

**EVALUATING THE PERFORMANCE OF LOW COST
HYDRO-COOLING SYSTEM AND EFFECT OF
SANITIZER APPLICATION IN MAINTAINING
POSTHARVEST QUALITY OF SELECTED
VEGETABLES**

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2015

Evaluating the performance of low cost hydro-cooling system and
calcium chloride application in maintaining postharvest quality of
selected vegetables

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A thesis submitted in partial fulfilment for the degree of Master of
Science in Food Science and Technology in the Jomo Kenyatta
University of Agriculture and Technology

2015

DECLARATION

I hereby declare that this thesis is my original work and that it has not been presented to any other university or institution for the award of a degree.

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This thesis has been submitted for examination with our approval as the university supervisors

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DEDICATION

To my parents Jeremiah and Alice Langat and Siblings Ben, Gilbert, Bildad and
Gideon

Thanks for your love and support.

God has enabled us!

ACKNOWLEDGEMENT

Thanks to God almighty for the health and strength in pursuing this course.

Special gratitude and appreciation goes to my Supervisors, Dr. W. O. Owino and Dr. J. N. Kinyuru for their invaluable guidance, comments, suggestions and positive criticisms throughout the research and the writing of the thesis manuscript.

Deserving no less gratitude are the technicians of the Department Food Science and Technology, Jomo Kenyatta University of Agriculture and Technology; P.N. Karanja, D. Abuga, J. Oruka, D. Votha, C. Waswa and J. Wambugu for their technical help during the laboratory analyses.

My parents and siblings, I owe you much gratitude, may God bless you abundantly. Special mention to Kibet Rono, my cousin for encouragements throughout the research, with you tough times became bearable. Thanks a lot.

I offer my sincere gratitude to the Bureau for Food Security, U.S. Agency for International Development, under the terms of Award No. AID-BFS-IO-1200004 through AVRDC-Arusha to Dr. W. Owino and the Kenyan National Commission of Science, Technology and Innovation (NACOSTI), (Postgraduate research Grant number NACOSTI/rcd/ST&I/6TH CALL/MSC/079) for the financial support for this research project.

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LIST OF ABBREVIATIONS AND ACRONYMS

CaCl₂	Calcium Chloride
CFU	Colony forming units
FAO	Food and Agricultural Organization
FW	Fresh weight basis
GDP	Gross Domestic Product
GRAS	Generally Regarded as Safe
HCCR	Hydrocooled and stored at ambient temperature(20-25 °C)
HCDA	Horticultural Crop Development Authority
HCRT	Hydrocooled and stored at ambient temperature(20-25 °C)
HPLC	High performance Liquid Chromatogram
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KARI	Kenya Agricultural Research Institute now KALRO (Kenya Agriculture and livestock Research Organization)
NCCR	Not cooled and stored at low temperature(7-10 °C)
NCRT	Not cooled and stored at ambient temperature(20-25 °C)
PH	Postharvest
PHL	Postharvest life
PPR pipe	Polypropylene Random copolymer pipe
RH	Relative Humidity
TPC	Total plate count

ABSTRACT

Fruits and vegetables constitute an important subsector in horticultural industry in Kenya a major part of human nutrition. However, due to their high perishability, limited postharvest technologies in most of the developing countries and inadequate cold storage, huge postharvest losses are incurred. Cool temperatures are essential in perishable produce for preservation of flavour, texture, aroma volatiles, appearance prolonging postharvest life. 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. The present study was undertaken with the objective of establishing the time required to cool specific fruits and vegetables to target temperatures using the low cost hydrocooling system designed and also assess its effects on postharvest characteristics in the selected produce. It also sought to establish the effect of hydrocooling, low temperature storage and use of calcium chloride as a sanitizer in maintaining the postharvest quality of selected perishables, i.e. tomatoes, African eggplants, carrots and courgettes. Fresh produce of tomatoes, African eggplants and carrots were harvested from the JKUAT experimental farm and courgettes from a farmer's field in Ngarariga Limuru. The produce was transported to the laboratory in crates lined with moist paper towels within 3 hours, where sorting for uniformity in size grading and measurement was done. Fresh produce of each product were divided into 7 portions of equal number of fruits. Using a the hydrocooling system design constituting a water reservoir, electric powered pump, two identical shower heads, flow valve and polypropylene copolymer pipe, a shower type hydrocooling system was made and used to hydrocool the produce. Two portions were hydro cooled using the low cost hydrocooling system, with water at 2 ± 10 C, another two were not hydrocooled. During hydrocooling, temperature monitoring at the core of the produce was done using a temperature data logger. From the four portions, one in each category was kept at low temperature (7°C or 10°C) while the other was stored at ambient conditions (25°C) in a room. The remaining three portions were hydrocooled with water at $2\pm 1^{\circ}\text{C}$ containing 0.5 %, 1.0% and 1.5% CaCl_2 and subsequently stored at low temperature, all at constant relative humidity of 95%. Time required to hydro-

cool the produce to target temperature was 10.5 ± 0.47 , 4.9 ± 0.21 , 7.42 ± 0.25 , 3.33 ± 0.34 minutes for tomatoes, carrots, courgettes and African eggplants respectively. The quality assessment carried out included weight loss, respiration rate, total soluble solids, colour, soluble sugar content, vitamin C, β carotene, total titratable acidity, total viable count and spoilage during storage. Quality assessment done at two days intervals revealed progressive loss in weight in all the produce, ranging from 0.86 ± 0.13 % to 4.43 ± 0.46 %, 1.46 ± 0.16 to 30.71 ± 0.35 %, 1.32 ± 0.19 to 20.45 ± 0.68 % and 0.30 ± 0.04 to 6.25 ± 0.39 % for tomatoes, courgettes, carrots and African eggplants respectively. Hydrocooling coupled with low storage temperatures resulted in significantly ($P \leq 0.05$) superior postharvest quality characteristics with regard to throughout the storage period implying better postharvest quality. However, for the African eggplant produce stored at 10° C, both hydro-cooled and the control was significantly ($P \leq 0.05$) inferior in quality from 3 days after storage. More weight loss occurred and higher respiration rates were observed, this was accompanied by visible chilling injury symptoms such as shrivelling and darkening of the calyx. When calcium chloride (CaCl_2) was added to the hydro-cooling water and produce subsequently stored at lower temperatures, retention of vitamins (beta carotene and ascorbic acid) was higher in all the produce. In tomatoes, African eggplants, carrots and courgettes, the highest retention was at 1.0 %, 1.5%, 0% and 1.5%, for both vitamin C and beta carotene. Microbial populations were also reduced by 78.2 %, 59.4% 63.9% and 71.6% for tomatoes, African eggplant, carrots and courgettes respectively in total plate count and by 63.1%, 46.2% 79.4% and 69.7% in yeast and moulds for all produce at 1.5% CaCl_2 . In African eggplant, CaCl_2 delayed the onset of chilling injury and lowered the respiration rates significantly.

Keywords: Calcium Chloride, Low Cost hydro cooling, Postharvest Quality, Field heat, Specific Sugars, Microbial loads.

CHAPTER ONE

INTRODUCTION

1.1 Background

Horticulture plays a significant role on Kenya's economy (ERA-MOALF, 2015). Agriculture and food processing is key in Kenya's economy, engaging about 75 % of the population, with nearly three quarters deriving their livelihood from farming. This contributes about 25 % to Kenya's Gross Domestic Product (GDP) (ERA-MOALF, 2015).

Fruits and vegetables are a key component of a healthy diet (Hounsome *et al.*, 2008). They are sources of vitamin C, thiamine, niacin, pyridoxine, folic acid, minerals and dietary fibre; important for human health. Some of these nutrients are prone to losses when the produce management after harvest is poor (Oguntibeju *et al.*, 2013).

Postharvest losses in quality and quantity occurring in fruits and vegetables is an issue of great concern to postharvest technologist in the world (Kitinoja *et al.*, 2011). Produce quality begins to deteriorate soon after harvest. The deterioration rate in produce is affected by level of maturity, initial quality, temperature, humidity, environmental gas composition, physical stress, packing and packaging conditions as well as presence of pest and diseases (Rickman *et al.*, 2007; Kitinoja *et al.* 2011).

Maintenance of cold chain is an important postharvest practice. Heat decreases produce quality resulting in rapid spoilage. To attain longer postharvest quality and produce marketability, temperature control for produce is quite important (Li, 2011).

Harvesting when temperatures are lower e.g early mornings or late evening , or timing harvest to coincide with cool weather; are some of the practices that have been used to reduce field heat in the produce (Kiaya, 2014). This however does not provide a long term solution due to a variety of reasons such as s production areas have increased, while the labour required to complete the task still within the specified periods is limited. Besides temperature, other factors that influence produce quality and deterioration include avoidance of injury, harvesting fruit and

vegetables when free of dew or morning moisture, and overall cleanliness which help maintain quality (Jannasch, 2010).

The desire to prolong product storage life and reach distant markets with quality that satisfies consumer calls for uniform and fast cooling of perishables (Manganaris *et al.*, 2007a). Reduction in produce temperature after harvest results in reduction in respiration rate, volume losses and extends shelf-life while maintaining produce quality (Kitinoja *et al.*, 2011). Precooling should be done immediately after harvest and should be accomplished before the produce is placed in cold storage (Kitinoja & Thompson, 2010). Rapid precooling to the product's lowest safe temperature is most critical for crops with inherently high respiration rates (Batchmann & Earles, 2000). Temperature maintenance involves continued removal of respiratory heat and heat generated while moving produce into the storage environment by use of cold storage (Kitinoja, 2010).

Proper temperature management plays a significant role in delaying produce deterioration. It involves maintaining temperature as low as possible without freezing the produce. Several mechanisms have been developed for removal of field heat and maintenance of the low temperature (Acedo, 2010). These include ice cooling, where finely crushed or flaked ice is packed with the produce. This is commonly used for produce shipped in non-refrigerated vehicles (Vigneault *et al.*, 2009). Ice cooling helps to maintain high humidity in the produce container, minimizing moisture loss once the produce has cooled. However, the application is limited to produce that is tolerant to direct contact with ice or those packaged in moisture-resistant containers (Kader & Rolle, 2004).

1.2 Problem statement and justification

Problem statement

Fruits and vegetables losses range between 30 % and 40% of total production at the farm to consumer in the world (Kitinoja *et al.* 2011; FAO 2014). This is valued at approximately 0.86 Billion USD (FAO, 2014). The lead contributing factor to postharvest food losses of perishable produce has been identified as absence or poor cold chain due to lack of investment in storage and cooling facilities (Gogh *et al.*,

2013). Conventional hydro-cooling systems are usually expensive, with the cheapest being approximately \$3,000 (Dongguan Coldmax Refrigeration Equipment Co., Ltd.), limiting the number of subsistence farmers who can afford it (Onyango & Imungi, 2007). It is therefore important to develop and test a low cost batch hydro-cooling system that can yield equivalent results to a conventional hydro cooling system. The system can offer an affordable practical solution to farmers who over time have been forced by the circumstances to bear the loss of up to 50% in their produce. This study was therefore undertaken to evaluate the efficiency of a locally assembled hydrocooling system and establish its potential for utilization by small and middle holder farmers.

Justification

Reduction of postharvest losses in fruits and vegetables remain to be a worldwide goal (Vigneault *et al.*, 2009). Physical and quality losses are mainly due to poor temperature management, poor quality packages used, rough handling and a general lack of education regarding the needs for maintaining quality and safety of perishables at the producer, wholesaler and retailer levels (Kitinoja *et al.*, 2011; Winkworth-Smith *et al.*, 2014).

Although the biological and environmental factors that contribute to postharvest losses are well understood and many postharvest technologies have been developed to reduce these losses, lack of adoption of these technologies has continued to prevail especially in developing countries such as Kenya. This is because there is lack of information, materials, tools and or equipment needed are not available and costs to acquire the conventional systems are prohibitive (Kitinoja *et al.*, 2011). In addition, there is relatively little published information about the suitability of small-scale hydro-cooling, especially regarding the range of crops and environments found in developing countries (Kitinoja & Thompson, 2010)

1.3 Objectives

Main objective

To evaluate the performance of a low cost batch hydro-cooling system designed as well as effect of calcium chloride; a sanitizer application in maintaining postharvest quality of selected perishables.

Specific objectives

- i. To establish the relationship between the product dimension and the time required to hydro-cool the produce to attain target temperature.
- ii. To establish the effect of hydro-cooling on the physical and chemical quality characteristics of tomatoes, African eggplant, carrots and courgettes.
- iii. To determine the effect calcium chloride concentrations in extending the shelf-life stability of tomatoes, African eggplant, carrots and courgettes.

1.4 Hypothesis

1. The product geometry and volume does not significantly affect the time required to hydro-cool to attain target temperature.
2. Hydro-cooling using a low-cost hydro cooling system does not significantly prolong postharvest quality of selected vegetables.
3. The addition of sanitizers in hydro cooling water has no significant effect on shelf life stability of selected vegetables.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

Recently, there has been a rise in number of people consuming fresh fruits and vegetables even when they are out of season (Vigneault *et al.* 2009). This has placed a demand for product quality maintenance after harvest in order to maximize returns. Immediately after harvest of horticultural produce, deterioration begins. The rate of deterioration determines the shelf life of the produce (Li, 2011).

To study the effect of hydrocooling using the low cost hydrocooling system, produce of global importance in nutrition and economy were selected. Tomatoes were selected based on their economic importance (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 postharvest protocol for this crop, as well as its addition to the diversity of diet. (Kitinoja *et al.* 2011; Msogoya *et al.* 2014).

2.2 Current precooling practices for horticultural crops

Hydro-cooling uses clean, sanitized water as the cooling medium (Kitinoja and Thompson 2010; Li 2011). It is the fastest precooling method reaching the target temperature within minutes (Elansari, 2008). Past studies show that hydro-cooling removes heat about five times faster than air (Batchmann & Earles, 2000). This can be done by either showering or immersing the produce in the cold water (Kader and Rolle 2004; Vigneault *et al.*, 2009). The process is efficient in removing field heat and also serves to clean the produce. A disinfectant may be added to water to reduce the spread of diseases (Batchmann and Earles 2000; Vigneault *et al.*, 2009). Hydro-cooling reduces water loss and thus produce appear fresh for longer periods. In addition, hydro-cooling may revive wilted produce (Li, 2011).

Room cooling involves placing produce in insulated rooms equipped with refrigeration units. This method can be used with most commodities. However, it is slow compared to the others. A room used only to store previously cooled produce

requires a relatively small refrigeration unit, whereas when used to cool produce, a larger unit is needed (Batchmann & Earles, 2000).

Forcing refrigerated air through produce packed in boxes or pallet bins is another method of precooling produce. Although it is applicable to most horticultural perishables (Batchmann and Earles 2000; Kader and Rolle 2004), its limitation is the tendency to cause water loss from the fresh produce due to air movement unless humidity is kept near 100% (Li, 2011). The cooling rate depends on flow rate and temperature of the air (Batchmann & Earles, 2000) as well as the produce physical characteristics such as surface area exposed to the cooling medium (Teruel, Kieckbusch, & Cortez, 2004). Other cooling mechanisms include vacuum cooling generally applied to leafy vegetables that release water vapour quickly, thereby allowing them to be rapidly cooled. Use of refrigerated trucks which are designed to maintain temperature of pre-cooled commodities is also a method used to maintain produce temperature, especially while on transit (Batchmann & Earles, 2000).

Forced-air cooling and hydro-cooling have however been found to be the most effective and economical methods in preserving optimum produce quality and thus increase shelf life (Acedo, 2010). The initial capital costs however put these technologies beyond the reach of most small holder farmers. However, with adoption of cheaper technologies that enables lowering of cost of the cooling systems especially, the hydrocooling system can make them affordable for small holder farmers. With the application of adequate technology to prevent deterioration after harvest, and considering the biochemical characteristics of the produce, postharvest losses can be reduced significantly (Pinheiro *et al.*, 2014).

2.3 Overview of selected produce

2.3.1 Tomatoes

Tomato (*Lycopersicon esculentum*) fruit is a good source of Vitamins A and C and is generally harvested at edible maturity, characterized by attaining pink-reddish colour and maximum size (Rab *et al.*, 2013). Tomato production in 2014 was highest in Kajiado, Bungoma, Kirinyaga and Makeni counties of Kenya; (ERA-MOALF, 2015) mainly in the fresh market (Odame *et al.*, 2008). Kenya's tomato

production is significant to the world food basket. Its production in 2014 was 400,204 tonnes ranking (ERA-MOALF, 2015). It is a potential source of employment in the rural and urban as people can trade in the crop (Odame *et al.*, 2008). The economic importance of this crop in Kenya is presented in Table 2-1 which shows the area under production in Kenya and the proportional income value to the country.

Despite the economic potential the crop bears, the world postharvest loss in tomato is at 4% in developed countries while the developing nations face huge amounts accounting for up to 40% of the production. The losses have been attributed to several factors with absence of precooling and cold chain infrastructure being the major components (Gogh *et al.*, 2013).

Table 2-1: Tomato production trends in selected counties in Kenya for years 2012-2014

County	Area (Ha)			Quantity (Tonnes)			Value (Kshs millions)		
	2012	2013	2014	2012	2013	2014	2012	2013	2014
Kajiado	1,603	1,668	1,680	35,937	50,884	47,368	921	962	1,624
Bungoma	1,344	1,474	1,700	39,232	41,568	50,399	1,221	1,227	1,610
Kirinyaga	1,903	1,795	1,648	54,464	30,774	48,560	1,159	750	1,155
Makueni	431	485	558	17,581	22,560	21,098	560	990	856
Muranga	1,032	1,039	1,026	6,807	6,814	7,180	157	300	292
Homabay	1,000	1,052	897	6,004	9,543	9,051	166	150	153

Source: (ERA-MOALF, 2015)

The tomato fruit accumulates heat during the harvest and postharvest operations, which decrease their storage quality Rab *et al.* (2013) and therefore require thorough and rapid cooling soon after harvest to remove field heat. This facilitates the maintenance of postharvest quality. Prompt and sufficient washing and cooling reduces the effects of dehydration and minimizes decay. Alternatives such as harvesting late in the evening when temperatures are cool have been practised to help curb the problems of high field heat (HCDA, 2010).

The fruit quality is often perceived by the consumer from the appearance of uniform colour, absence of decay, injuries or shrivelling. Most postharvest losses occurring in tomatoes have been attributed to, external damage incurred during harvest and handling, and harvest at the improper maturity stage (Watkins & Nock, 2012).

The removal of field heat, by precooling the fruit, reduces postharvest decay, control development of physiological disorders; maintain fruit quality and delay aging or ripening (Rab *et al.*, 2013).

The end-use of the produce and the distance to the market will determine the harvest time or stage of produce. Tomatoes for processing are harvested when they are fully mature. Fruit to be shipped for long distance is harvested at a less mature stage, while the crop for local markets is picked at a more mature stage (Directorate of plant protection, 2010).

Kenyan farmers are faced with a huge risk of losing their produce; due to lack of access to adequate and timely transport; especially to distant markets coupled with the high perishability of the produce. This calls for need to invest in cold chain facilities (HCDA, 2010).

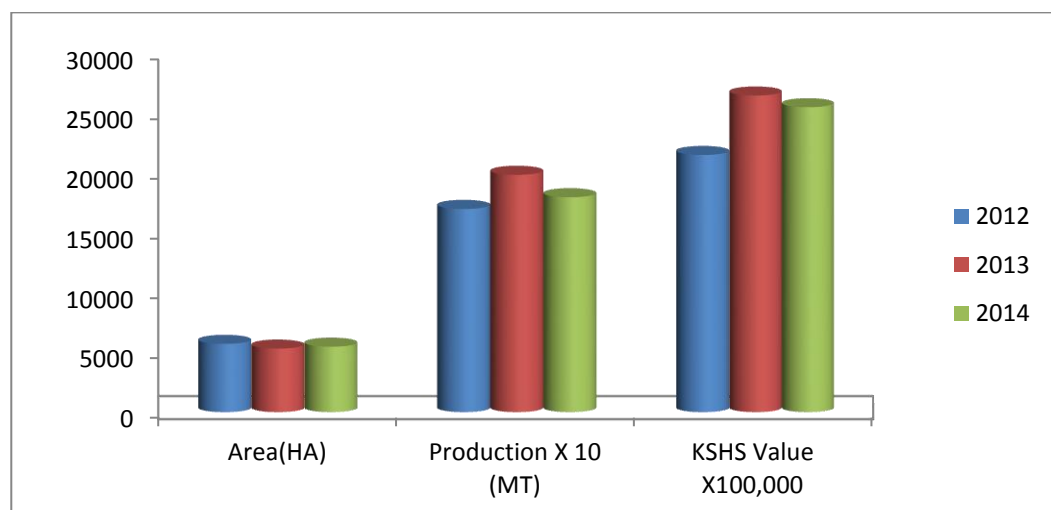
2.3.2 Carrots

Carrot (*Daucus carota*) a root vegetable rich in beta carotene and dietary fibres Sharma and Karki (2012) produced in Kenya mainly for the domestic market (HCDA, 2008) with small quantities of baby carrots being exported (ERA-MOALF, 2015). It is consumed both fresh and in processed forms (HCDA, 2010). Most production occurs under rain fed farming (HCDA, 2008). In 2014, carrot production was highest in Kiambu county accounting for 61 % of the national production (ERA-MOALF, 2015). The leading counties in production of this crop are Meru and Nyandarua. The area under carrot cultivation in 2014 was 5,503 Ha, yielding 179,844 MT with a value of Kshs 2.55 billion (ERA-MOALF, 2015).

Figure 2-1 shows the trend of production from 2012-2014, where there was progressive increase in production to 2013, with a slight decline in 2014; this was despite the notable increase in area under production and was attributed to low productivity.

Carrots of good quality are usually firm, straight from the shoulder to the tip, smooth, sweet with no bitter or harsh taste, and show no signs of cracking or sprouting (Watkins & Nock, 2012). The stage of harvesting carrots is usually determined by their end use. Immature carrots are usually harvested for fresh markets to ensure tenderness and sweetness. Late harvesting may improve storability by reducing decay development during long term storage. Hydro-cooling is the best option for precooling of carrots, after they have been pre-washed. Although carrots are not as perishable as many other vegetables, they still need to be cooled on the day of harvest to reduce wilting and shrivelling, prevent heating due to carrot respiration, and prevent decay (Watkins & Nock, 2012)

Figure 2-1: National production trends for carrots for the years 2012-2014



Source (ERA-MOALF, 2015)

Farmers face the challenge of high postharvest losses upon production; heavy losses are incurred during transport as a result of poor postharvest handling and low shelf life during distribution and retailing (KARI, 2013).

2.3.3 Courgettes

Courgettes (*Cucurbita pepo*) also known as Zucchini is the most widely grown and economically important summer squash. It is a non-climacteric fruit usually harvested when physiologically immature (Carvajal *et al.*, 2011).

Zucchini are usually harvested young, with the skin still shiny and the fruit is tender in texture and without seeds. Change of colour towards yellow or dullness,

pitting and loss of firmness are signs of quality deterioration. It also exhibits chilling injury, when stored at low temperatures. Rapid cooling reduces water loss from the fruit. The fruits are susceptible to chilling injury and the optimum storage regime is 41 to 50°F with 95 % relative humidity (RH) (Watkins & Nock, 2012).

2.3.4 African Egg Plants (*Solanum aethiopicum* L.)

Solanum aethiopicum L. is an indigenous leaf and fruit vegetable in Africa (Adeniji *et al.*, 2012). It presents several fruit shapes such as oval, ridged and cylindrical shapes, sizes from large, medium and small; and colours such as purple, white/cream or striped but each characteristic is typical to the particular accession (Concello'n *et al.*, 2007). Like most fruits originating from tropical Africa, the *S. aethiopicum* is susceptible to chill injuries when stored at low temperatures. This is manifested by appearance of surface pitting and scald, seed darkening and flesh browning (Concello'n *et al.*, 2007). *S. aethiopicum* is an important crop for production in marginal areas, and can be used to alleviate food insecurity (Adeniji *et al.*, 2012).

2.4 Importance perishable produce' storage temperature

Fresh produce generally contain internal heat load at harvest due to respiration as well as external heat load from the environment (Moretti *et al.*, 2010). To enhance the postharvest life of the fresh produce, the perishable produce need to be rapidly cooled (Kitinoja, 2010). Precooling of produce ensures decreased enzymatic and respiration rates, wilting due to loss of water and delays growth and multiplication of microbes (Lozano, 2006). The rate of eliminating field heat in fresh produce is affected by the several factors, which include the temperature of the cooling medium and the speed at which the cooling medium moves past the produce Manganaris *et al.* (2007a) and the size or geometry of the produce being hydrocooled (Pathare *et al.*, 2012). Hydrocooling is a fast precooling method using chilled water estimated to be up to fifteen times faster than forced air cooling, due to the high heat capacity of water (Manganaris *et al.*, 2007a). It can be used for most products that are not sensitive to wetting (Lozano, 2006). The efficiency of a hydroooling system is estimated by dimensionless cooling rate. These is described as either TAT $\frac{1}{2}$ or $\frac{7}{8}$,

which represent the fractional difference between the cooling medium and the product core temperature (ASHRAE, 2010). According to (Jobling, 2000) faster movement of cooling medium would correspond to faster cooling, however, the relation is not linear and at certain flow rates 20 gpm/ft² do not reduce the cooling time.

The temperature difference between cooling medium and produce also influences the cooling time, the cooling medium and the produce geometry. The report of Thorpe (2008) showed that the greater the temperature difference, the faster the rate of cooling, while produce with greater surface area to volume ratio also cool faster than those with lower surface area to volume ratio (Teruel *et al.*, 2004). Although hydrocooling technology has been in existence for a long period of time, its utilization in developing countries has been limited. This has been attributed to the high initial capital costs and complexity of the technologies involved (Kitinoja, 2013).

2.5 Produce hygiene and sanitation

Although produce washing after harvest is the recommended postharvest practice; most subsistence farmers have not adopted the practice with a claim that the washing of produce results in faster deterioration (Acedo, 2010).

Use of sanitizers which reduce the levels of microorganisms on surfaces of fruits and vegetables to levels considered safe from a public health point of view has been practised in the past (Dvorak, 2008). The disinfectants have been documented to prevent postharvest diseases and food-borne illnesses that have been transferred through fresh fruits and vegetables. Microbes that have been transferred include *E. coli* 0157:H7, *Salmonella*, *Cryptosporidium*, *Hepatitis*, and *Cyclospora*.

Various sanitizers as in Table 2-2 have been used in the past which include chlorine in water used during hydro-cooling and to disinfect packinghouse, packaging and transport facilities. Hydrogen peroxide (food grade) has also been used as a disinfectant. Concentrations of 0.5% or less are effective for inhibiting development of postharvest decay caused by a number of fungi (Acedo, 2010). Although there are many sanitizers available, cost of acquisition and their suitability to application in

the food industry poses a challenge on their use. Other substances used include Organic and inorganic salts which must be of the GRAS (Generally Regarded as Safe) category (Youssef *et al.*, 2012). Below is a table of commonly used sanitizers and their effectiveness, showing both their advantages and disadvantages of these sanitizers.

Table 2-2: Commonly used sanitizers in fresh fruits and vegetables

Sanitizer	Advantage	Disadvantage
Chlorine (Commonly used)	<ul style="list-style-type: none"> • Relatively inexpensive • Effective on many Microbes • No residue is left on commodity 	<ul style="list-style-type: none"> • Maybe corrosive to equipment • PH sensitive. Effective between 6.5 and 7.5 • May be irritating to skin
Chlorine dioxide	<ul style="list-style-type: none"> • Activity is less dependent on PH 	<ul style="list-style-type: none"> • Require to be generated on site • Greater human exposure than chlorine Off-gassing of noxious gases is common • Can be explosive in high concentration
Peroxyacetic acid	<ul style="list-style-type: none"> • No known toxic residues or by products • Little off-gassing produced • Not affected by organic matter • Not corrosive to equipment 	<ul style="list-style-type: none"> • Activity reduced in presence of metal ions • High concentration is toxic to human beings • PH sensitive. Activity reduced beyond 7
Ozone	<ul style="list-style-type: none"> • Strong sanitizer • Can reduce pesticide residue in water • Less sensitive to PH 	<ul style="list-style-type: none"> • Require on-site generation • Toxic to human beings • Highly unstable in water

Table adapted from the Vegetable Hand book (Sargent, *et al.*, 2007)

2.6 Storage temperature

Fruits and vegetables begin to deteriorate soon after harvest. To retain quality, fresh produce must be stored at their optimal temperatures. Low temperatures are associated with reduced respiration and metabolic, decreased water loss, reduced susceptibility to ethylene and lower decay incidence (Watkins & Nock, 2012). As a result, undesirable changes in colour, composition, texture, flavour and nutritional status and undesirable growth such as sprouting are minimized. Different produce however, have different optimal storage conditions, due to the growth environment, stage of maturity and the species specificity (Carvajal *et al.*, 2011).

Extremely low temperatures are also harmful to produce that are chill sensitive. In such instances, the produce exhibit chilling injury symptoms which include irregular ripening, failure to ripen; pits on the skin surface and increased susceptibility to decay. In crops that are non-chill sensitive, longest shelf life is associated with the lowest temperature. Storage temperature therefore influences the produce quality greatly (Concello'n *et al.*, 2007).

Another factor that has an impact on produce quality is relative humidity (RH), defined as the ratio of water vapour pressure in the air to the saturation vapour pressure at the same temperature. When the RH is low in the storage environment, excessive water loss occurs in the produce. This results in wilting, shrivelling, flaccidness, soft texture and loss of nutritional value as well as saleable weight of the produce (Watkins & Nock, 2012).

2.7 Quality measurements

According to Artés and Gómez (2006), the quality of a product is defined as the ability of the product or produce to satisfy the intended use. The ability of a produce to satisfactorily meet its commercial shelf life starts with proper selection of raw materials, subsequent appropriate handling, packaging and storage. Lee and Kader (2000) also indicate that fruits and vegetables are subject to continual changes after harvest, which cannot be stopped but controlled within certain limits by using various postharvest procedures such as precooling and low temperature storage. The change in quality of produce and thus decline in consumer acceptability of fruits

and vegetables is maybe due to change in physical (colour, weight loss and decay incidence) chemical (titratable acidity, vitamin C, beta carotene, total soluble solids, specific sugar content), physiological (respiration and ethylene production rates) and microbial (total plate count and total yeast count) qualities where each product has a unique set of attributes desired by the consumer (Yan *et al.*, 2013) .

2.7.1 Weight loss

Weight loss is a parameter used to determine the reduction in the saleable weight of produce. It is associated with respiration and continued moisture evaporation from the skin (Herna´ndez-Mun˜oz *et al.*, 2008). The water loss and respiration rates however are influenced by the temperature and relative humidity of the surrounding environment. Higher temperatures and low relative humidity has been shown to increase the weight loss in fresh produce (Herna´ndez-Mun˜oz *et al.*, 2008).

2.7.2 Colour

Colour, an external characteristic representing quality of a product is important as it manifests the internal composition of the fruit or vegetable pigments. Camelo and G3mez (2004) stated that although produce exhibit different colours, their colours are unique to the specific product and different shades of the same will indicate quality of the product.

The colour of commodities is not static and changes during maturation, ripening and senescence (Mutari & Debbie, 2011). In fruit ripening and vegetable yellowing, the yellow-to-orange xanthophylls and carotenes constitute colour due to the disappearance of chlorophyll, which is triggered by plant hormones such as ethylene (Yan *et al.*, 2013). Colour measurements done using a colour meter gives readings as L*, a*, and b* representing the degree of lightness, the redness or greenness and blue to yellow tendencies of a surface (Yumbya *et al.*, 2014).

2.7.3 Decay incidence/ Spoilage and chilling injuries

Fresh fruits and vegetables continue to deteriorate during storage regardless of the conditions they are kept in (Rickman *et al.*, 2007). As a result, the quality of the

produce diminishes, characterized by shrivelling, microbial growth, colour change and pitting in the produce (Rickman *et al.*, 2007; Luna-Guevara *et al.*, 2014).

Quality deterioration is however not the same in all produce. In developing countries like Kenya, the lack of effective postharvest control practices, high costs and lack of understanding of the principles involved in controlling decay continues to pose a challenge (Workneh *et al.*, 2003). Some exhibit physiological disorders such as chilling injury Ait-Oubahou (1999), which involves either stimulation or inhibition of some cell wall enzyme activity (Baladrán-Quintana *et al.*, 2007).

The proportion of chilled, decayed or spoiled fruits in a lot is an estimate of the effectiveness of a particular treatment in maintaining the postharvest quality of perishables (Ding *et al.*, 2002).

Microbial loads

Fresh fruits and vegetables get contaminated by microbes from the soil, irrigate on water, harvesting, handling and storage (Heaton and Jones 2008; Abbadias, *et.al* 2008). As a result, sanitation and microbial populations control in fresh fruits and vegetables is of primary importance to quality, shelf stability, and safety of fresh produce (Mamun *et al.*, 2012). The recent changes in lifestyle leading to more consumption of fresh and minimally processed vegetables for their health benefits poses a necessity to have safe foods (Abadias *et al.*, 2008; Agriculture Organization of the United Nations World Health Organization FAO 2008). The desire for safe good quality fresh fruits and vegetables has raised concerns over handling and storage of these produce prior to consumption (Abbadias, *et.al* 2008). Temperature has been known to be a number one factor in controlling the growth and proliferation of microorganisms (Artés & Gómez, 2006) .

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 has been known to delay or suppress their growth, thus delaying the overall quality deterioration as they limit the number of pathogens that can grow on the substrate (Abbadias, *et.al* 2008).

2.7.4 Vitamin C (Ascorbic Acid)

Vitamin C is an organic acid bearing strong antioxidant properties Hounsome *et al.* (2008) and one of the most important nutrients obtained from horticultural crops in the human diet (Lee & Kader, 2000). Due to its high sensitivity, its retention in fruits and vegetables after storage is used to estimate the overall nutritional quality of the produce (Rickman *et al.*, 2007; Barrett *et al.*, 2010). Its content in fresh fruits and vegetables is influenced by a number of factors which include genotype, pre-harvest climatic conditions, cultural practices, maturity, harvesting methods and postharvest handling. During postharvest, temperature is an important factor in maintaining this vitamin. At higher temperatures, vitamin C loss is accelerated. With longer storage, a decline in vitamin C content is also evident (Kader & Rolle, 2004).

2.7.5 Total Soluble solids and Specific Sugars

Soluble sugars are an important component of fresh fruits and vegetables. They have been described by Sánchez-Mata *et al.*, (2002) as an important factor in sensory attributes such as taste of the vegetables and a component of dietary importance. Besides the importance of TSS in sensory attributes, this parameter is used to rapidly determine the quality the produce (Oz and Ulukanli 2014; Teka 2013). The quantities of these components in perishable produce are unique to the product. However, it is affected by storage temperature and degree of senescence or ripening in each product (Apai *et al.*, 2007).

2.7.6 Beta carotene

Beta carotene is one of the most widely distributed carotenoid in foods. It is a strongly coloured red-orange pigment found in plants with pro-vitamin A activity (Mueller & Boehm, 2011) and involved in vision, cell differentiation, synthesis of glycoproteins, mucus secretion from the epithelial cells, and overall growth and development. It is found in yellow to orange coloured foods in abundance such as carrots, pumpkins and orange fleshed sweet potatoes. However other plants such as green vegetables also contain beta carotene (Dutta *et al.*, 2005).

Nutritionally, beta carotene is an antioxidant, important in binding active compounds in the body (Sharma & Karki, 2012). Beta carotene is a highly versatile

compound affected by length and temperature of storage. As a result, there is need to retain and preserve this pigment (Dutta *et al.*, 2005; Mueller and Boehm 2011).

Beta carotene is a compound of great nutritional importance due to its pro-vitamin A activity, especially in the developing countries, where it constitutes about 82 % of vitamin A intake, because other source foods are expensive (Kidmose *et al.*, 2006).

2.7.7 Respiration

Fruits and vegetables are living commodities and as such is the case; they continue to respire even after harvest. Respiration is an important aspect to determine shelf life of produce, measured by the amount of carbon dioxide evolved by known weight of produce in a particular volume over a specified period of time (Gallagher & Mahajan 2011). It is the oxidative breakdown of substrates to simple molecules, carbon dioxide water and heat. Respiration is proportional to the rate of nutrient utilization in plants and as result corresponds to nutrient loss in fruits and vegetables (Wu *et al.*, 2014). Higher respiration rates correspond to faster loss of nutrients in produce. Fruits and vegetables fall into two categories based on their respiratory behaviour, where some are classified as climacteric and others as non-climacteric. Climacteric produce display rise in respiration rates accompanied by autocatalytic ethylene production (Luengwilai & Beckles, 2013).

2.7.8 Titratable Acidity

This is a measure of the organic acids present in fruits and vegetables. Although various fruits and vegetables have varying dominant acids in them, the use of a conversion factor equalizes them to equivalence of 0.1N sodium hydroxide. It gives an indication of degree of ripeness or senescence in produce, since they are substrates for respiration (Alam *et al.*, 2014). Titratable acidity is also a function of respiration rate, where reduced respiration leads to slower decline in the organic acids (Yan *et al.*, 2013).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Sample Acquisition

Tomatoes (*Lycopersicum esculentum*), carrots (*Daucus carota*) and African eggplant (*Solanum aethiopicum* L) were obtained from Juja 1° 10' 60S , 37° 7' 0E and 1840M and courgettes (*Cucurbita pepo*) from Ngarariga Limuru 1° 4' 60S, 36° 37' 0E and 2274M latitude, longitude and altitude, both locations within Kiambu county Kenya. The vegetables were produced under rain fed production system, but irrigation was used to complement where rain was not sufficient. The experiment was conducted between March and December, 2014. Three sample sets of produce each with about 350 fruits were obtained from the farm for every crop in one season and data presented as average of the three samples. The produce was harvested when they had attained physiological maturity, and commercially acceptable sizes in the market. Tomatoes were harvested at 57 days from transplanting when the fruits showed about 30% change from green to yellow. Eggplants were harvested when the fruits attained the cream-yellow colour, 60 days from transplanting. The carrots were harvested 63 days after planting when the shoulder diameter was about one and a quarter inches while courgettes were harvested when their length was between 20 to 25 centimetres. All produce were harvested between 10: 00 hours and 11:00 hours, and ambient temperatures averaged between 25 ° C and 27 ° C. The samples were packed in cushioned plastic crates, lined with moist paper towels to prevent moisture loss and immediately transported within three hours to the laboratory at Jomo Kenyatta University of Agriculture and Technology (JKUAT), Nairobi Kenya, where internal temperature of produce was measured using a digital thermometer.

3.2 Setting up the low cost hydro-cooling system

An electric powered pump (Pedrollo pump Pkm60) was used to circulate the water in the hydrocooling system, which constituted a water reservoir of a capacity of 144 litres (Dimension 1.4m× 0.302m × 0.35m) placed on the floor level ; for temperature management and monitoring as well as a water treatment point. Polypropylene Random Copolymer pipes (PP-R pipes) with a diameter of 25mm was used in

plumbing and done to a height of 1.3 meters high (based on pump capacity) and fitted with 2 plastic showers heads. Flow rate and pressure of the circulating water was controlled from the outlet of the reservoir using a valve. The setup design was as shown in Figure 3-1 below.

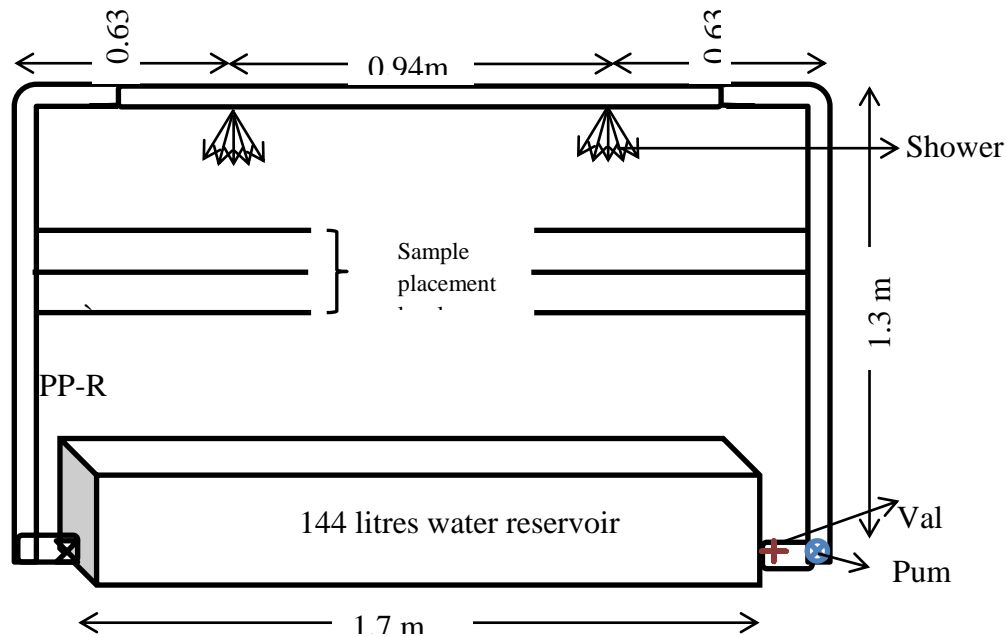


Figure 3-1: Elements comprising the low cost batch hydro-cooling system

3.3 Hydro-cooling the selected perishables to target temperature

The produce to be hydro-cooled was placed in perforated plastic crates, positioned at the top of the reservoir as shown in Figure 3-1, and temperature monitored at mid-point as shown in Figure 3-2 below using a temperature data logger, while allowing space at the top and bottom; for cooling water to flow through the produce with ease so that the water can be re-circulated. The water used was portable water, free of microbial contamination, with a pH of between 6.7-7.3. Water-drop distance in the hydro-cooling system from the shower head to the produce surface was set at 150 to 200 mm (adjustable), to avoid causing physical damage to produce (Vigneault *et al.*, 2009). The produce was showered with the cold water until the core temperature declined to the target safe storage temperature was attained. The water flow rate was regulated using a flow valve and uniformity of water distribution getting to the

produce was checked and ratified as per requirements in setting up a hydro-cooling system using valves (Vigneault *et al.*, 2009). The water receiver at the bottom of the produce was fitted with a filter/sieve to remove organic matter and other debris from the recirculating water that may contaminate the produce as well as unnecessarily reduce the disinfectant activity (Thorpe, 2008).

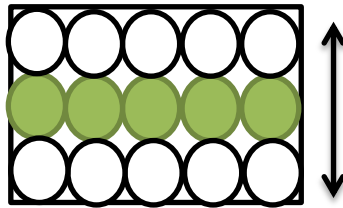


Figure 3-2: Sample temperature monitoring position in the batch hydrocooler

3.4 Testing the hydrocooling system using different vegetables

The time required to lower the internal temperature of produce is a function of a number of factors. This includes the temperature difference existing between the cooling medium and the product being cooled, continuous contact between cooling medium and product and the desired target temperature Pathare *et al.*, (2012) and also the size and geometry of the produce (Teruel *et al.*, 2004).

Probes of a temperature data logger were inserted into the commodity according to the $r/4$ (spherical products) or $r/3$ (cylindrical products) relation as described by (Van der Sman, 2003). Temperatures and time data were obtained from the data logger using USB interface and data readout on a computer. The longitudinal (rL) and transverse (rT) radius of the selected commodities were measured using a vernier calliper rule, and fruit Sphericity ($E= rT/rL$) calculated based on the data.

From this setup, a table of values for cooling times, cooling time and volume ratio and sphericity of fruits cooled in water specific to produce was determined.

The produce selected for hydrocooling were courgettes, African eggplants, tomatoes and carrots. The efficiency of the cooling system was evaluated by taking note of the time used to cool the produce to target temperature as described by (Teruel *et al.*, 2004). Two terms relating to cooling time were considered, namely half cooling

time ($TAT_{1/2}$), and seven-eighth cooling time ($TAT_{7/8}$) by use of dimensionless temperature rate (TAT) where :-

$$TAT_{\frac{1}{2}} = \frac{T_p - T_a}{T_i - T_a} = 0.5 \quad \text{i}$$

$$TAT_{\frac{7}{8}} = \frac{T_p - T_a}{T_i - T_a} = 0.125 \quad \text{ii}$$

Where: T_i is the initial product temperature and T_p is product temperature during hydrocooling and T_a is the temperature of cooling medium (Chilled water, at $2 \pm 1^{\circ} \text{C}$) (Teruel *et al.*, 2004).

3.5 The effect of sanitizer incorporation in suppressing microorganisms and maintaining postharvest quality

Three concentrations of a conventional sanitizer Rico and Henehan (2007) calcium chloride 0.5%, 1.0% and 1.5% used in the hydrocooling water were evaluated for their effect on microbial loads and postharvest qualities in the selected perishables, and compared with a control, which was hydrocooled using portable water only over a storage time of 9 days. Higher concentrations of CaCl_2 resulted in incomplete dissolution of the salt at $2 \pm 1^{\circ} \text{C}$ and thus the effective concentration would not be effectively established.

3.6 Hydrocooling and low temperature storage effect on postharvest quality of vegetables

After precooling the produce, the effect of low temperature on quality during storage was evaluated by dividing the produce into two categories. One category was kept at the optimal low temperature specific to the produce i.e. 10°C , for courgettes, tomatoes and African eggplants and 7°C for carrots (Watkins & Nock, 2012), while the other category was kept at ambient temperature ($25 \pm 3^{\circ} \text{C}$) in a room. The same was also done for the control and the produce sampled at two days interval for 9 days in storage for observation using the parameters indicated in 3.6.1 below.

3.6.1 Quality assessment of produce after treatment

The parameters used in establishing sample quality during storage were grouped as physical, chemical and microbial as described below.

a. Physical parameters

i. Produce dimension and sphericity

Produce dimension (transverse and longitudinal diameters) were measured using a vanier scale and sphericity and volume calculated as shown in equation iii (Teruel *et al.*, 2004).

$$\textit{sphericity} = \frac{\textit{Transverse Radius}}{\textit{Longitudinal Radius}} \quad \text{iii}$$

ii. Weight loss

Weight loss in fruits was measured gravimetrically on individual fruits as described by (Juan *et al.*, 2007), using a digital weighing balance (Model Libror AEG-220, Shimadzu Corp. Kyoto, Japan).where five fruits per treatment were clearly labelled and placed in trays, kept at respective temperature regimes with a constant relative humidity of 95% and their weights measured 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:

$$\% \textit{ weight loss} = \left(\frac{\textit{Initial sample weight} - \textit{Current sample weight}}{\textit{Initial sample weight}} \right) \times 100\% \quad \text{iv}$$

iii. Colour

Produce external colour was evaluated objectively using a Chroma colour meter (CR-300, Minolita Japan) (Herna'ndez-Mun'oz *et al.*, 2008). Four readings were taken from each fruit at 90⁰ interval using five fruits from each treatment and measurements done in triplicate. CIELAB output readings were obtained and used to obtain the three attributes of colour, hue, chroma and value as shown below.

$$C = \sqrt{a^{*2} + b^{*2}} \quad \text{v}$$

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

iv. **Decay Incidence/ 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.

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

b. **Physiological parameters**

i. **Respiration rates**

Respiration rate measurement was done using the static method described by Herná'ndez-Mun'oz *et al.*, (2008). Produce of known weight were placed in jars of known volume whose covers are fitted with a self-sealing rubber septum for gas sampling and incubated at room temperature for one hour. One (1) ml of 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 respectively. Rate of carbon dioxide production was calculated as mg CO₂/Kg/hr at standard atmospheric pressure.

c. **Chemical parameters**

i. **Beta carotene**

Beta carotene extraction was done using acetone and petroleum ether as described by (Rodriguez-Amaya and Mieko Kimura 2004). About 5 g of the sample was weighed accurately. The samples were quantitatively transferred to a mortar where 10 ml of cold acetone was added and ground thoroughly. The extract of acetone was then transferred to a 100 ml volumetric flask. The residue was extracted again with acetone until the extract gave no colour to acetone. The combined extract was then made up to 50 ml with cold acetone. The extract was then evaporated to dryness at 40 °C on a rotary vacuum evaporator (RE 100 BIBY with a water bath). The residue was dissolved in 1ml of 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 from

absorbance of the calibration standard prepared as described by (Imungi , et al., 1983).

ii. Total soluble solids

The total soluble solid (TSS) content was determined using a digital refractometer where three fruits per treatment were individually blended to obtain the juice (Model PAL-S, Atago, Tokyo, Japan) and expressed as degrees brix (°B).

iii. Total Titratable acidity

Total titratable acidity was determined by titrating a known volume of juice from the sample was titrated against 0.1N sodium hydroxide with phenolphthalein as an indicator until the pink colour was noted (Yumbya *et al.*, 2014). Volume of sodium hydroxide was noted and used to calculate the TTA as follows

$$\% \text{ Acidity} = \text{ml of NaOH used} \times 0.1N \times 0.064g \times 100 \quad \text{viii}$$

iv. 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 100 ml conical flask. Ethanol of 96% alcohol, 50 ml was added and refluxed at 100 ° C for 1 hour. The samples were then stirred and the slurry filtered into a quick fit- 100 ml rotary evaporating flask. This was then evaporated in a rotary evaporator at 60 ° C to dryness, and then 10 ml 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 0.45 µm membrane filter and the filtrate collected Vials. The sample was then injected into the HPLC with NH2P-50E column at 10 Pkm pressure and 1 ml/min flow rate and refractive index detector and the quantity of specific sugars determined using freshly prepared standard sugar concentration curve.

v. Vitamin C

Vitamin C was determined using the method described by Mamun *et al.*, (2012) with a few modifications where; about 10 g of from 3 fruit samples were 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 °C for 15 minutes. The supernatant was filtered and diluted with 10 mL of 0.8% metaphosphoric acid. This was passed through 0.45 µm microfilter and 20 µL injected into the HPLC machine. Various concentrations of ascorbic acid standards were also made to make a calibration curve. 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.

d. Microbiological Assays

i. Total plate count

Produce 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°C for 24 hours (Monaghan, Adams, & Hutchison, 2009).

ii. Total yeast and mould

Produce 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 °C for 24 hours (Badosa *et al.*, 2008).

3.7 Statistical Analysis

Data obtained from the three harvest replicates were pooled together and treated as a single experiment as the variation in the data was not significant. Data was analysed using Genstat statistical package 16th edition. Microbial count data was transformed to logarithmic scale to normalize the data before being analysed using Genstat. Mean comparison was done by analysis of variance (ANOVA) and least significant difference (LSD) $P \leq 0.05$. The data is presented in tables and graphs showing various treatments throughout the storage period for the selected vegetables.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 System setup

The system shown below in Plate 4-1 was setup at a cost of 500 USD. This initial capital cost was cheaper than the conventional shower type batch hydro cooling systems of same capacity, whose cost averaged at \$ 3,000 to \$ 3,600, among key suppliers (Dongguan Coldmax Refrigeration Equipment Co., Ltd. and Focusan Refrigeration (Shanghai) Co., Ltd). This is still a high cost for small holder farmers although Kitinoja and Thompson (2010), indicate that hydro coolers are among the cheapest cooling methods to purchase.

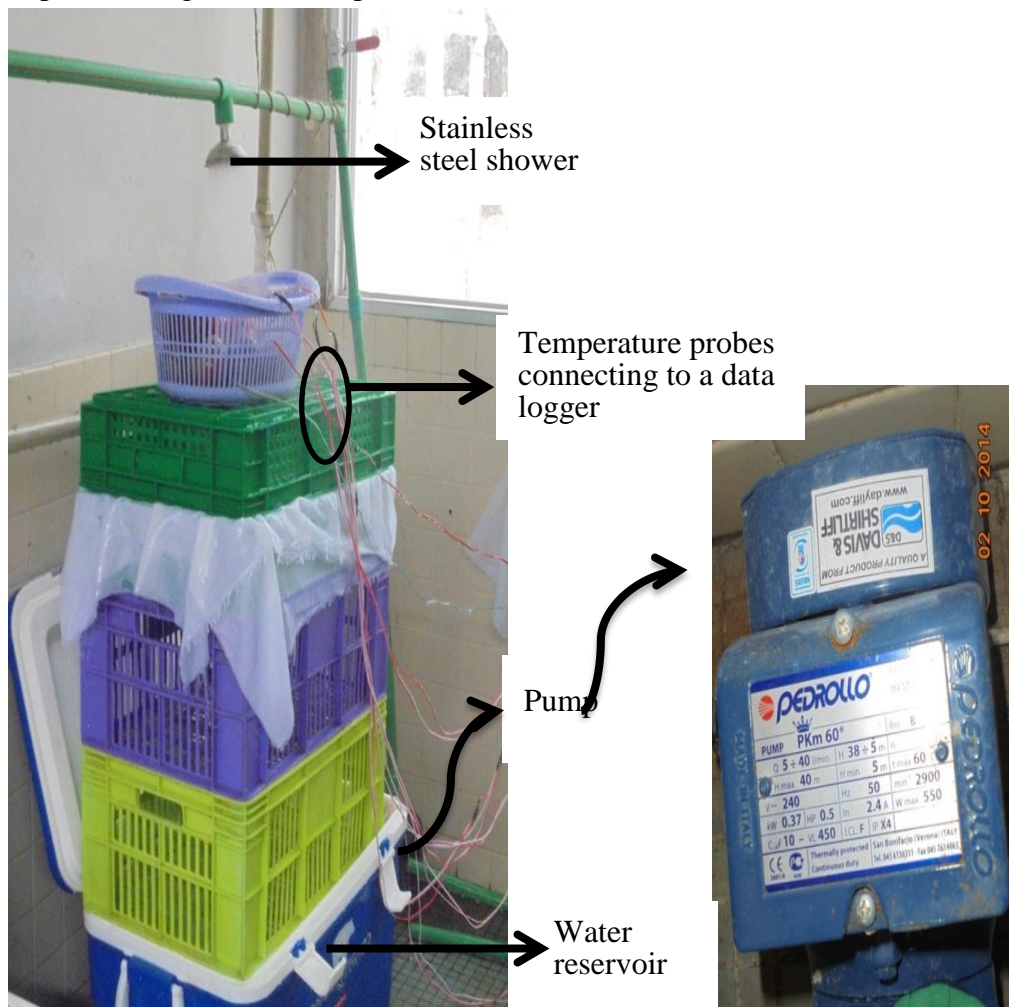


Plate 4-1: Hydro Cooling System setup

The system constituted a jacketed water reservoir, holding water at $2 \pm 1^{\circ}\text{C}$ capacity of 144 litres (Dimension $1.4\text{m} \times 0.302\text{m} \times 0.35\text{m}$) placed on the floor level; for temperature management and monitoring as well as a water treatment point. Jacketing of the water reservoir ensured the temperature of the hydrocooling water remained constant. The water flow rate used was controlled using a flow valve and 20 ± 2 liters per minute was used in hydrocooling of produce. The circulation was done using Pedrollo Pkm 60” pump. Produce temperature monitoring during hydrocooling was measured using a temperature data logger, with a USB interface, accuracy of 0.1°C . The whole setup of hydrocooling was done indoors to eliminate possible heat infiltration into the cooling system during hydrocooling. This system was used to hydrocool the produce of the characteristic dimensions in 4.2, and the time required to cool the produce to safe temperature using the system is as shown in 4.3 below.

4.2 Produce dimensions

The fresh produce in this study were of difference in sizes and shapes, characteristic of each vegetable. The produce exhibited difference in volume and sphericity as shown in Table 4-1. The geometrical properties of the produce, i.e the surface area exposed to the cooling medium and the volume of the produce have been shown to affect the time required to cool the produce to target temperature (Teruel *et al.*, 2004).

Table 4-1: Dimensions of the produce hydrocooled .

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

- Data presented is mean \pm SE, where n=80

Carrots and courgettes presented more cylindrical shapes, characterized by their low sphericity values of 0.21. Tomatoes were more spherical while the eggplants presented a more obloid shape. Although both the courgettes and the carrots were similar in their cylindrical appearance and sphericity, produce volume was different. The volumes of the courgette and carrot fruits were $145.13 \pm 1.40 \text{ cm}^3$ and $82.78 \pm 0.24 \text{ cm}^3$ respectively. These parameters were taken in order to establish a relationship between the cooling time and the produce dimension. Sphericity and volume of products have been found to significantly influence the rate of cooling in the produce (Teruel *et al.*, 2004; Thorpe, 2008; ASHRAE, 2010).

4.3 Cooling time

The mean initial temperatures of produce at harvest was $20.7 \pm 0.6 \text{ }^\circ\text{C}$, $21 \pm 0.9 \text{ }^\circ\text{C}$, $24 \pm 0.2 \text{ }^\circ\text{C}$ and $22 \pm 0.4 \text{ }^\circ\text{C}$ for tomatoes, carrots, courgettes and African eggplants respectively. Cooling time of all the produce varied proportionally with the produce volume/ geometry and sphericity, a phenomenon previously observed by (Pathare *et al.*, 2012). Produce of larger volumes, i.e. the courgettes took 3.2 minutes longer than carrots although both had the same sphericity values. By plotting the fractional unaccomplished difference against time, product specific nomographs of cooling rates were obtained as shown in Figure 4-1 below.

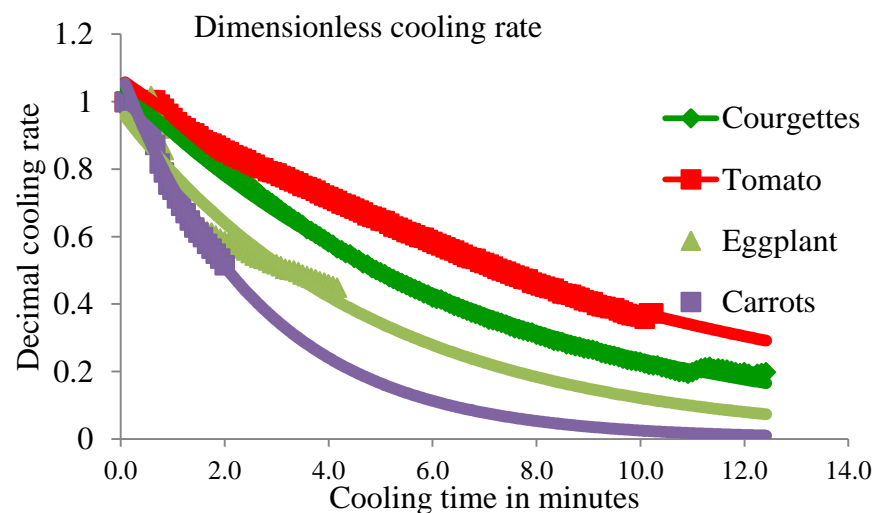


Figure 4-1: Produce cooling rate placed at $20 \pm 5 \text{ cm}$ below shower head

*cooling medium is chilled water at $2 \pm 1 \text{ }^\circ\text{C}$. Data presented is means of 3 replicates

Tomatoes which were more spherical, (sphericity 0.873) than the other produce (0.20, 0.21 and 1.40) for courgettes, carrots and eggplants, reached the half cooling time ($TAT_{\frac{1}{2}}$) at 10.25 ± 1 min, which was the highest time in the selected vegetables. This could be due to the tomatoes high sphericity values Teruel *et al.* (2004). African eggplants, carrots and courgettes attained the half cooling time ($TAT_{\frac{1}{2}}$) at 3.3 ± 0.2 , 2.1 ± 0.2 and 4.9 ± 0.3 minutes respectively. Although the courgettes and carrots had almost equal sphericity, the courgettes took longer time to hydro cool to the target temperature of 10°C .

Similar results with regard to sphericity and volumes of produce were obtained by Teruel *et al.* (2004) in green beans and acerola fruit and by Elansari (2008) when cooling barhee dates of various sizes. This phenomenon was explained in ASHRAE (2010) handbook that the internal cooling rate of the produce is a function of the rate of heat transfer from the centre to the surface, which is influenced by the surface area to volume ratio. Produce with a larger surface area in contact with cooling media such as the obloid shaped African eggplant required a shorter time to cool to the target temperature as compared to the more spherical products such as the tomato. This concept was termed the hot point phenomenon by Vigneault *et al.*, (2000), 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).

4.4 Physical measurements

4.4.1 Percentage weight loss

Weight loss in all the produce increased gradually over the storage time regardless of the treatment, as shown in Table 4-2 and Figure 4-2below.

4.4.1.1 Weight loss of various vegetables after hydrocooling and storage

Table 4-2: Produce percentage weight loss during storage

Product	Treatment	Day 3	Day 5	Day 7	Day 9
Tomatoes	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	3.82±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
African Eggplant	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
Courgettes	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
Carrots	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

*Means ± SE of percentage weight loss in the same column for a particular crop

with different subscript are significantly different ($P \leq 0.05$) $n = 5$

NCRT, NCCR HCRT and HCCR are not cooled and stored at ambient temperature, not cooled and stored at low temperature (7-10 ° C), Hydrocooled and stored at ambient temperature and Hydrocooled and stored at low temperature (7-10 ° C).

The percentage weight loss in all the produce increased cumulatively and gradually over the storage time regardless of the treatment. The produce hydrocooled (HC)

and kept at lower temperatures (CR) showed the least percentage weight loss throughout the storage period reaching 1.83 %, 13.91 % and 8.09 % in tomatoes, courgettes and carrots respectively Table 2-1. Fruits that were not hydro-cooled and subjected to ambient storage temperatures (NCRT) and those hydrocooled and stored at ambient conditions (HCRT) had the highest percentage weight loss in day 9 as compared to the other treatments. In tomatoes, the mean percentage weight loss for NCRT and HCRT at 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 ($P \leq 0.05$). The African eggplants had the highest weight loss under the same conditions as compared to the other treatments reaching 6.25 % for HCCR as compared to 2.15% for the control (NC) kept at room temperature (RT) as shown in Table 4-2. This phenomenon can be attributed to the chilling injuries observed in the African egg plant under this treatment.

Precooling and low storage temperatures have been used to manage weight loss in agricultural produce (Manganaris *et al.*, 2007a). Post-harvest weight loss in tomato is a common serious problem during storage. The weight loss is attributed to loss of moisture and breakdown of carbohydrates during respiration. Pre-cooling was found by Reina *et al.* (1995) 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, thus better postharvest quality of produce. 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 had an effect on weight loss in zucchini (Carvajal *et al.* 2011). Weight loss in vegetables increased with increase in storage time. Higher losses were also observed at higher temperature. The higher weight losses when precooled and stored at lower temperatures of 10 °C in African eggplant fruits is attributed to the chilling injuries that the fruit showed under this treatment, a phenomenon previously reported by Luengwilai & Beckles, (2013) in tomato mutants, where high weight losses were observed in in fruits that exhibited chilling injuries.

4.4.1.2 Effect of sanitizer application on weight loss

Progressive weight loss was observed in produce hydrocooled with the calcium chloride solutions at 0%, 0.5%, 1.0% and 1.5% during storage as shown in **Error! eference source not found..** below.

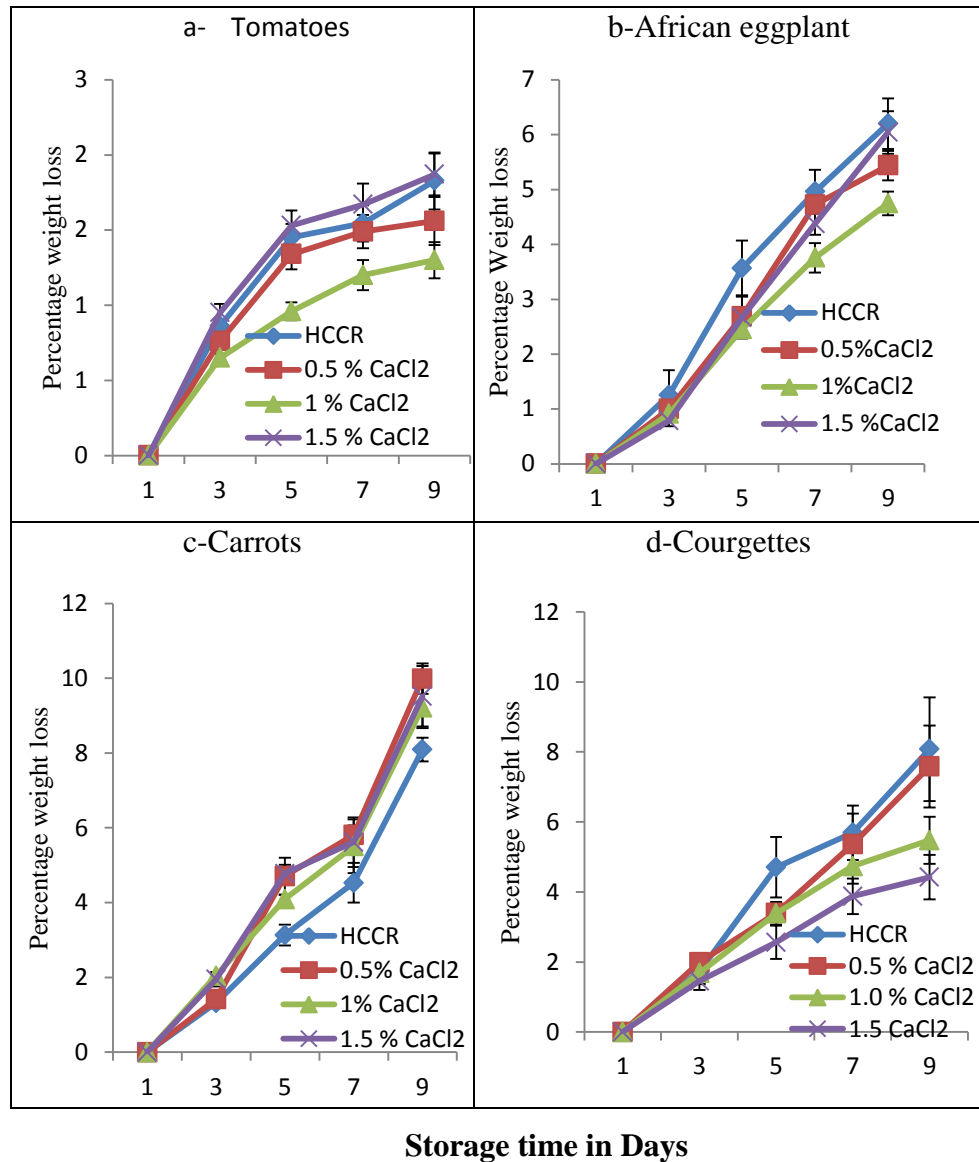


Figure 4-2: Percentage weight loss in produce with Calcium Chloride treatments

Where **a**, **b**, **c** and **d** are tomatoes, African eggplant, carrots and courgettes respectively. HCCR is produce Hydrocooled and stored at low temperatures. 0.5%, 1.0% and 1.5% is concentration of calcium chloride added to the cooling water. The produce in these treatments were also stored at low temperature.* *Values are presented as means \pm Standard error, n=5

Weight loss was influenced by both the storage time and the CaCl₂ concentration used. The difference between the various CaCl₂ was significantly ($P \leq 0.05$). Different produce responded differently to the calcium chloride solutions. Tomatoes hydrocooled with water containing 1% CaCl₂ showed the least weight loss attaining 1.30 % loss in day 9, remarkably the lowest, for all treatments. This could be due to the reduced respiration rates observed in the tomatoes under this treatment.

Carrots showed higher weight losses when hydrocooled with water containing CaCl₂, attaining 9.9% weight loss at 0.5% with the control, water only (0% CaCl₂) showing the least weight loss of 9.0 % at the end of the storage period. Courgettes showed decreasing weight loss with increasing salt concentration. The least weight loss was obtained in the 1.5% CaCl₂, with 4.42 % in day 9 as compared to 0% CaCl₂ 8%. African eggplants showed less percentage weight loss at 1% CaCl₂, with 4.75 %. This was significantly lower ($P \leq 0.05$) than in fruits hydrocooled with water only. However, this was higher than the weight loss in the control fruits, indicating that hydrocooling on its own was not sufficient for the product. Increasing CaCl₂ 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 the hydrocooling. Similar findings were found in tamarillo fruits treated with various CaCl₂ concentration depths by Pinzón-Gómez *et al.*, (2014), where more weight loss was observed at higher calcium chloride concentrations.

4.4.2 Decay incidence/ Chilling injury/ Shrivelling and sprouting

The marketable portion of all produce declined with storage time in all treatments. The changes observed in quality deterioration were however specific to each produce in the study. Tomatoes became flaccid and some decayed and shrivelled as shown in Plate 4-2 below. Eggplants became scalded and skin shrivelled, with brown lesions developing near the seeds. Carrots wilted and re-sprouted at the base where leaves had been chopped off, with a few root hairs also developing. Courgettes developed pinched ends in some treatments, with clear discolouration

and softening of the product. The results of observable changes are as shown in Figure 4-3 and Figure 4-4 and pictorials as shown in Plate 4-2 below.






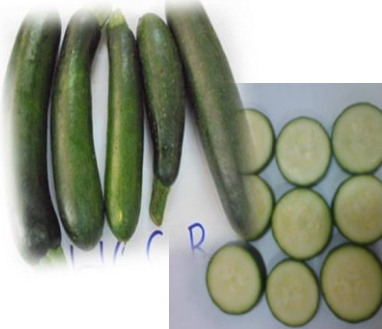



Produce	Initial appearance	Unmarketable characteristics
Tomato		
African Eggplant	 	
Courgettes		
Carrots		

Plate 4-2 : Pictures showing the unmarketable characteristics of produce

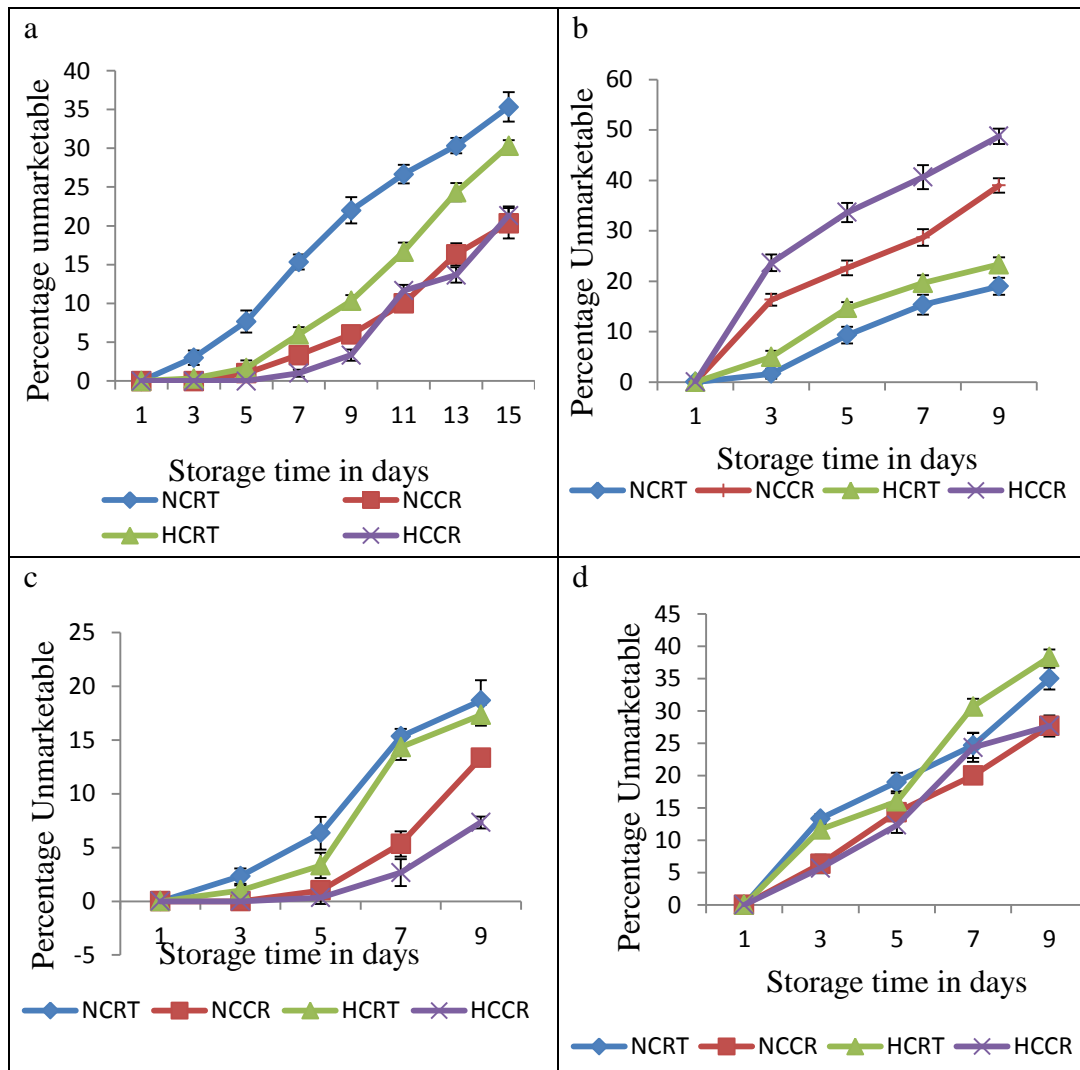


Figure 4-3: Decay incidence under different treatments

Where a, b, c and d are tomatoes, African eggplants, carrots and courgettes with unacceptability level due to decay or flaccidness and skin shrivelling, chilling injury, sprouting and shrivelling and decay respectively. NCRT, NCCR, HCRT and HCCR are not cooled and stored at ambient temperature, not cooled and stored at low temperature, Hydrocooled and stored at ambient temperature and Hydrocooled and stored at low temperature.

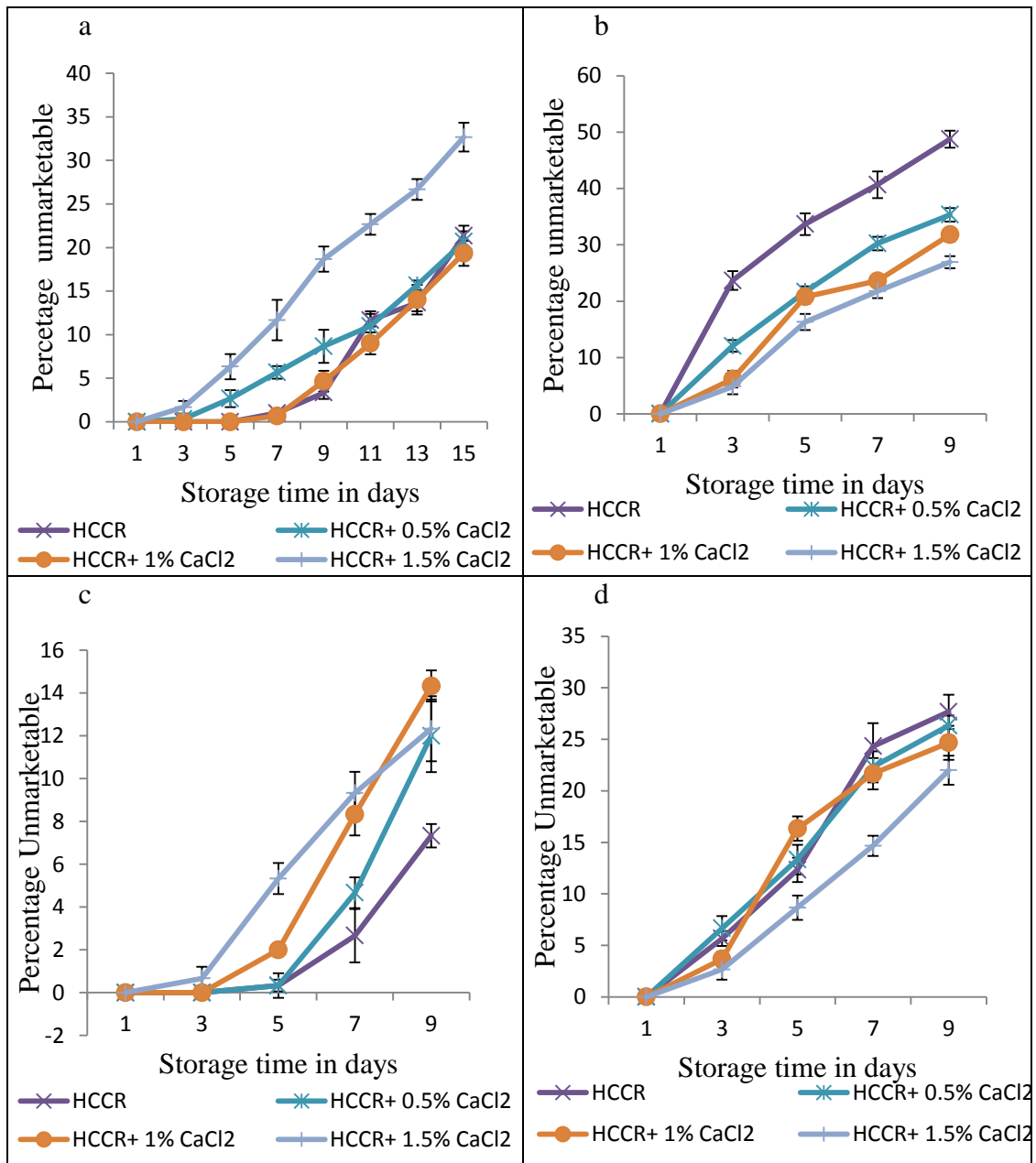


Figure 4-4: Percentage unmarketable produce with CaCl₂ treatment at various concentrations

Where a, b, c and d are tomatoes, African eggplants, carrots and courgettes with unacceptability level due to decay or flaccidness and skin shrivelling, chilling injury sprouting and shrivelling and decay and chilling injury respectively. HCCR is produce Hydrocooled and stored at low temperatures. 0.5%, 1.0% and 1.5% is concentration of calcium chloride added to the cooling water. The produce in these treatments were also stored at low temperature.

Deterioration in African eggplants was characterized by chilling injury portrayed in the produce, characterized by surface pitting, and development of brown colour around the seeds. Highest unmarketable fraction was observed in produce stored at low temperatures after hydrocooling throughout the storage period. This was significantly different ($P \leq 0.005$) from produce in the control treatment. According to Carvajal *et al.*, (2011) pitting on the produce surface maybe attributed to loss of cell membrane and cell wall integrity. These changes are related to low storage temperature resulting in quality loss.

The fact that the eggplants stored at 10°C lost more weight and showed higher incidence of chilling injury despite this being the recommended temperature (Shitanda, Oluoch, & Pascall, 2011), could be attributed to variations in growing conditions and cultivars Emongor (2015), or chilling injury tolerance is at higher temperatures (Mutari & Debbie, 2011). Kang *et al.* (2002) found that growing zucchini at an ambient temperature of $27 \pm 1^{\circ}\text{C}$, resulted in more chill sensitivity zucchini. These conditions are the typical ambient conditions in the cultivation of this crop.

The proportion of acceptable amount in carrots declined with storage time for all treatments, as shown in **Figure 4-3**. Carrots lost acceptable quality from day 5 under the control treatment due to shrinkage and development of shoots. Highest unmarketable fractions were observed in hydrocooled samples kept at room temperature, with only 62 % being marketable by day 9. Under this treatment, the common phenomenon was sprouting of roots and leaves. In the control, shriveling was more predominant leading to only 77.2% acceptability by day 9. These findings are similar to Negi and Roy (2000) where carrots stored at ambient conditions lost became commercially unacceptable.

Application of 1% CaCl_2 during hydrocooling resulted in the least decay incidence in tomatoes, shown in Figure 4-4, however, this was not significantly different ($P \leq 0.001$) from produce in HCCR and NCCR by the end of the storage period. Similar findings were observed by Chen *et al.* (2011) in strawberry fruits where decay rate was slightly slowed by the 1% CaCl_2 treatment during the first 10 days of storage.

This can be attributed to the protection of calcium against fungal contamination by reinforcing fruit tissues (Lara *et al.*, 2004).

Higher concentration of CaCl₂ i.e. 1.5% resulted to more deterioration in tomatoes possibly due to phytotoxicity. Phytotoxicity could lead to cell wall disintegration and substrate delocalization (Manganaris *et al.*, 2007b), thus produce become more susceptible to deterioration and thus unmarketable.

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 (Manganaris *et al.*, 2007b). Application of Calcium Chloride delayed the onset of deterioration in all produce, although the products responded optimally to different concentrations. As shown in Figure 4-4above, 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.

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. The interaction results in maintenance of the cell integrity, Akhtar *et al.*, (2010) for a longer 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).

4.4.3 Colour

Hue describes a visual sensation according to which an area appears to one or two proportions of the perceived colours, red, yellow, green and blue (Yumbya *et al.*, 2014). Hue angle is therefore the actual colour. Chroma (C) is the intensity of fundamental colour with respect to amount of white light on the background. L* value is therefore an indication of lightness (Kassim *et al.*, 2013).

According to Muir *et al.*, (2009) duration and temperature of storage are two important factors responsible for the loss of pigments and colour, and special care

must be taken to produce food that retains its bright attractive colour during subsequent marketing and consumption.

The change was significantly ($P \leq 0.005$) fast in fruits kept at ambient temperatures, attaining a deep red colour within 7 days in tomatoes. Those in the low temperatures storage took another 7 days to attain the same hue angle of about 40° . Similar findings were also found by Mutari and Debbie (2011) in tomatoes, where tomatoes stored at 20°C attained ripening faster than those kept at 13°C , 10°C or 5°C . Tomato fruit colour is usually a function of lycopene and carotene concentration, growing conditions, genotype and ripeness (Radzevičius *et al.*, 2012). According to Camelo and Gómez (2004) colour development in tomatoes is temperature sensitive, with lower temperatures slowing down degradation of chlorophyll, thus slower accumulation of lycopene and other carotenoids. This corresponds to a slow increase in a^* values which typically increases during ripening of tomatoes (Pinheiro *et al.*, 2014).

As shown in Figure 4-5 precooling resulted in brighter produce during storage for all produce except the African Eggplant. However, precooling with CaCl_2 in water showed higher L^* values in all produce. Values for a^* and b^* were also significantly different ($P \leq 0.05$) in control, hydrocooled with tap water and chlorinated water produce.

L^* values in carrots was highest on day 1 with a score of between 58 and 55, which declined to between 53 and 51. The decline in tomatoes ranged between 3% and 12% for L^* values.

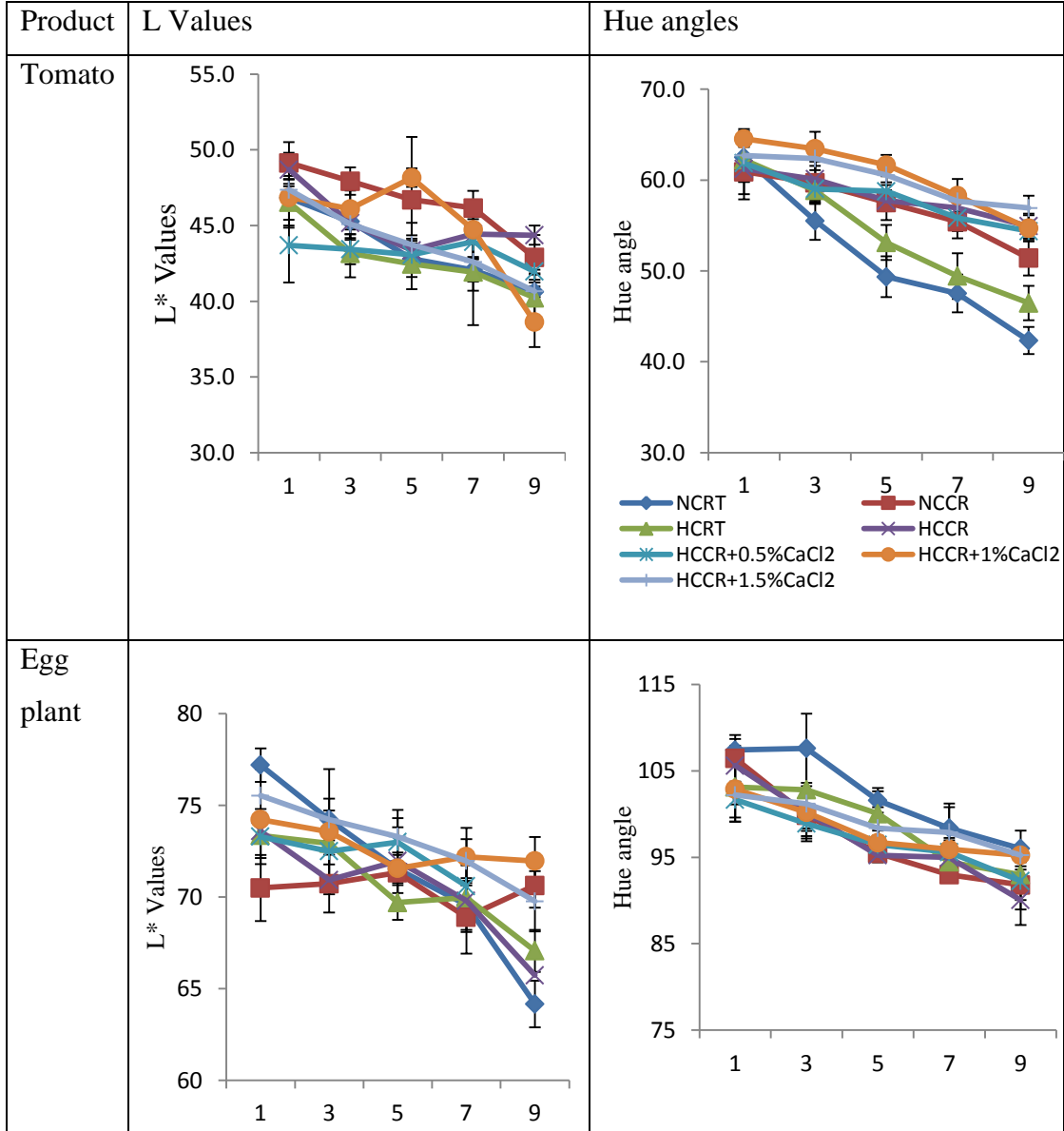
Hue angles in the produce also declined over the storage time. Hue angles in tomatoes declined by 15.2%, 12.33 %, 10.2% and 14.4% for 0%, 0.5%, 1.0% and 1.5% CaCl_2 respectively in tomatoes by the end of the 9 day study period.

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 decline 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

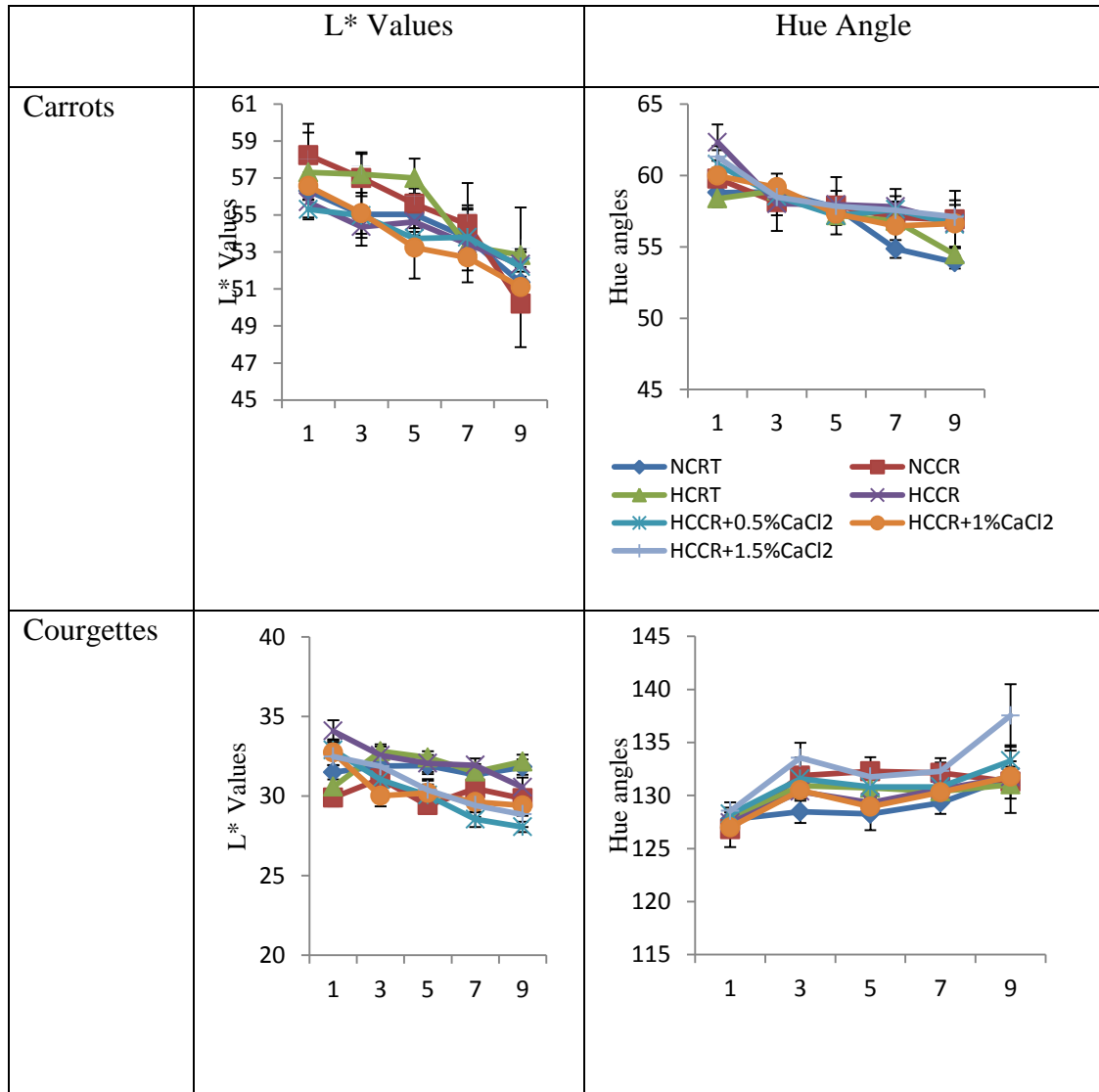
between 14.7% and 6.8% for 0% and 1% CaCl₂ respectively. These were significantly different ($P \leq 0.05$).

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% CaCl₂ respectively. Courgettes have been observed to develop brown lesions and pitting on the surface in case of chilling injury which would bring about colour change in the produce (Ait-Oubahou, 1999). 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% CaCl₂ 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 % CaCl₂ 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 reduced colour change in tomatoes.



***Horizontal axis represents storage time in days**



***Horizontal axis represents storage time in days**

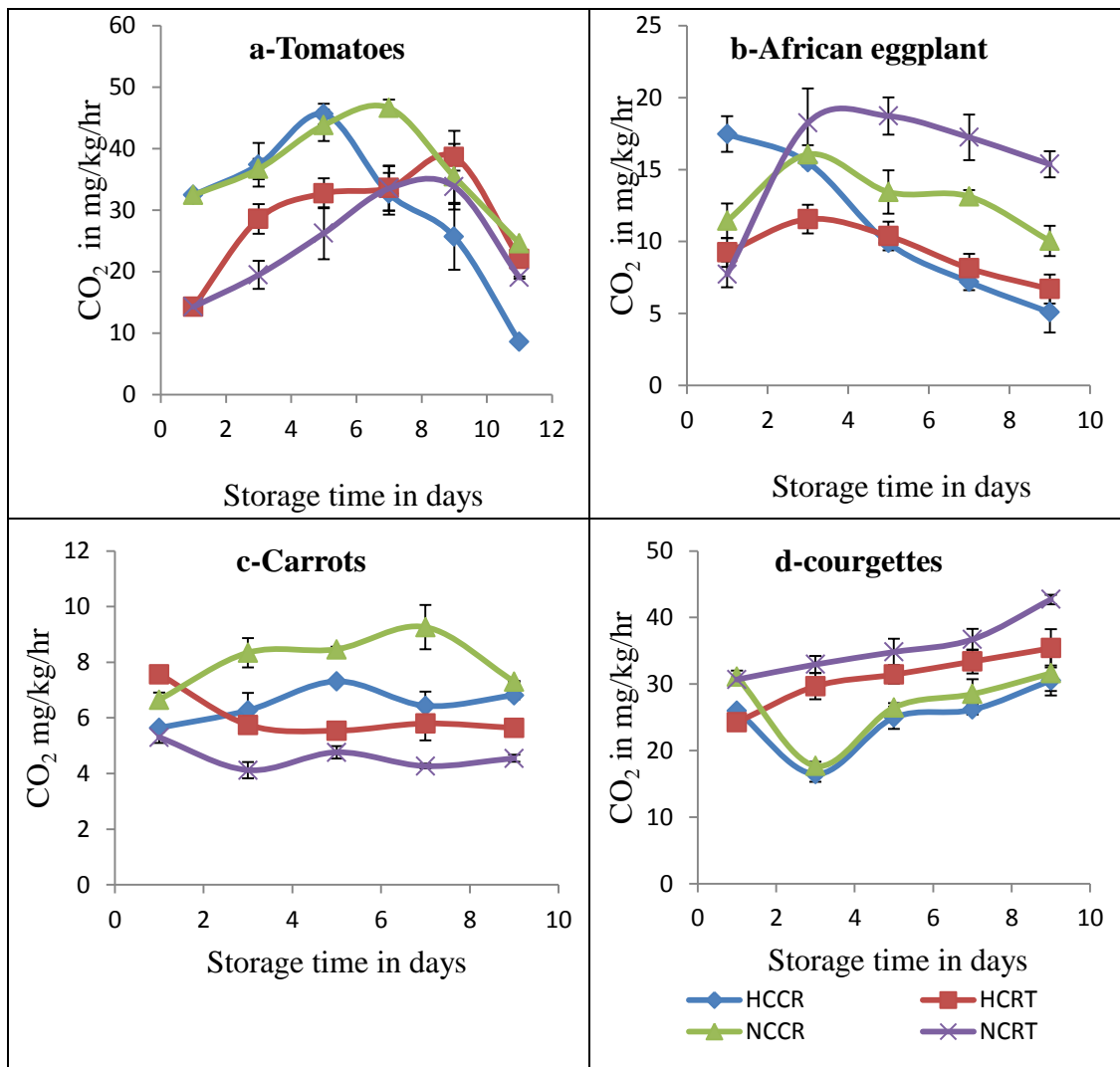
Figure 4-5: Colour changes due to precooling and storage at different temperatures

NCRT, NCCR HCRT and HCCR are not cooled and stored at ambient temperature, not cooled and stored at low temperature, Hydrocooled and stored at ambient temperature and Hydrocooled and stored at low temperature. 0.5%, 1.0% and 1.5% is concentration of calcium chloride added to the cooling water. The produce in these treatments were also stored at low temperature.

4.5 Physiological measurement

4.5.1 Respiration rates

Respiration was highly influenced by precooling and storage temperatures as shown in Figure 4-6. Generally, produce hydrocooled and stored at lower temperatures exhibited lower respiration rates throughout the storage period.



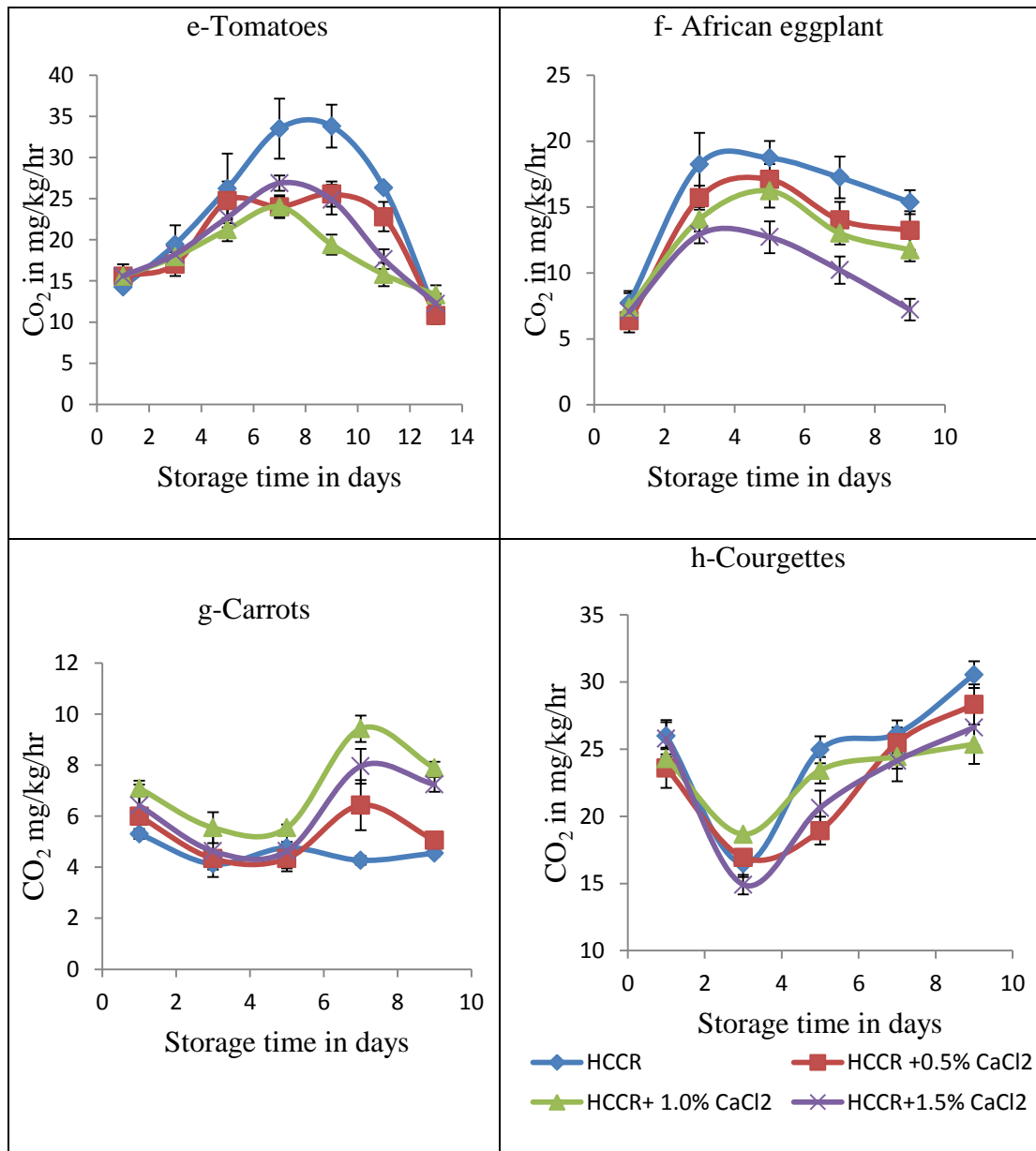


Figure 4-6: Respiration rates in produce over storage time.

Graphs (a,e) , (b, f,) (c ,g) and (d ,h) represent tomatoes, African eggplant, carrots and courgettes respiratory behaviours under various treatments respectively. NCRT, NCCR HCRT and HCCR are not cooled and stored at ambient temperature, not cooled and stored at low temperature, Hydrocooled and stored at ambient temperature and Hydrocooled and stored at low temperature. 0.5%, 1.0% and 1.5% is concentration of calcium chloride added to the cooling water. The produce in these treatments were also stored at low temperature.

* Vertical bars represent standard errors and n=3

Respiration rates were significantly different ($P \leq 0.05$) between the storage temperatures in all the produce studied. The tomatoes attained maximum climacteric respiration on different days based on the storage temperature and precooling treatment. The HC tomato fruits in CR and RT storage reached their maximums on day 9 and 7 respectively. This was significantly different ($P \leq 0.05$) from the controls which reached the maximum peaks on 9 and 5 respectively. The other crops, which exhibited non climacteric behaviour i.e. carrots and courgettes showed lower respiration rates with lower storage temperatures. CR eggplants were however an exception in this study. It showed highest respiration throughout the storage period for both the precooled and the control stored at low temperature. This may be attributed to the chilling injury symptoms observed in the fruits in this storage condition.

Progressive increase in respiration during storage is a common phenomenon in agricultural produce as a result of ripening related processes in climacteric fruits (Youssef *et al.*, 2012; Luengwilai and Beckles, 2013) and spoilage development in non-climacteric fruits (Stephen & James, 2010).

Respiration is slowed down by low temperature storage in most commodities. However, in chill sensitive produce, lower temperatures sufficient to cause chill injury will increase the respiration rates in them (Luengwilai & Beckles, 2013). In the tomato fruits, respiration increased progressively throughout storage, reaching climacteric peaks on different days based on treatments. NCRT tomatoes reached the maximum peak earliest on Day 5 while the produce in NCCR and HCCR attained climacteric maximum on Day 11. Respiration rates however declined in the fruits kept in the cold room after the 11th day. The decline occurring after the climacteric peak is a result of senescence beginning to set in. The results were similar to those obtained by (Mutari and Debbie, 2011; Khanal and Uprety, 2014), where produce kept at low temperatures showed lower respiration rates than those kept at higher temperatures. Lower respiration rates according to Batchmann and Earles, (2000) and Youssef *et al.*, (2012) are desirable in perishable produce because respiration rate determines the postharvest life and quality.

Respiration rates in the 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 4-6. Addition of Calcium chloride to the hydrocooling water significantly reduced respiration rates ($P \leq 0.05$) only at optimum concentrations which was specific to the produce.

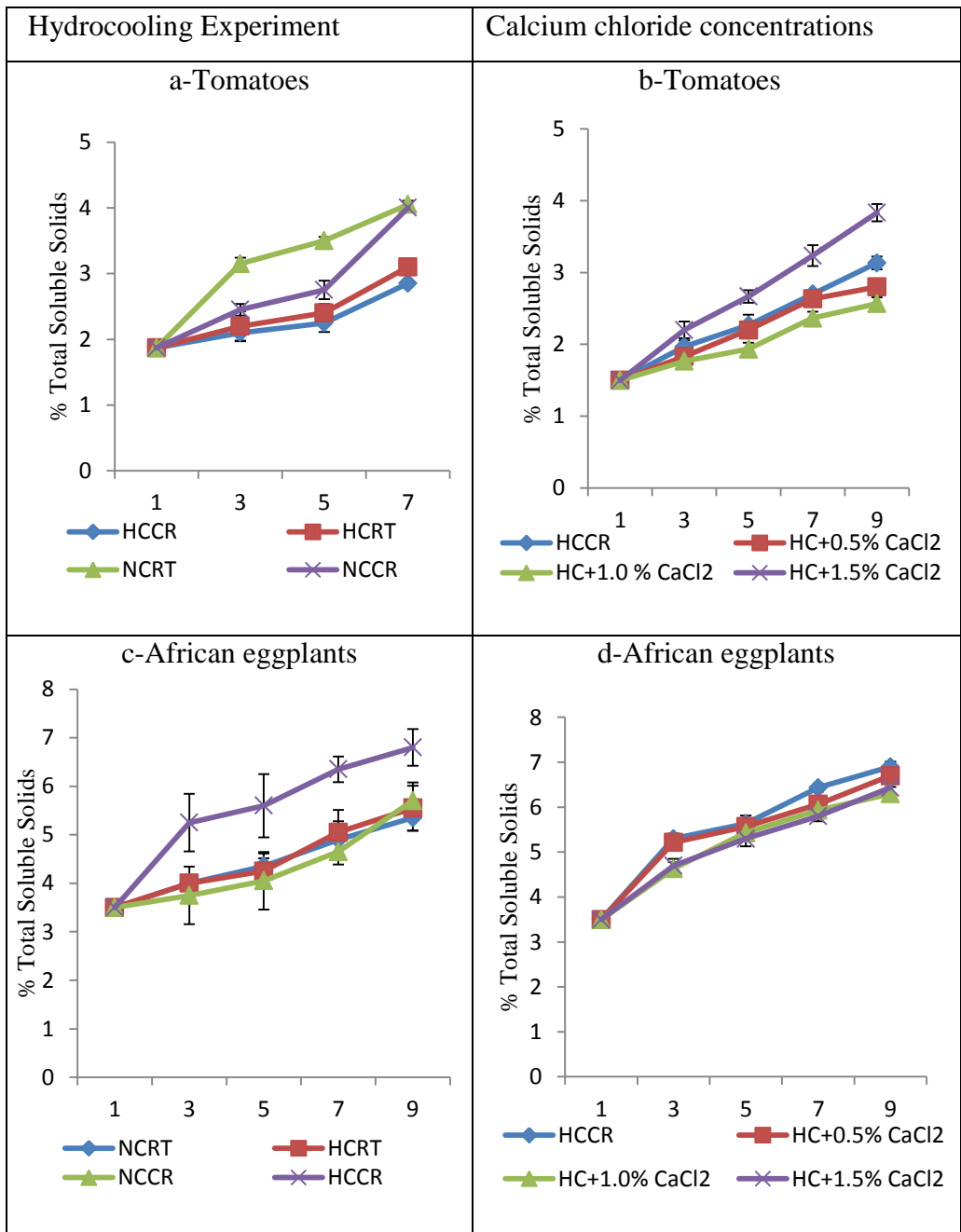
Tomatoes treated with 1% CaCl_2 showed the least rates of respiration, throughout the storage period. In courgettes and African eggplants, the least respiration rates were observed in 1.5% CaCl_2 . Although this was lower in eggplants than those hydrocooled and stored at 10°C , it was still higher than the respiration rates observed in the control eggplants. In carrots, addition of Calcium Chloride resulted in increased respiration rates 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).

4.6 Chemical measurements

4.6.1 Total soluble solids

The percentage soluble solids content in the produce increased throughout the storage period in all produce regardless of the treatments. A significant interaction was observed between the storage time and temperature ($P \leq 0.05$) for all produce. The results of the treatment and storage time and temperature interaction for these produce are as shown below in Figure 4-7 below.



Storage time in days

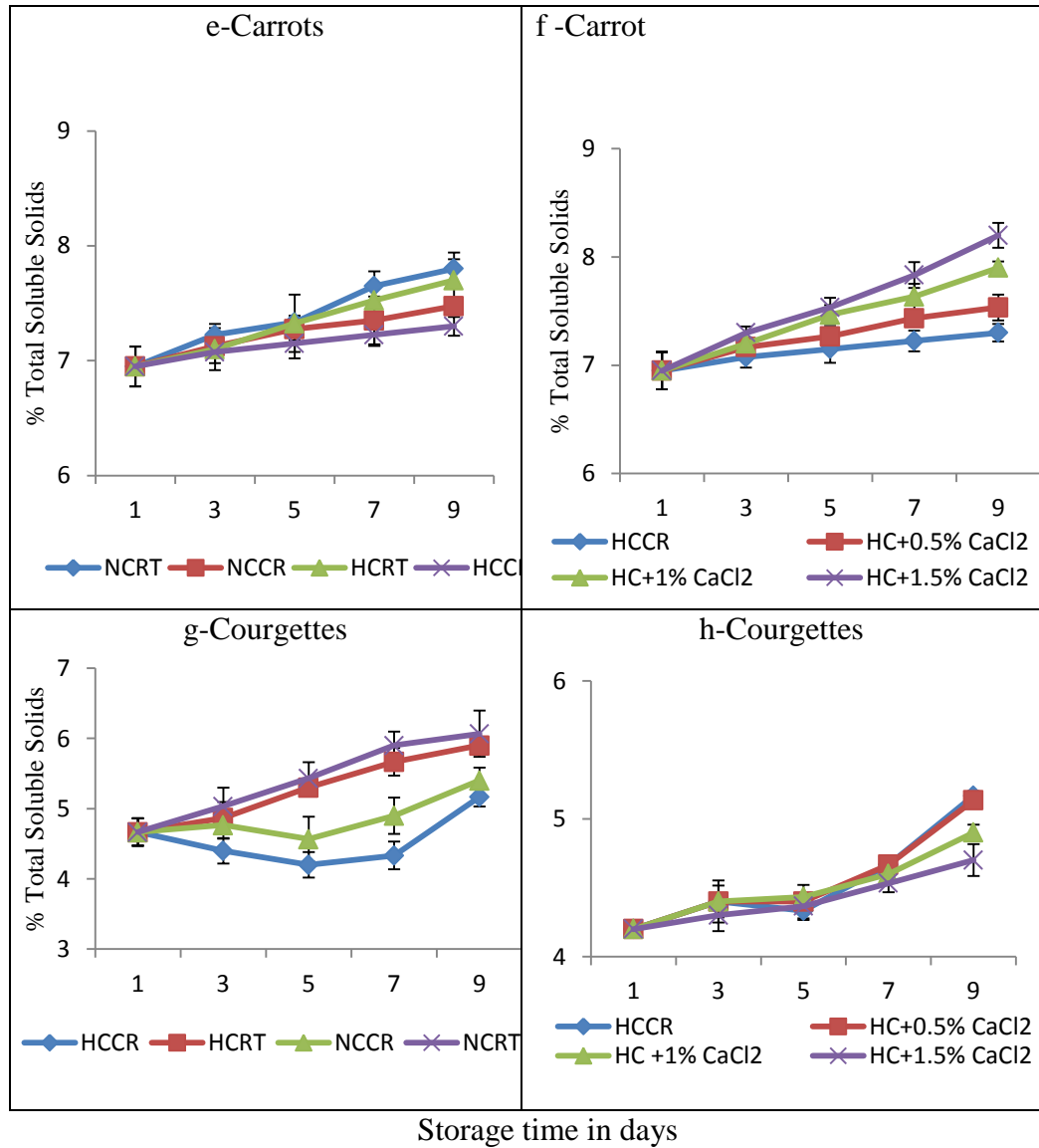


Figure 4-7 % TSS content due to precooling, storage temperature and time

Graphs a and b, c and d, e and f, g and h are tomatoes, African eggplant, carrots and courgettes respectively, with TSS build-up during storage under various treatments. NCRT, NCCR HCRT and HCCR are not cooled and stored at ambient temperature, not cooled and stored at low temperature, Hydrocooled and stored at ambient temperature and Hydrocooled and stored at low temperature. 0.5%, 1.0% and 1.5% is concentration of calcium chloride added to the cooling water. The produce in these treatments were also stored at low temperature.

* Vertical bars represent standard errors and n=3

Hydrocooling 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 compared to the other treatments. This may be attributed to the chilling injuries observed in fruits in this treatment.

On day 9, TSS in courgettes in HCCR had increased from 4.67% to 5.17% compared to the NCRT which increased to 6.07% which was significantly different ($P \leq 0.05$). 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.

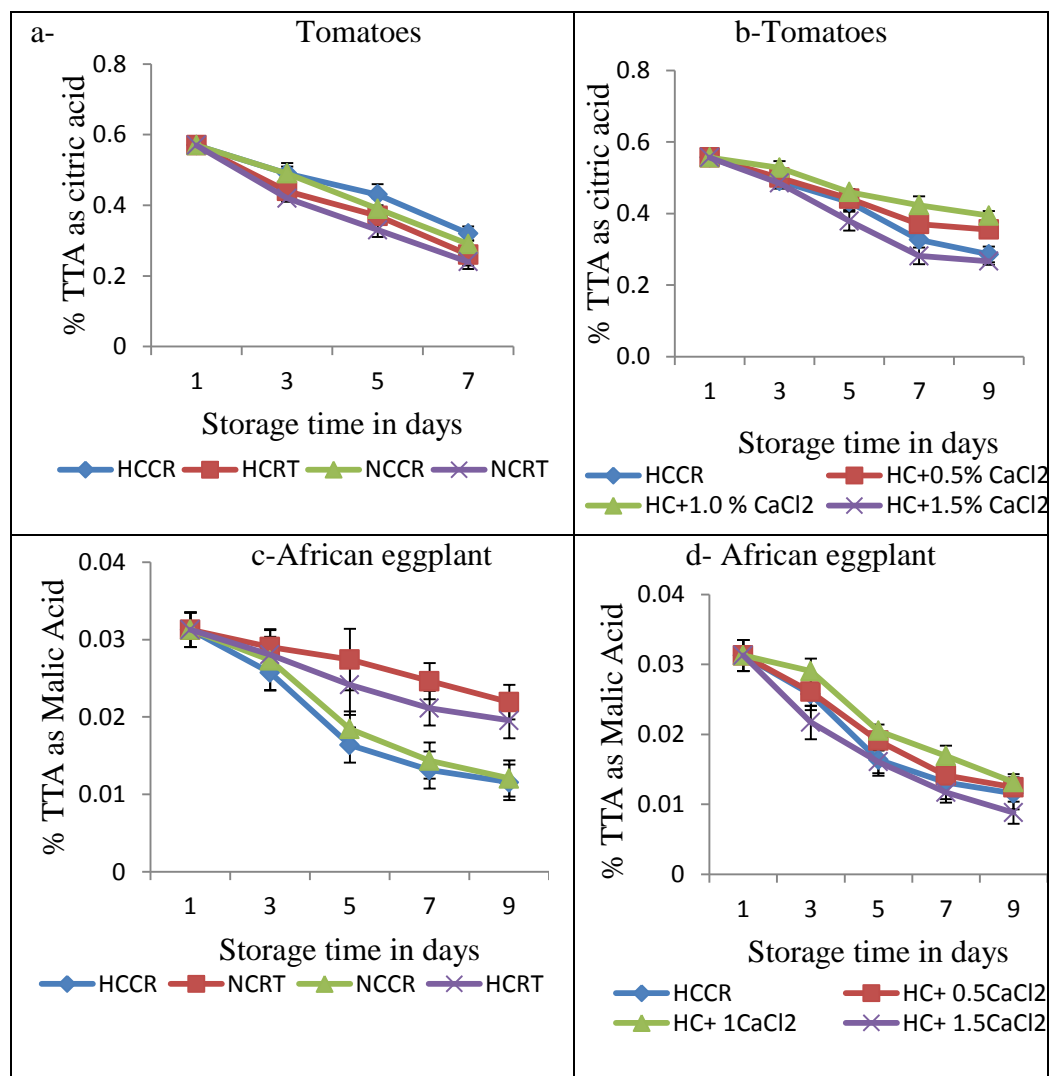
Addition of CaCl_2 to the hydrocooling water and storage at low temperature further slowed the increase in TSS. By the end of the storage period, TSS in CaCl_2 treated samples was lower than the control (water only) in tomatoes, courgettes and eggplants. In tomatoes, the least TSS of 2.6% was recorded in HCCR +1.0% CaCl_2 . At 1.0% CaCl_2 , better postharvest life was attained in tomatoes. Courgettes and African eggplants had the least TSS under HCCR +1.5% CaCl_2 treatment. Carrots however showed no response to the CaCl_2 treatments. Although the TSS was lower in eggplants at HCCR +1.5% CaCl_2 , it was still higher than in control fruits, indicating that hydrocooling even with CaCl_2 at the studied concentrations yielded no positive results in preventing chilling injury.

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 tomatoes (Azene *et al.* (2014); Youssef *et al.* (2012); (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 attributed 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 °C for eight hours and stored at 8 °C. In the carrots, courgettes and African eggplants which do not ripen off the plant, TSS build-up during storage is maybe attributed to moisture loss, where solutes present in the cells become more concentrated. It also

correlates positively with the produce weight loss. A positive relationship 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 (Hernańdez-Munñoz *et al.*, 2008).

4.6.2 Titratable Acidity

The titratable acidity declined throughout the storage period, in all produce for all treatments as shown in Figure 4-8 below. Titratable acidity is expressed in the most dominant acid in the specific produce.



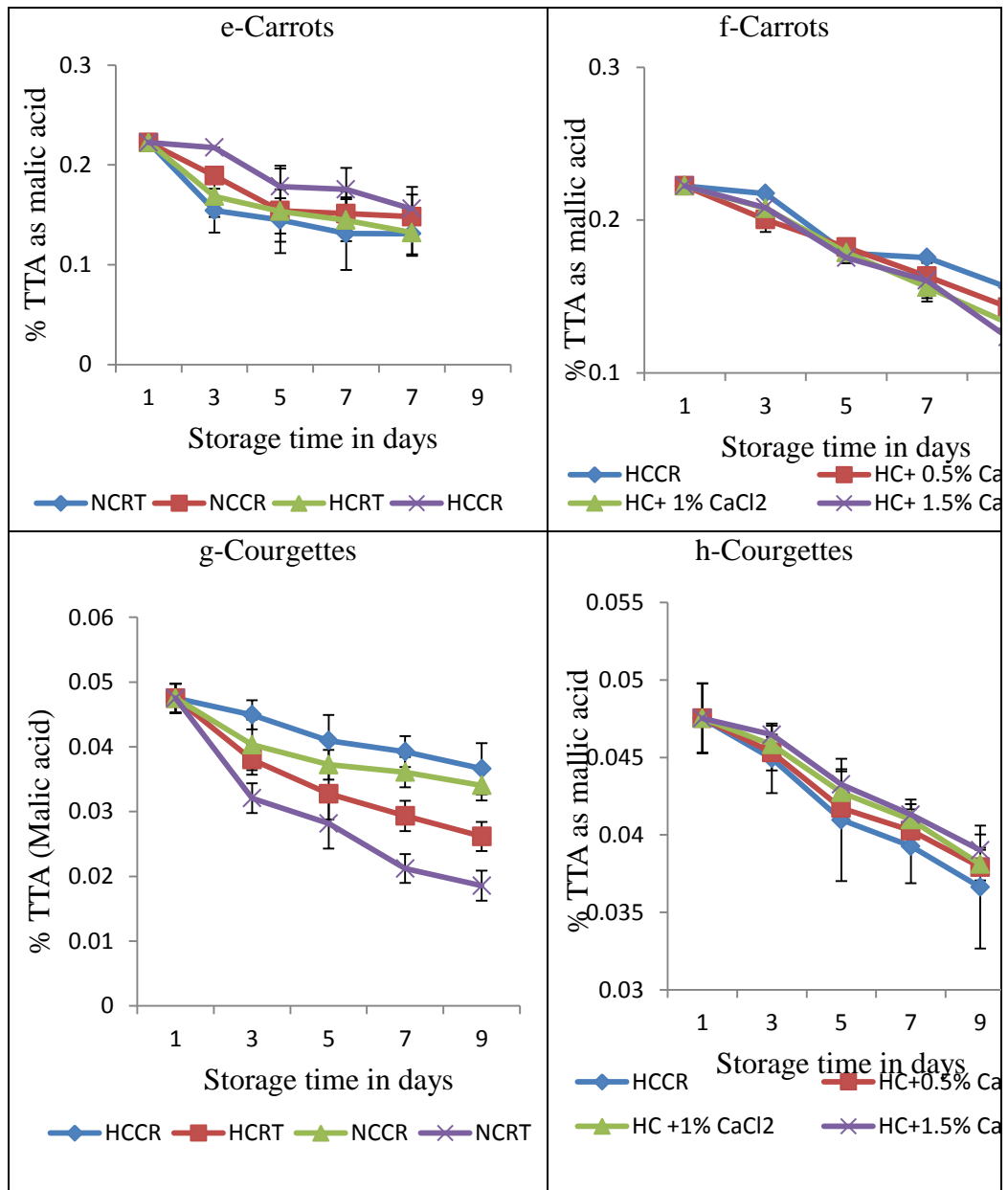


Figure 4-8 Titratable Acidity change of produce due to treatments during storage

* Vertical bars represent standard errors and n=3

Graphs a and b, c and d, e and f, g and h are tomatoes, African eggplant, carrots and courgettes respectively, with Titratable acidity decline during storage under various treatments. NCRT, NCCR, HCRT and HCCR are not cooled and stored at ambient temperature, not cooled and stored at low temperature, Hydrocooled and stored at ambient temperature and Hydrocooled and stored at low temperature. 0.5%, 1.0% and 1.5% is concentration of calcium chloride added to the cooling water. The produce in these treatments were also stored at low temperature.

Faster decline in acidity was however observed in control stored at room temperature (NCRT) reaching 0.13% from 0.22% on day 9 in carrots. The produce that were hydrocooled and stored at low temperature (HCCR) showed a gradual 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. There was a typical acidity reduction over storage time in tomatoes, associated with ripening. This findings were similar to the results obtained by Shahi *et al.* (2012) ; Tigist and Workneh (2013) where fully ripe tomatoes had TTA of 0.31% and 0.334 %. Similar findings have been reported by Senevirathna and Daundasekera (2010) and mangoes Rathore *et al.* (2007) or due respiratory activities which utilize organic acids present as substrates (Mahajan & Dhatt, 2004).

The African eggplant 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 metabolic processes. Decline in acidity is attributed to ripening , since showed that the amount of organic declined as they are a substrate of respiration in tomatoes (Žnidarčič and Požrl 2006).

Addition of calcium chloride to the hydrocooling water yielded similar results as in TSS, where least decline in TTA occurred in tomatoes at 1%. Courgettes and eggplants showed least at 1.5% while carrots lost more acidity at 1.5%.

4.6.3 Beta carotene

Beta carotene content in the vegetables under study was significantly affected by the length of time in storage and the temperature. The effects of the various treatments on beta carotene are as shown in Figure 4-9 below.

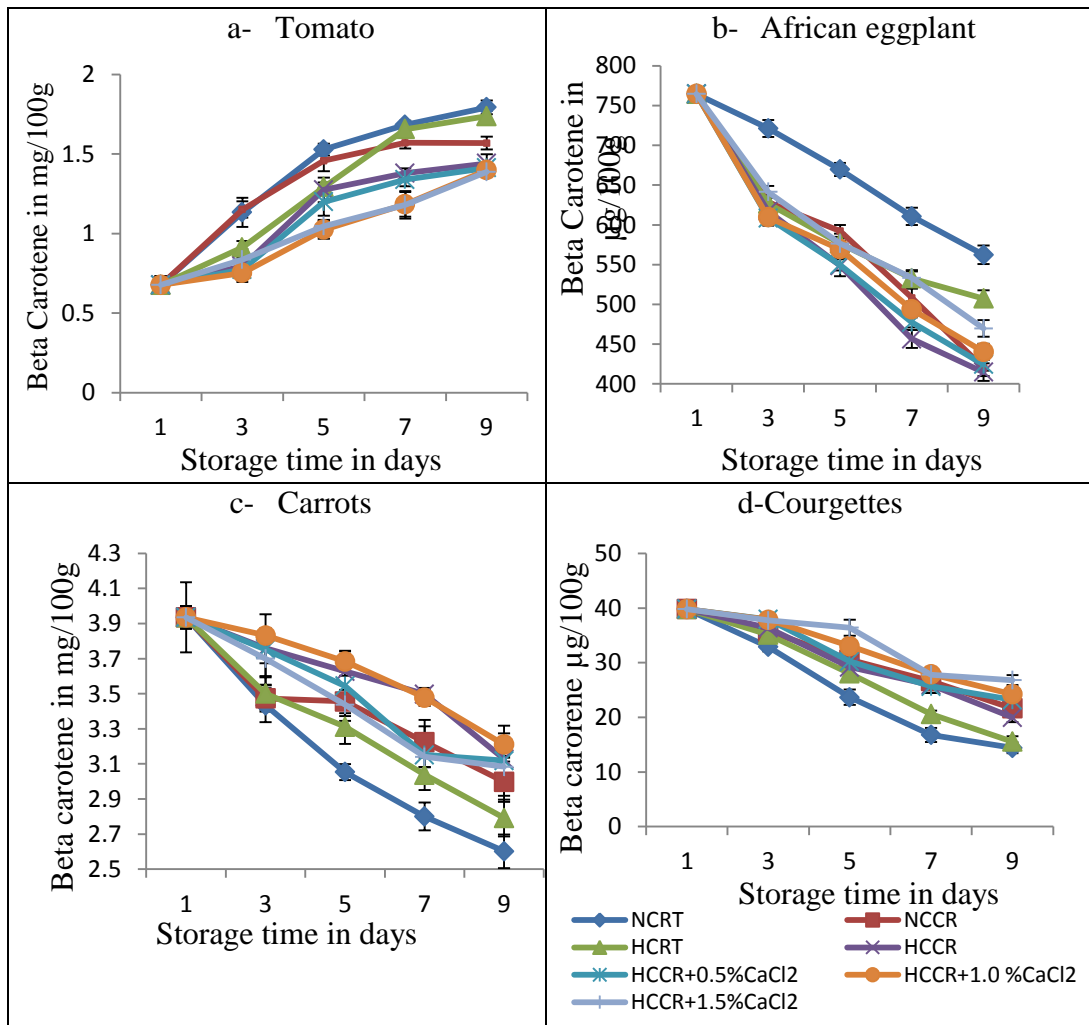


Figure 4-9 Beta carotene content in produce during storage

Graphs a, b, c and d, are tomatoes, African eggplant, carrots and courgettes respectively, with change in beta-carotene in the produce during storage under various treatments. NCRT, NCCR HCRT and HCCR are not cooled and stored at ambient temperature, not cooled and stored at low temperature, Hydrocooled and stored at ambient temperature and Hydrocooled and stored at low temperature. 0.5%, 1.0% and 1.5% is concentration of calcium chloride added to the cooling water. The produce in these treatments were also stored at low temperature.

* Vertical bars represent standard errors and n=3

Beta carotene content in tomatoes increased during storage for all treatments applied as shown in Figure 4-9. The initial beta carotene content in tomato was, 0.67 mg/100g. During storage, the beta carotene increased to 1.79 mg/100g, on the 9th day in the control tomato fruits the highest amount in this study. This was

significantly different ($P \leq 0.05$) from the produce kept at lower temperature for all other treatments. In tomato fruits kept at low temperatures, the HCCR fruits had 1.44 mg/100 g while and the lowest concentration was found in HCCR+1% CaCl_2 which had 1.39 mg/100 g which were not statistically different ($P \leq 0.05$). Similar findings were observed by Radzevičius *et al.* (2012) and Abdul-Hammed *et al.*, (2014) with β carotene content ranging from 1.40 mg/100 g to 1.69 mg/100 g in fully ripe tomatoes. The increase was however affected by the storage temperature with produce kept at 10^0 C showing the least beta carotene content in day 9. Similar findings were found by Yumbya *et al.* (2014) where beta carotene content increased with ripening in passion fruits. The increase in the beta carotene is associated with chlorophyll degradation and carotenoids synthesis processes, where chloroplasts are synthesized to chromoplasts (Radzevičius *et al.*, 2012).

In carrots, courgettes and African eggplants, Beta carotene content decreased gradually during storage for all treatments as shown in the Figure 4-9. β -carotene in carrots declined from 3.93 mg/100g to 2.6 mg/100g in the control in day 9. Conversely, samples in low temperature storage attained a minimum of 2.9 mg/100g, 3.13, mg/100g, 3.12 mg/100g, 3.21 mg/100g and 3.08 for NCCR, HCCR, HCCR+0.5% CaCl_2 HCCR+1.0% CaCl_2 HCCR+1.5% CaCl_2 respectively.

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 were similar to those of Ilic *et al.* (2013) that the loss of beta carotene in carrots is significantly affected by the storage temperatures. Their findings indicated that higher loss of β -carotene during carrot storage occurred in the cellar with temperature of $25^0\text{C} - 30^0\text{C}$ than in cold storage.

Higher storage temperature resulted in higher decline in beta carotene content. Control carrots and courgettes kept at ambient temperatures lost more beta carotene. Negi and Roy (2000) also found that higher storage temperatures and longer storage time resulted in higher loss of beta carotene content accompanied by progression of senescence (Msogoya *et al.*, 2014). This losses could be due to the non-oxidative

changes and isomerization of the carotenoids during storage as a result of metabolic processes in the produce (Dutta *et al.*, 2005).

4.6.4 Vitamin C

Figure 4-10 shows the effect of various treatments and storage temperature on the vitamin C in tomatoes, African eggplants, carrots and courgettes.

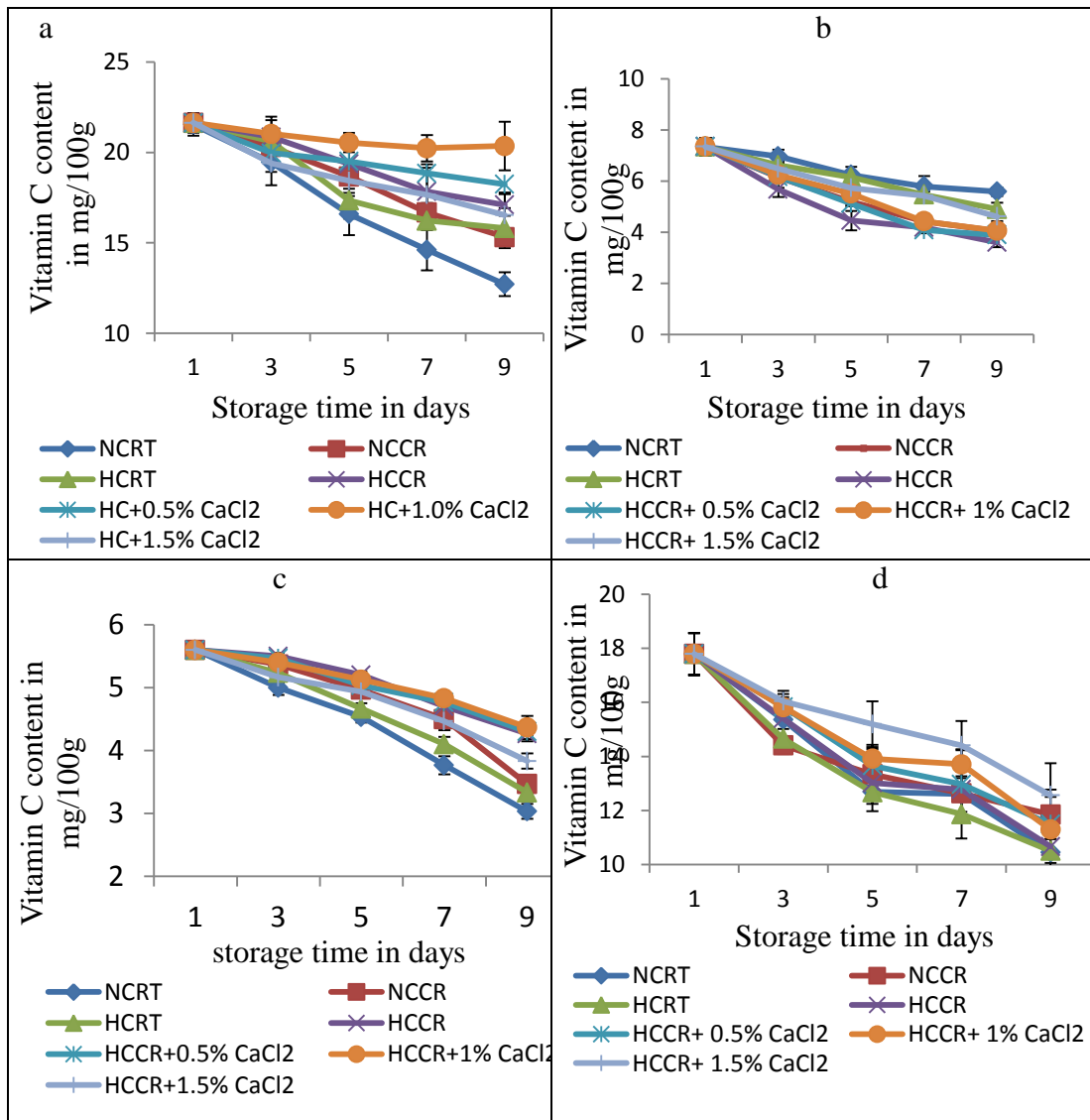


Figure 4-10 Vitamin C content in mg/100g

Graphs a, b, c and d, are tomatoes, African eggplant, carrots and courgettes respectively, with NCRT, NCCR HCRT and HCCR are not cooled and stored at ambient temperature, not cooled and stored at low temperature, Hydrocooled and stored at ambient temperature and Hydrocooled and stored at low temperature.

0.5%, 1.0% and 1.5% is concentration of calcium chloride added to the cooling water. The produce in these treatments were also stored at low temperature.

* Vertical bars represent standard errors and n=3

Vitamin C content declined in all the produce studied for all treatments as storage progressed, with higher declines occurring at higher temperatures (20-25 °C) in tomatoes, carrots and courgettes. Carrots for example had 5.6 mg/100 g ascorbic acid at the start of the experiment. This declined to 3.03 mg/100 g on the 9th day in the control fruits stored at ambient conditions. The Vitamin C content in courgettes also declined from 17.8 mg/100 g to 10.05 mg/100 g in the 9th day in the control fruits at ambient temperatures.

The ascorbic acid quantity in all the produce was significantly affected by storage time, temperature and precooling treatment. Vitamin C retention was highest in carrots hydrocooled with 1.0 % calcium chloride declining 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 and water with 0.5% calcium chloride, both kept at 7°C.

In tomatoes, the Vitamin C content declined from 21.63 mg/100g at the start of the experiment, reaching the lowest of 12.71mg/100g in control fruits by the 9th day. Similar findings were observed by (Moneruzzaman *et al.*, 2008) in tomatoes, where decline was observed during ripening of tomatoes.

Decline in the ascorbic acid content was significantly affected negatively by storage temperature and time. Similar findings were observed by Ilic *et al.*, (2013); Workneh *et al.*, (2011) in carrots and Safdar *et al.*, (2010) in tomato stored at various temperature profiles.

Eggplants had an initial vitamin C content of 7.3 mg/100 g which declined in control experiment to 5.6 mg/100g by day nine. In HCCR, by 9th day, Vitamin C was 3.6 mg/100g. Although this was lower than the findings of Eze and Kanu (2014), who reported vitamin C content of 14mg/100g, Msogoya *et al.*, (2014) observed similar trends for fruits stored at ambient temperatures, 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. The stage 2 in African eggplants closely corresponds to the turning stage of fruits used in this study.

These decline in vitamin C has been observed in other vegetables such as broccoli Carvalho & Clemente, (2004), caspicum 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 and Požrl (2006) or temperature degradation (Iwuagwu *et al.*, 2013). When the produce was stored at their lowest safe temperatures (10 °C or 7 °C), there was little loss of Vitamin C, which collaborates the findings of (Ilic *et al.*, 2013 ; Lee and Kader 2000) .

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 decline in ascorbic acid content was however significantly high at 1.5% CaCl₂ concentration compared to HCCR, 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 (Manganaris, Vasilakakis, *et al.*, 2007).

4.6.5 Specific Sugars

The specific sugar composition in the produce changed throughout the storage period for all treatments as shown below in Figure 4-12. Fructose and glucose accumulated during storage for all produce, while sucrose declined.

At the start of the experiment, tomatoes had initial sugar content of 0.55 mg/100g, 0.38 mg/100g and 0.80 mg/100g for glucose, fructose and sucrose respectively. At the end of the study period, glucose and fructose had increased under the control treatment to 1.49 mg/100g and 1.58 mg/100g, while sucrose declined to 0.40 mg/100g. The values obtained under control treatment were significantly different ($P \leq 0.05$) from those of produce of in HCCR for all sugars studied. These findings were similar to those of Yilmaz (2001) in tomatoes. The changes in sugar content

can be attributed to ripening in tomatoes, which results in breakdown of polysaccharides to simple sugars (Sood *et al.*, 2011).

African eggplants, courgettes and carrots followed similar trends of increase in glucose and fructose, while sucrose decreased during storage time. However, in African eggplants, highest increase was observed in fruits placed in HCCR treatment. The initial glucose, fructose and sucrose content in African eggplant were 0.14 mg/100g, 0.18 mg/100g and 0.13 mg/100g respectively. This rose to 0.41 mg/100g and 0.47 mg/100g in glucose and fructose, while sucrose declined to 0.04 mg/100g in day 9. These values were significantly different ($P \leq 0.05$) from the controls with 0.26 mg/100g, 0.35 mg/100g and 0.04 mg/100g respectively on the same day. Similar findings were observed by Jose *et al.* (2013) in eggplants and Palma *et al.* (2014) in zucchini. These changes in sugar composition could be due to chilling injury portrayed by the product. Chilling injury has been observed to cause an upsurge in respiratory rates, which in turn leads to more soluble solids and thus sugar in produce in courgettes (Beckles, 2012). Increase in sugar concentration in produce may as well be attributed to loss of water, characterized by weight losses which followed similar trends Muir *et al.* (2009); Palma *et al.* (2014), portraying an increase in soluble carbohydrates. This may be the case as there was a positive correlation between weight loss and the soluble solids content in all produce studied.

With 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 sucrose 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 HCCR treatment and 1.5% CaCl_2 . This implies that respiration was kept at minimum at 1.0 % CaCl_2 , resulting in minimum build up sugars in the produce. The positive correlation observed between respiration rates, weight loss and soluble solid contents similar to the findings of Irfan *et al.* (2013) in fig fruits for each concentration shows CaCl_2 can be used in maintenance of postharvest quality.

Similar trends of change in specific sugar composition were observed for African eggplant, courgettes and carrots with least change at 1.5% CaCl₂ in courgettes and African eggplants, significantly different ($P \leq 0.05$) from control while carrots responded best to 0% CaCl₂. Similar correlations weight loss and specific sugar composition have been observed in strawberries by Chen *et al.* (2011) with CaCl₂ concentrations. The higher specific sugar change in produce at higher CaCl₂ to existence of phytotoxicity (Pinzón-Gómez *et al.*, 2014).

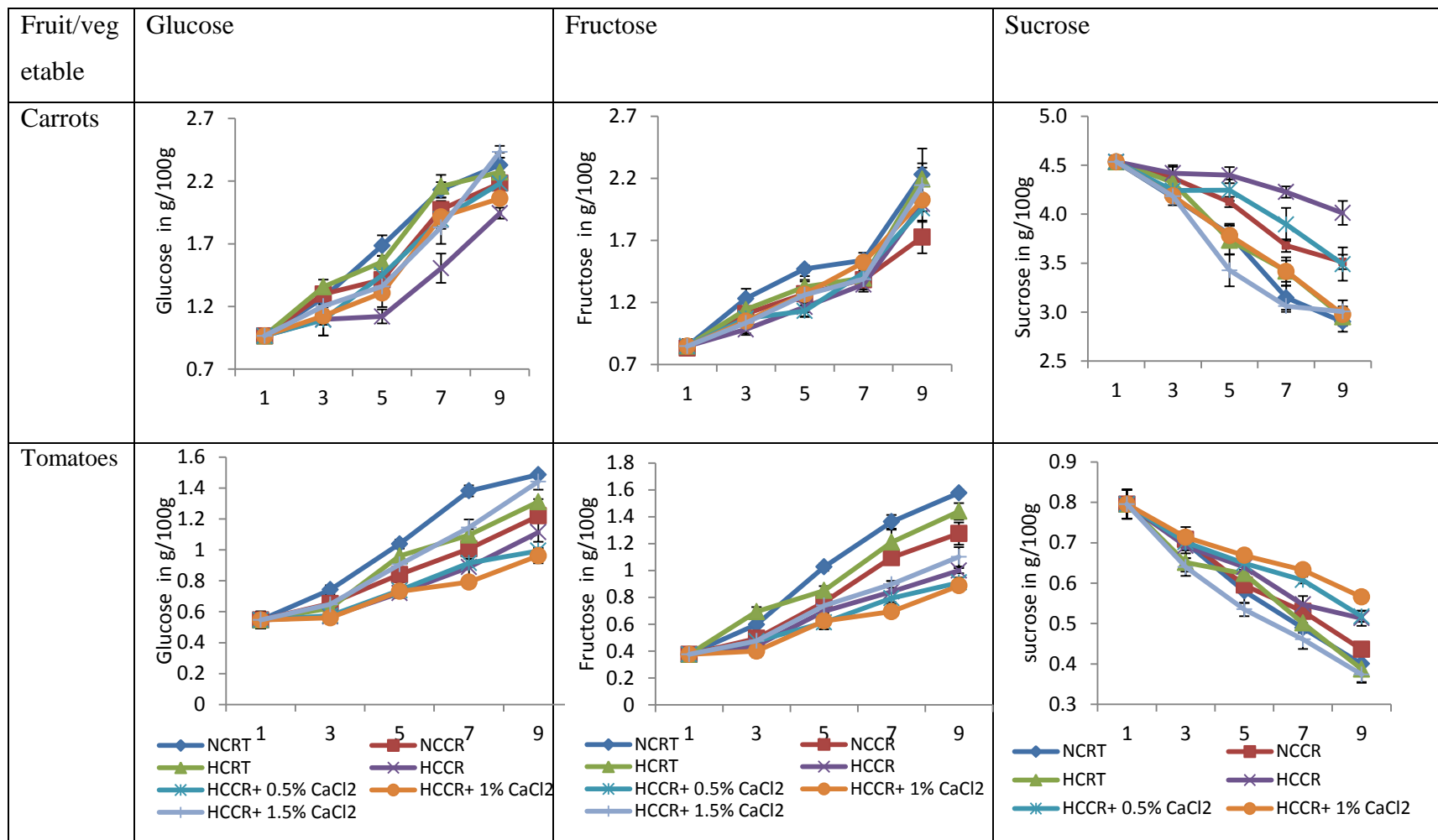


Figure 4-11: Specific sugar change in produce during storage *Horizontal Axis is storage time in days

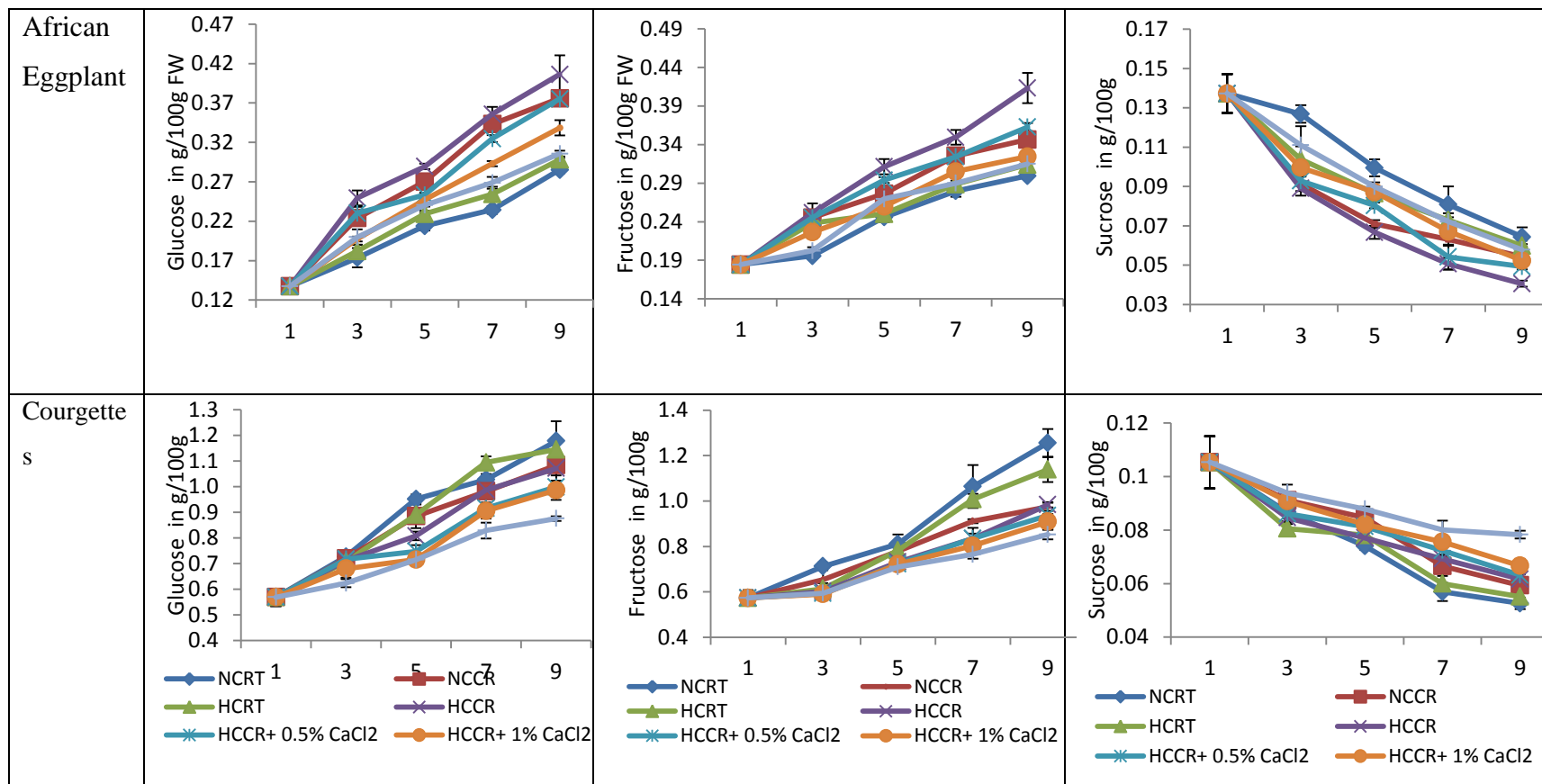


Figure 4-12: Specific sugar composition in produce

• Horizontal axis is storage time in days

NCRT, NCCR HCRT and HCCR are not cooled and stored at ambient temperature, not cooled and stored at low temperature, Hydrocooled and stored at ambient temperature and Hydrocooled and stored at low temperature. 0.5%, 1.0% and 1.5% is concentration of calcium chloride added to the cooling water. The produce in these treatments were also stored at low temperature. * Vertical bars represent standard errors and n=3

4.7 Microbiological Assays

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 at the beginning of the experiment, before hydrocooling. Tomatoes had the least for both. The microbial load was generally affected by precooling treatments, the storage temperature and length of storage time. The microbial populations increased with increase in storage time in all the produce. Produce stored at lower temperatures exhibited lower microbial loads. Hydrocooling of all produce with water alone resulted in reduction of microbial populations by approximately half. Addition of the calcium chloride at 1.5 % to the hydrocooling water further reduced the microbial load by 78.2 %, 59.4% 63.9% and 71.6% for tomatoes, African eggplant, carrots and courgettes respectively.

The effect of hydrocooling the produce with 0.5 %, 1.0% and 1.5% CaCl₂ yielded results with significant difference from the control at ($P \leq 0.05$). Microbial populations generally increased over the storage period as shown below in Figure 4-13 for TPC and Figure 4-14 for yeast and molds

Effect of storage temperature, time and precooling with water, or water with calcium chloride at various concentrations had a significant effect ($P \leq 0.05$) on total plate count and in yeasts and moulds. Produce stored at lower temperatures showed lower microbial loads throughout storage time. Higher calcium chloride concentrations resulted in lower count in total plate count and yeast and moulds for all the produce studied.

Hydrocooling the produce with portable tap water (free of microbial contamination) significantly reduced the initial microbial load in all produce. Although this was contrary to the findings of Mamun *et al.*, (2012) in red amaranth leaves, it was similar to those of Workneh *et al.*, (2003) in carrots when he compared the effects of tap water, anolyte water and chlorinated water on microbial load.

This can be attributed to its contact with soil, water and possibly manure associated with the cultural practices (Abadias *et al.*, 2008). The effect of washing the produce with various concentrations of CaCl₂ yielded results with significant difference at

($P \leq 0.05$). Microbial populations generally increased over the storage period as shown below in Figure 4-13 for TPC and Figure 4-14 for yeast and molds.

Hydrocooling the produce generally reduced the initial microbial loads as shown below, although it did not completely eliminate the microbes from the produce. The least microbial growth in all produce occurred in 1.5% CaCl_2 . This can be attributed to osmolytic stress 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 of sanitizers 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.

4.7.1 Total plate count

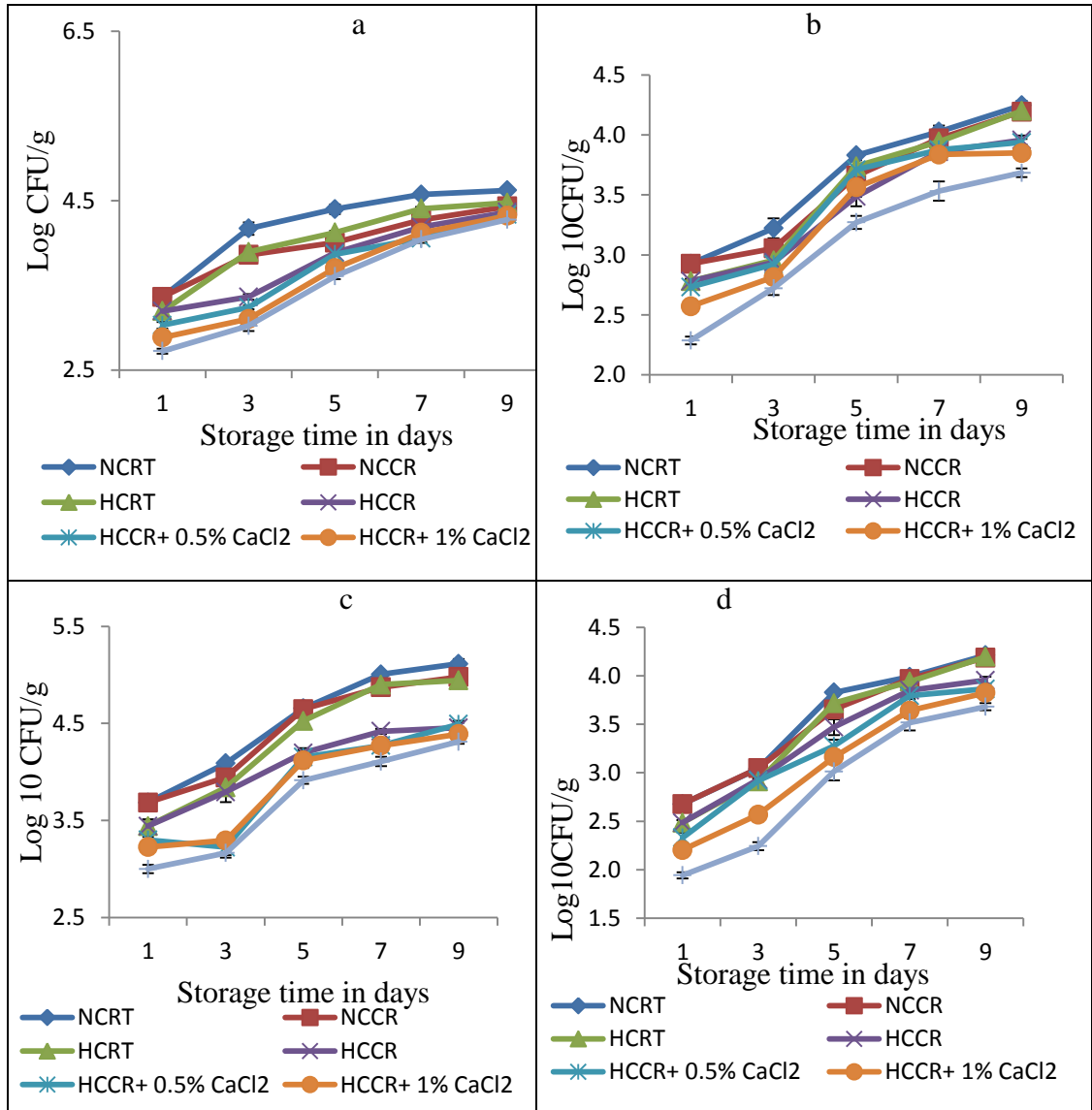


Figure 4-13: Total plate count in Produce

*Data presented in logarithmic scale \pm standard error. N=3

Graphs **a**, **b**, **c** and **d** represent TPC in tomatoes, eggplants, carrots and courgettes respectively. NCRT, NCCR HCRT and HCCR are not cooled and stored at ambient temperature, not cooled and stored at low temperature, Hydrocooled and stored at ambient temperature and Hydrocooled and stored at low temperature. 0.5%, 1.0% and 1.5% is concentration of calcium chloride added to the cooling water. The produce in these treatments were also stored at low temperature.

4.7.2 Yeast and moulds

Yeast and mould growth and presence was significantly affected by hydrocooling process, storage temperature and time. Hydrocooling using water alone reduced the yeast and mould counts in all produce at the start of the experiment by 26.2%, 37.3% 56.3% and 31.9% for tomatoes, African eggplants, carrots and courgettes respectively. Addition of calcium chloride at 1.5% in hydrocooling water showed a positive result with further reduction of yeast and moulds by 63.1%, 46.2% 79.4% and 69.7% respectively for tomatoes, African eggplants, carrots and courgettes. However, the levels of yeast and moulds did not show significant increase during the first 5 days of storage for tomatoes and eggplants stored at low temperature, for both hydrocooled with or without calcium chloride and control produce. Carrots and courgettes showed an increase in yeast and mould counts after day 3 in all treatments, although the increase was lower in HCCR, NCCR and all treatments with CaCl₂. This was similar to the findings of Luna-guzma and Barrett (2000) in cantaloupes, where yeast and mould counts increased after 4 days when the produce were washed. This could be attributed to the initial high microbial load in carrots and the generally high pH in courgettes which provide ambient conditions for microbial proliferation. In general the highest calcium chloride treatment resulted in the least yeast and mould population for all the produce as shown below Figure 4-14. Similar findings were found by Irfan *et al.* (2013) in Fig fruits with 2% CaCl₂ reduced the amount of the yeast and mould significantly, resulting to an extended shelf life. According to Youssef *et al.* (2012) in a study on mango fruits, calcium ions from calcium chloride salts may be responsible for inducing firmness of the cell wall and middle lamella thus increasing mango resistance to fungal pathogens.

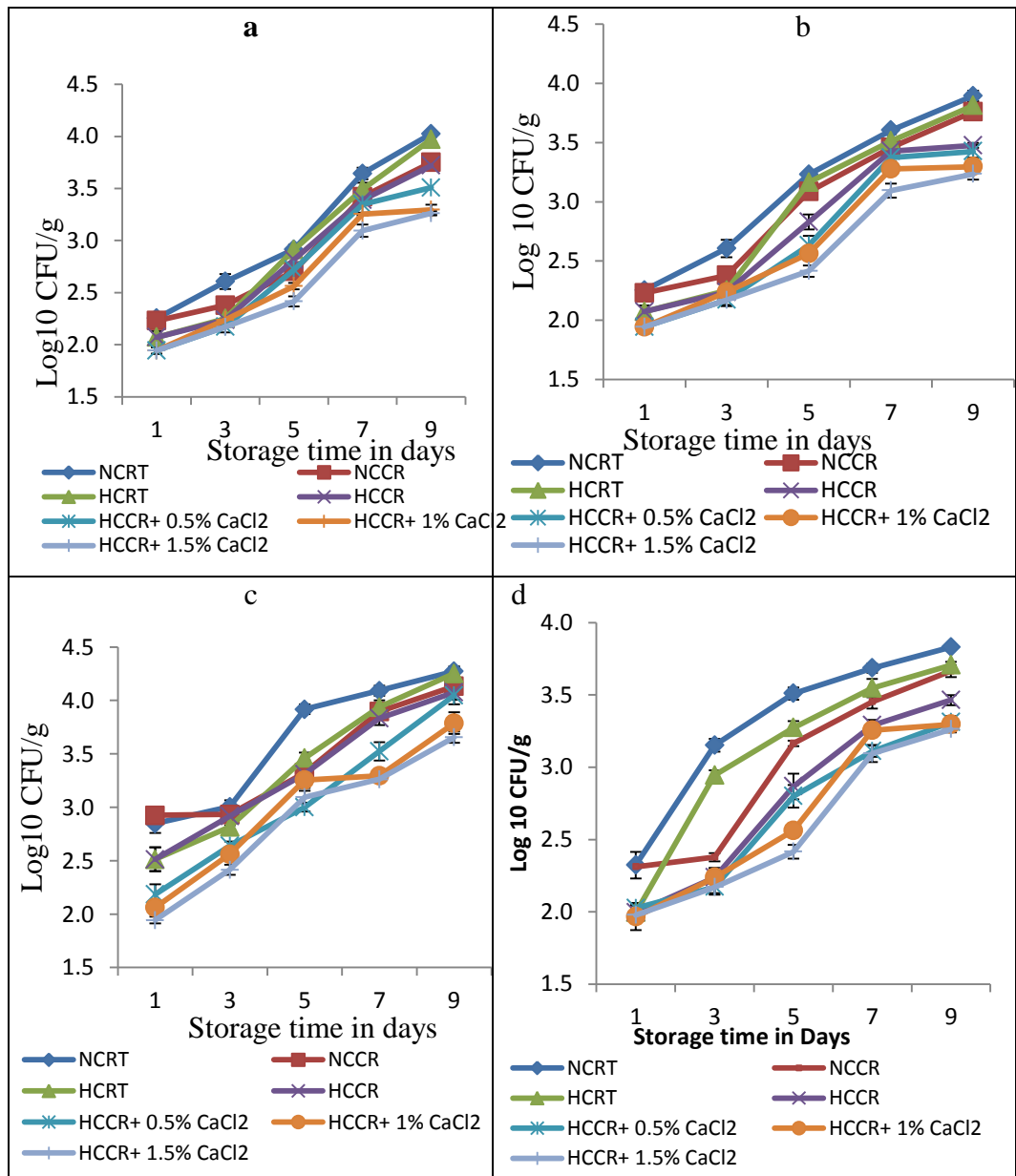


Figure 4-14: Yeast and Mould count in produce

Graphs **a**, **b**, **c** and **d** represent yeast and mould counts in tomatoes, eggplants, carrots and courgettes respectively. NCRT, NCCR HCRT and HCCR are not cooled and stored at ambient temperature, not cooled and stored at low temperature, Hydrocooled and stored at ambient temperature and Hydrocooled and stored at low temperature. 0.5%, 1.0% and 1.5% is concentration of calcium chloride added to the cooling water. The produce in these treatments were also stored at low temperature.

* Vertical bars represent standard errors and n=3

CONCLUSION

The performance of the low cost hydrocooling system designed and used in this study was satisfactory. The produce were cooled to target temperatures of 10 °C for tomatoes, courgettes and African eggplants and 7 °C for carrots within the expected time ranges specific to product as those of conventional coolers. Performance of the hydrocooler was evaluated using the decimal cooling time, which gives the time required to reduce the produce temperature by a particular proportion usually half ($TAT \frac{1}{2}$) or seven- eighth ($TAT \frac{7}{8}$). The dimensionless cooling rates obtained from this study, together with the produce sphericity values can be used to estimate cooling time for produce portraying similar geometrical characteristics.

Combining low storage temperature and hydrocooling has a significant effect on the postharvest quality of carrots, courgettes and tomatoes. Precooling of these vegetables to their target temperatures without further low temperature storage was only effective for 3 days. 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.

This study established that hydrocooling alone is not sufficient to maintain the postharvest quality of perishables. The data obtained for African eggplant indicates that either hydrocooling or low temperature storage (10 °C) or both, though recommended may have a negative effect on the quality and postharvest life. This may be due to its growth conditions or the crop has a higher temperature threshold with regard to chilling injury. 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.

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 the least postharvest losses in both quality and quantity in the parameters 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 CaCl₂ 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. Once chilling injury began, the severity and intensity was not significantly different ($P \leq 0.05$) from the samples hydrocooled with water only. The eggplants used in this study were therefore at their best quality under the control treatment. Low temperature storage and hydrocooling with or without calcium chloride did not yield positive results of extending postharvest life. To alleviate the chilling injury in eggplants, and Zucchini, preconditioning treatment at temperatures above 10 °C for a day or two may help alleviate these injuries.

The chilling injury incidence also observed may imply that the African eggplants have the chilling tolerance at a higher temperature. Although the findings in this study show benefits of low temperature storage and hydrocooling, there is need for further research on the African eggplants' response, so as to establish the chilling tolerance in this crop. This will facilitate greater utilization of the produce over long distances and thus better nutrition to communities consuming the product.

RECOMMENDATION

Since the low cost hydrocooling system yielded similar results to the conventional system with respect to the time required to cool produce to target temperature, the setup should be adopted by small and medium holder farmers, who trade their produce both at local and distant markets. It is assembled from locally available materials and in case there is need for repair, the parts are readily available.

Incorporating a solar powered pump into the system to facilitate water circulation will allow for utilization of the system in areas not connected to electricity, and allow for potential utilization in farmer fields.

As observed in this study, various produce have different cooling times, as well as response to hydrocooling treatment. There is need to conduct further research on produce response to hydrocooling, especially for the indigenous or traditionally important crops so as to ensure the optimal conditions are used for each crop while commercializing the system.

There is also need to establish the optimal concentration of CaCl_2 for each produce when used as a sanitizer. This is because the produce may respond differently to the various concentrations as observed in this study.

There is need to carry out demonstrations, to train farmers on how to use the system especially with regard to maintaining the quality of water used in the hydrocooling process. By setting up a demonstration system at a farmer field, farmers will be in a position to appreciate the innovation, and take up the setup for use in their produce.

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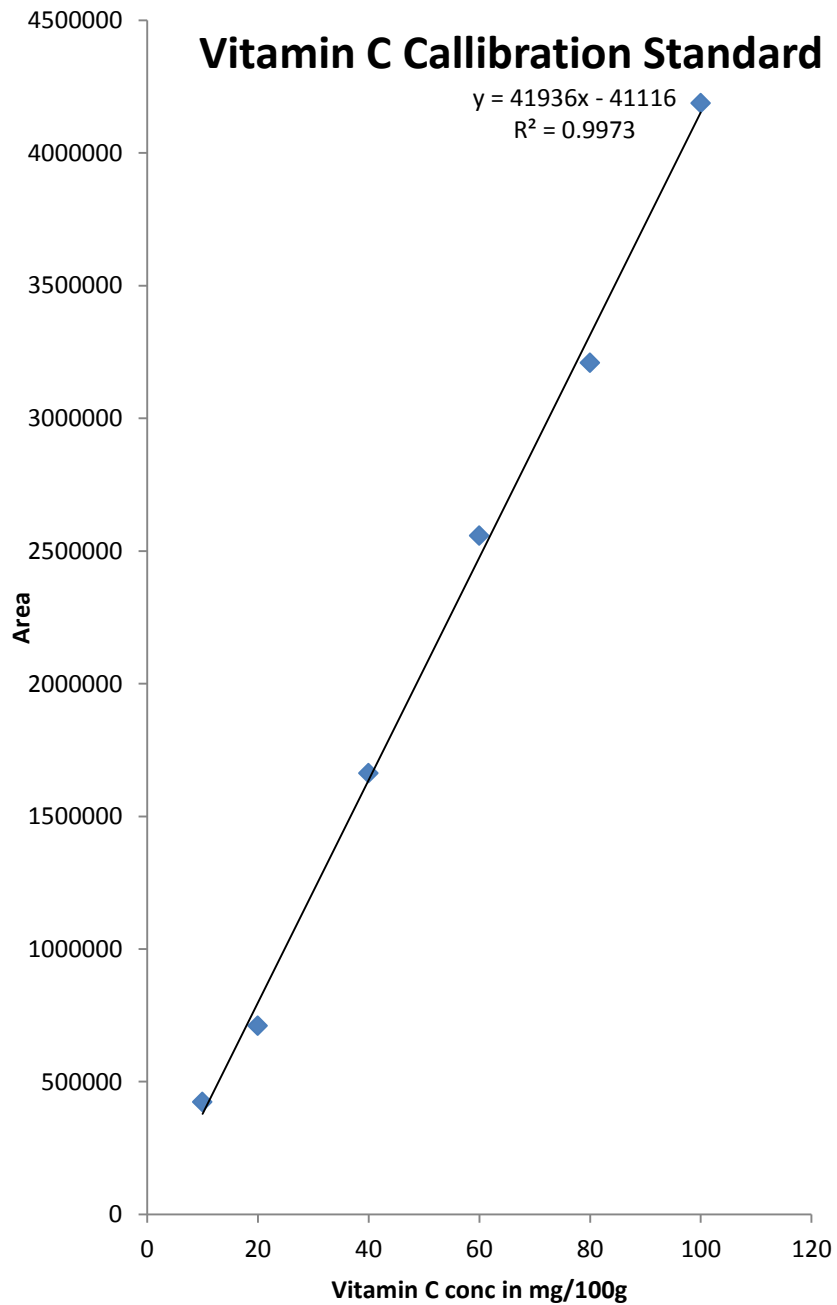
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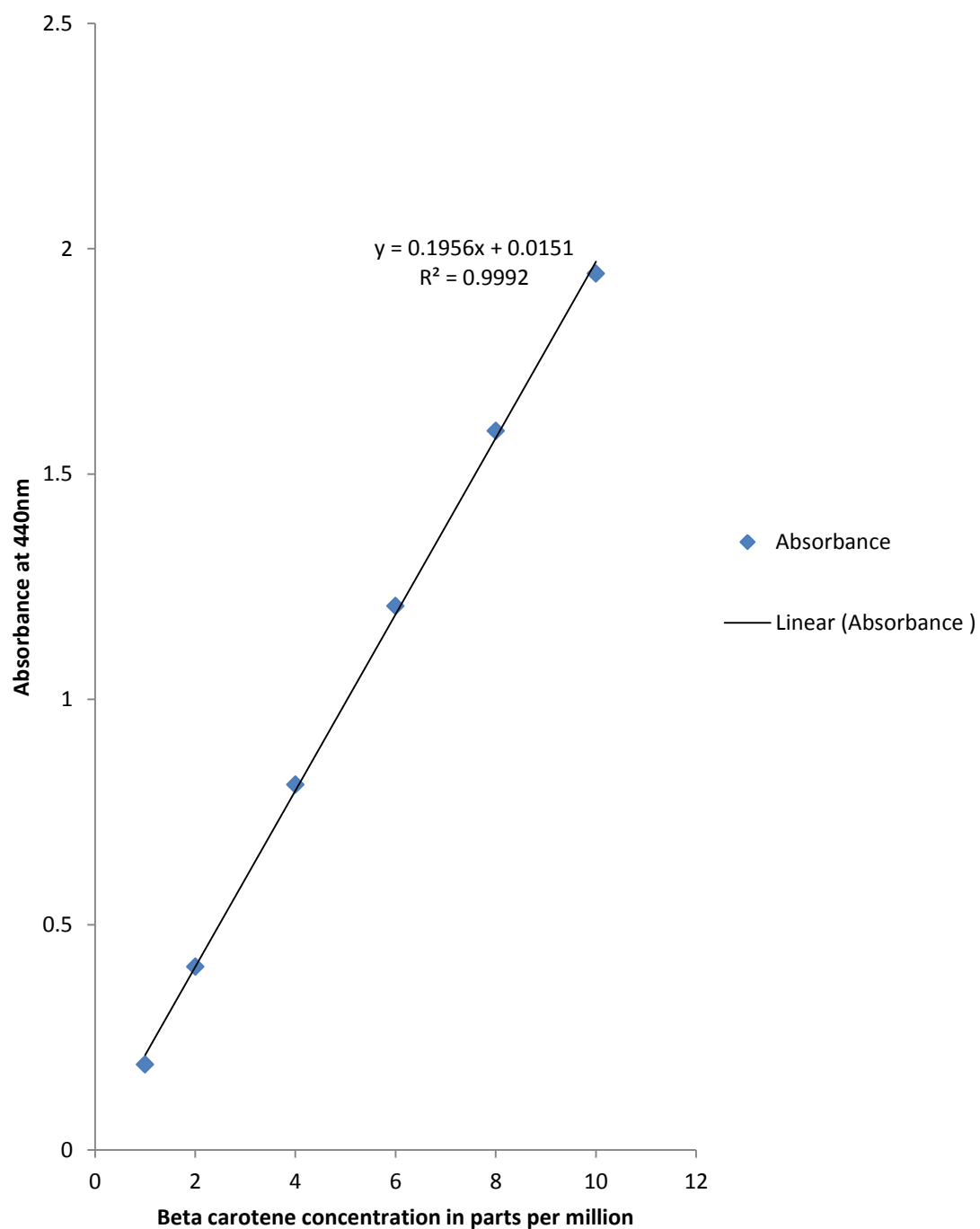
5 APPENDICES

Appendix 1: Vitamin C calibration curve

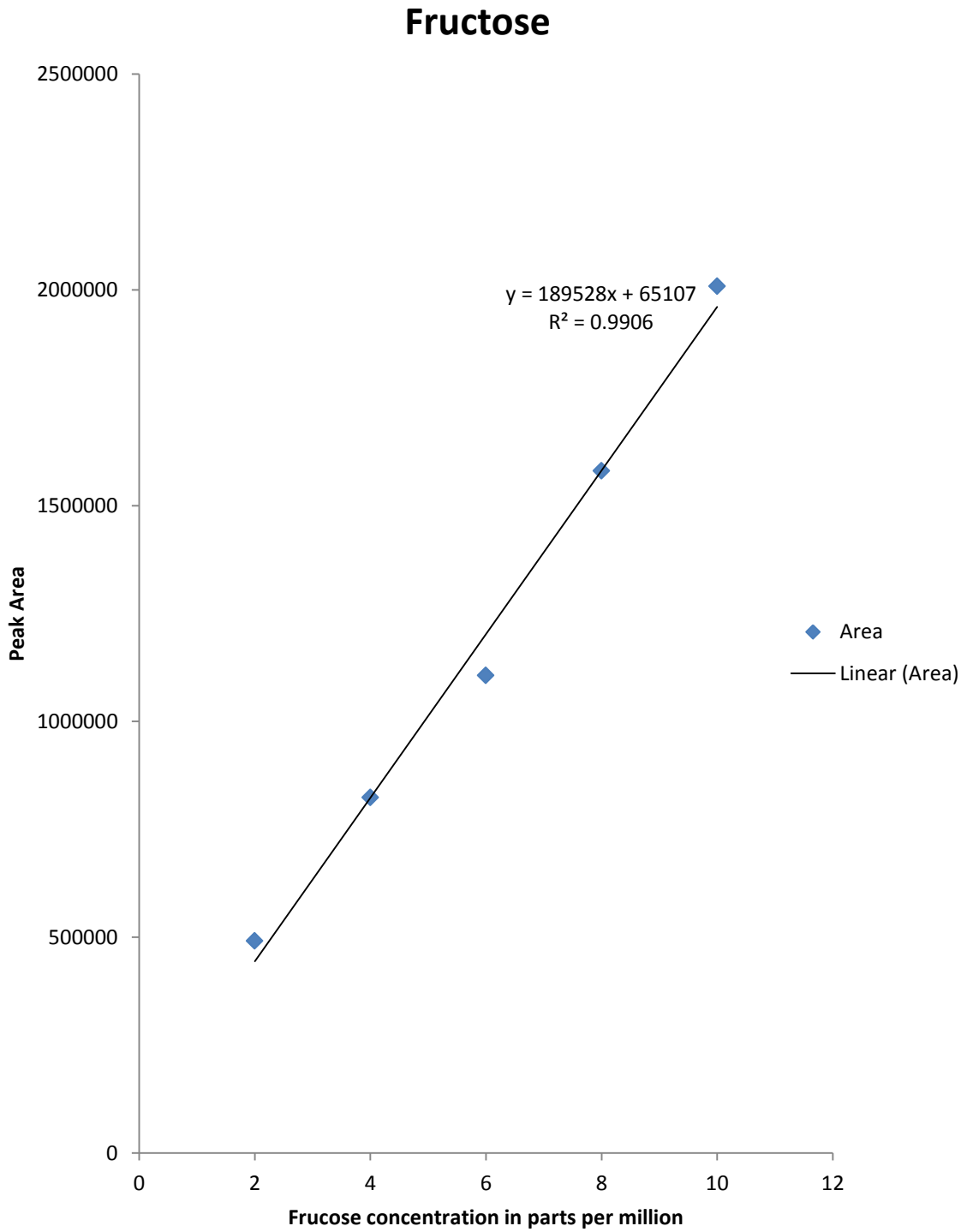


Appendix 2: Beta carotene standard curve

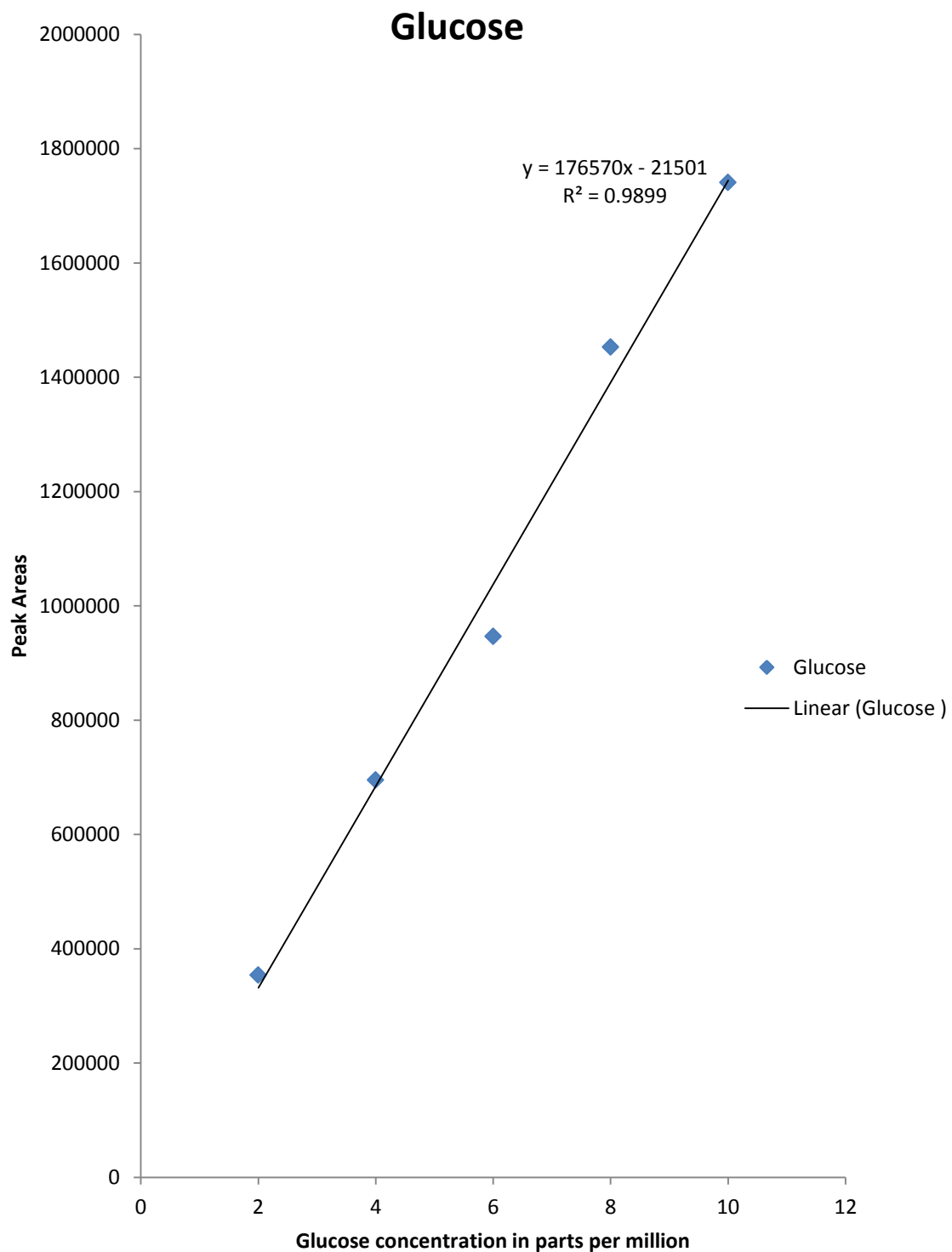
Absorbance



Appendix 3: Specific Sugar calibration - fructose



Appendix 4: Specific Sugar calibration - Glucose



Appendix 5: Specific Sugar calibration - Sucrose

