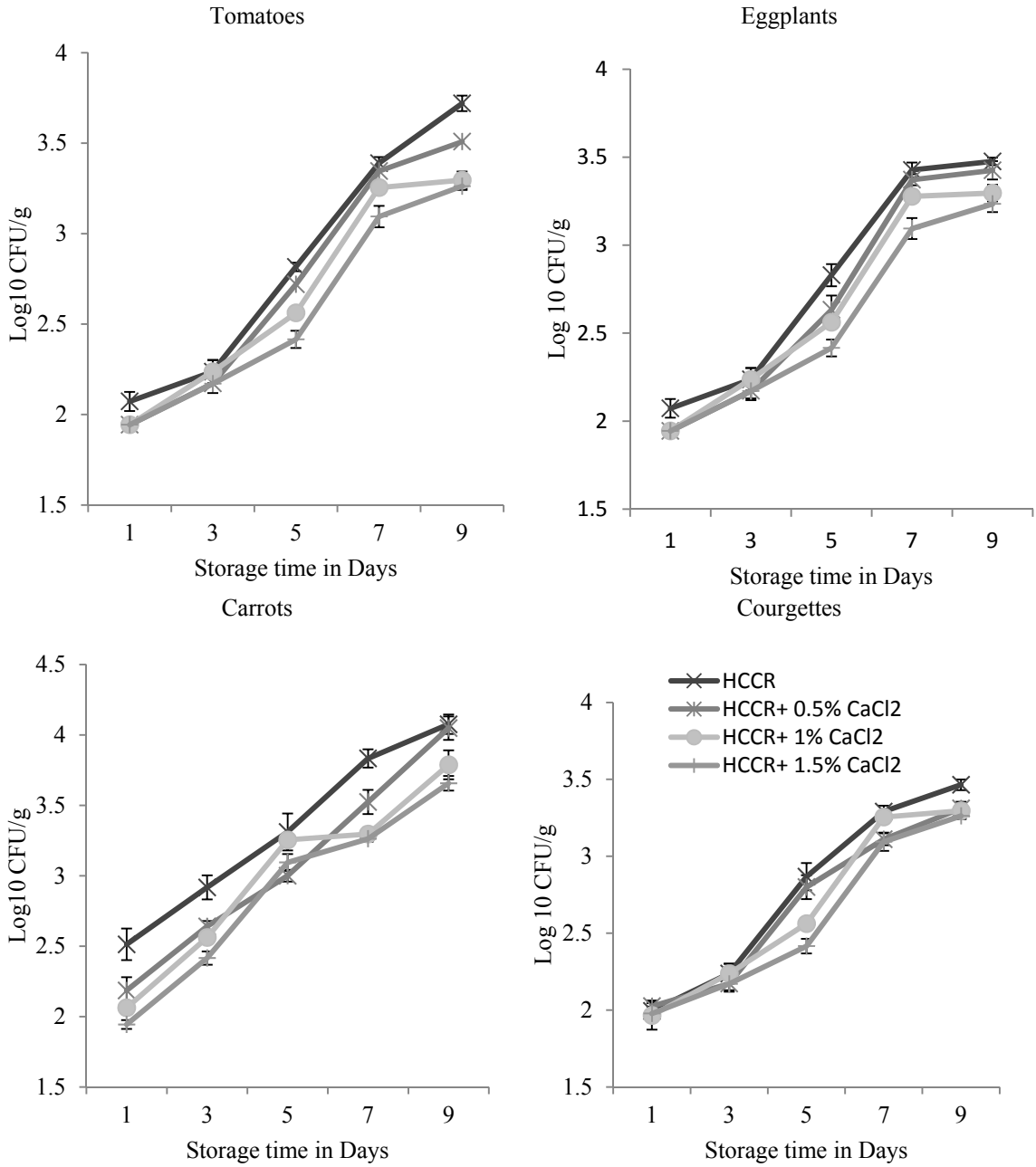

Figure 11. Yeast and mould in vegetables during storage. Data is presented as means ±SE. Calcium chloride concentrations in the hydrocooling water was 0% (HCCR), 0.5%, 1.0% and 1.5%

4. Conclusion

Calcium chloride addition to the hydrocooling water in this study showed varying responses in the selected vegetables. The highest concentration of 1.5% $CaCl_2$ resulted in less decay and a lower microbial population in all samples. However, the specific effect of the salt concentration on weight loss, vitamin C retention, beta carotene content, total soluble solids and titratable acidity was specific to each product.

By considering the above effects, 1.0 % $CaCl_2$ was the best concentration in this study for tomatoes, resulting in optimum characteristics studied throughout the study period.

For courgettes, the best concentration was at 1.5% while carrots exhibited the best postharvest quality characteristics when hydrocooled using cold water without calcium chloride application.

Application of $CaCl_2$ at the different concentrations delayed the onset and development of chilling injury symptoms in African eggplants. However, the concentrations used in this study only delayed and reduced the

severity of chilling injury, but did not completely stop it

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References

Abadias, M., Usall, J., Anguera, M., Solsona, C., & Viñas, I. (2008). Microbiological quality of fresh , minimally-processed fruit and vegetables , and sprouts from retail establishments. *International Journal of Food Microbiology, 123*, 121-129. http://doi.org/10.1016/j.ijfoodmicro.2007.12.013

Acedo, A. J. L. (2010). *Postharvest Technology for Leafy Vegetables*. Shanhua Taiwan.

Akhtar, A., Abbasi, N. A., & Hussain, A. (2010). Effect of calcium chloride treatments on quality characteristics of loquat fruit during storage. *Pakistan Journal of Botany, 42*(1), 181-188.

Apai, W., Sardsud, V., & Sardsud, U. (2007). Effects of hydrocooling on the quality of Fresh Longan fruits cv . Daw. *Asian Journal of Biology Education, 3*, 54-57.

Artés, F., & Gómez, P. A. (2006). Physical, physiological and microbial detrioration of minimally fresh processed fruits and vegetables. *Food Science and Technology International, 13*(3), 177-188. http://doi.org/10.1177/1082013207079610

Azene, M., Workneh, T. S., & Woldetsadik, K. (2014). Effect of packaging materials and storage environment on postharvest quality of papaya fruit. *Journal of Food Science and Technology*, *51*(6), 1041-1055. http://doi.org/10.1007/s13197-011-0607-6

Babu, I., Ali, M. A., Shamim, F., Yasmin, Z., Asghar, M., & Khan, A. R. (2015). Effect of calcium chloride treatments on quality characteristics of loquat fruit during storage. *International Journal of Advanced Research, 3*(1), 602-610.

Badosa, E., Trias, R., Pares, D., Pla, M., & Montesinos, E. (2008). Microbiological quality of fresh fruit and vegetable products in Catalonia (Spain) using normalised plate-counting methods and real time polymerase chain reaction (QPCR). *Journal of the Science of Food and Agriculture, 88*, 605-611. http://doi.org/10.1002/jsfa

Carvalho, P. D. T., & Clemente, E. (2004). The influence of the Broccoli (Brassica oleracea var . itálica) fill weight onpostharvest quality. *Ciênc. Tecnol. Aliment*, *24*(4), 646–651.

Chen, F., Liu, H., Yang, H., Lai, S., Cheng, X., Xin, Y., … Deng, Y. (2011). Quality attributes and cell wall properties of strawberries (Fragaria annanassa Duch .) under calcium chloride treatment. *Food Chemistry, 126*(2), 450-459. http://doi.org/10.1016/j.foodchem.2010.11.009

Chepngeno, J., Kinyuru, J., Nenguwo, N., & Owino, W. (2015). The Effects of a Low Cost Hydro Cooling System on the Postharvest Quality Characteristics of Selected Tropical Fruits and Vegetables. *Journal of Postharvest Technology*, *03*(04), 101–109.

Delia B Rodriguez-Amaya, & Kimura, M. (2004). *Handbook for Carotenoid Analysis*. Washington, DC: International Food Policy Research Institute (IFPRI) and International Center for Tropical Agriculture (CIAT).

Dhillon, B. S., & Kaur, S. (2013). Effect of postharvest application of calcium chloride on storage life of mango Var. Dushehari fruits. *HortFlora Research Spectrum, 2*(3), 265-267.

ERA-MOALF. (2010). *Economic Review of Agriculture 2010*. Nairobi: MOA.

ERA-MOALF. (2015). *Economic Review of Agriculture (ERA) 2015 Ministry of Agriculture; Livestock and Fisheries.* Nairobi: MOA.

Eze, S. O., & Kanu, C. Q. (2014). Phytochemical and Nutritive Composition Analysis of Solanum aethiopicum L. *Journal of Pharmaceutical and Scientific Innovation, 3*, 358-362. http://doi.org/10.7897/2277-4572.034172

Franco, J., Antunes, D., Melo, F., Guilherme, R., Neves, N., Curado, F., & Rodrigues, S. (2006). The influence of

pre and post harvest calcium applications on storage capability and quality of "Hayward" kiwifruit. In *Portugal 4th IASME/WSEAS International Conference on Energy, Environment, Ecosystems, and Sustainable Development, Algarve, Portugal. p* (pp. 512-6).

Gil, M. I., Selma, M. V, López-Gálvez, F., & Allende, A. (2009). Fresh-cut product sanitation and wash water disinfection : Problems and solutions. *International Journal of Food Microbiology, 134*(1-2), 37-45.

Hailu, S., Seyoum, T., & Dechassa, N. (2008). Effect of combined application of organic P and inorganic N fertilizers on post harvest quality of carrot. *African Journal of Biotechnology, 7*(13), 2187-2196.

Herna´ndez-Mun˜oz, P., Almenar, E., Valle, V. Del, Velez, D., & Rafael Gavara. (2008). Effect of chitosan coating combined with postharvest calcium treatment on strawberry (Fragaria Â ananassa) quality during refrigerated storage. *Food Chemistry, 110*, 428-435. http://doi.org/10.1016/j.foodchem.2008.02.020

Hussain, P. R., Meena, R. S., Dar, M. a., & Wani, a. M. (2012). Effect of post-harvest calcium chloride dip treatment and gamma irradiation on storage quality and shelf-life extension of red delicious apple. *Journal of Food Science and Technology*, *49*(4), 415–426. http://doi.org/10.1007/s13197-011-0289-0

Irfan, P. K., V. Vanjakshi, d, M. N., Prakash, K., Ravi, R., & Kudachikar, V. B. (2013). Calcium chloride extends the keeping quality of fig fruit (Ficus carica L .) during storage and shelf-life. *Postharvest Biology and Technology*, *82*, 70–75.

Ishaq, S., Rathore, H. A., Masud, T., & Ali, S. (2009). Influence of Post Harvest Calcium Chloride Application , Ethylene Absorbent and Modified Atmosphere on Quality Characteristics and Shelf Life of Apricot (Prunus armeniaca L .) Fruit During Storage. *Pakistan Journal of Nutrition, 8*(6), 861-865.

Juan, C. D., Muy-rangel, D., & Mascorro, A. G. (2007). Fruit size and stage of ripeness affect postharvest water loss in bell pepper fruit (Capsicum annuum L.). *Journal of Science of Food and Agriculture, 73*, 68-73. http://doi.org/10.1002/jsfa

Khanbarad, S. C., Thorat, I. D., Mohapatra, D., Sutar, R. F., & Joshi, D. C. (2012). Effect of temperature and period of storage on Physical,Biochemical and Textural properties of Banana during ripening. *Journal of Dairy Foods & Horticultural Sciences, 31*(3), 212-215.

Kitinoja, L., Saran, S., Roy, S. K., & Kader, A. a. (2011). Postharvest technology for developing countries: Challenges and opportunities in research, outreach and advocacy. *Journal of the Science of Food and Agriculture, 91*(January), 597-603. http://doi.org/10.1002/jsfa.4295

Mahajan, B. V. C., & Dhatt, A. S. (2004). Studies on postharvest calcium chloride application on storage behaviour and quality of Asian pear during cold storage. *Journal of Food, Agriculture & Environment, 2*(December), 157-159.

Makwana, S. A., Polara, N. D., & Viradia, R. R. (2014). Effect of Pre-Cooling on Post Harvest Life of Mango. *Food Science and Technology, 2*(1), 6-13. http://doi.org/10.13189/fst.2014.020102

Mamun, A. Al, Simul, H. A., Rahman, A., Gazi, N. N., & Bari, L. (2012). Prevalence of Foodborne Pathogens and Effectiveness of Washing or Cooking in Reducing Microbiological Risk of Contaminated Red Amaranth. *Agriculture, Food and Analytical Bacteriology, 2*(3), 222-231.

Monaghan, J., Adams, H., & Hutchison, M. (2009). *Monitoring microbial food safety of fresh produce*. *Monitoring microbial food safety of fresh produce*. Stoneleigh Park Kenilworth Warwickshire.

Moneruzzaman, K. . M. ., Hossain, A. . B. . M. . S. ., Sani, W. ., & Saifuddin, M. . (2008). Effect of Stages of Maturity and Ripening Conditions on the Biochemical Characteristics of Tomato Institute of Biological sciences, Faculty of Science, University of Malaya. *American Journal of Biochemistry and Biotechnology, 4*(4), 336-344.

Msogoya, T. J., Majubwa, R. O., & Maerere, A. P. (2014). Effects of harvesting stages on yield and nutritional quality of African eggplant (Solanum aethiopicum L .) fruits. *Journal of Applied Biosciences, 78*, 6590-6599.

Muthoka, M. N., & Ogutu, M. (2014). Challenges Facing the Horticultural Sector in Nairobi County , Kenya. *IOSR Journal of Humanities and Social Science, 19*(2), 121-124.

Negi, P. S., & Roy, S. K. (2000). Effect of low-cost storage and packaging on quality and nutritive value of fresh and dehydrated carrots. *Journal of the Science of Food and Agriculture, 80*(15), 2169-2175. http://doi.org/10.1002/1097-0010(200012)80:15<2169::AID-JSFA762>3.0.CO;2-J

Pinzón-Gómez, L. P., Deaquiz, Y. A., & Álvarez-Herrera, J. G. (2014). Postharvest behavior of tamarillo (Solanum betaceum Cav.) treated with $CaCl_2$ under different storage temperatures. *Agronomía Colombiana, 32*(2), 238-245.

Rahman, M. S., Al-rizeiqi, M. H., & Guizani, N. (2015). Stability of vitamin C in fresh and freeze-dried capsicum stored at different temperatures. *Journal of Food Science and Technology, 52*(March), 1691-1697. http://doi.org/10.1007/s13197-013-1173-x

Rathore, H. A., Masud, T., Sammi, S., & Soomo, A. H. (2007). Effect of storage on physico-chemical composition and sensory properties of mango (Magnifera indica L.) variety Dosehari. *Pakistan Journal of Nutrition, 6*(2), 143-148.

Sánchez-Mata, M. D. C., Cámara-Hurtado, M., & Díez-Marqués, C. (2002). Identification and quantification of soluble sugars in green beans by HPLC. *European Food Research and Technology, 214*, 254-258. http://doi.org/10.1007/s00217-001-0447-0

Senevirathna, P. A. W. A. N. K., & Daundasekera, W. A. M. (2010). Effect of postharvest Calcium Chloride Vacuum infiltration on the shelf life and quality of tomato (CV. Thilina). *Ceylon Journal of science (Biological Sciences), 39*(1), 35-44.

Senthilkumar, S., Vijayakumar, R. M., & Kumar, S. (2015). Advances in Precooling techniques and their implications in horticulture sector. *International Journal of Environmental & Agriculture Research, 1*(1), 24-30.

Souza, A. L. B. De, Paula, S. D. E., Scalon, Q., Isabel, M., Chitarra, F., Chitarra, A. B., … Morango, E. M. (1999). Postharvest application of Calcium chloride in strawbery fruits (Fragaria ananassa):Evaluation of fruit quality and postharvest life. *Ciênc. E Agrotec., Lavras, 23*(4), 841-848.

Sugar, D., & Basile, S. R. (2011). Orchard calcium and fungicide treatments mitigate effects of delayed postharvest fungicide applications for control of postharvest decay of pear fruit. *Postharvest Biology and Technology, 60*(1), 52-56. http://doi.org/10.1016/j.postharvbio.2010.11.007

Tripathi, A., Sharma, N., Sharma, V., & Alam, A. (2013). A review on conventional and non-conventional methods to manage postharvest diseases of perishables. *Researcher, 5*(6), 6-19.

Youssef, K., Ligorio, A., Marianna, S., Nigro, F., & Ippolito, A. (2012). Control of storage diseases of citrus by pre- and postharvest application of salts. *Postharvest Biology and Technology, 72*, 57-63.

Yumbya, P., Ambuko, J., Shibairo, S., & Owino, W. O. (2014). Effect of Modified Atmosphere Packaging on the Shelf Life and Postharvest Quality of Purple Passion Fruit (Passiflora edulis Sims). *Journal of Postharvest Technology, 02*(01), 25-36.

Žnidarčič, D., & Požrl, T. (2006). Comparative study of quality changes in tomato cv. 'Malike' (Lycopersicon esculentum Mill .) whilst stored at different temperatures. *Acta Agriculturae Slovenica, 87*(2), 235-243.