EVALUATION OF THE EFFECTS OF SUPPLY CHAIN ROUTES AND PRE-STORAGE TREATMENTS ON THE POSTHARVEST QUALITY OF STORED 'NEMO-NETTA' TOMATOES

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Submitted in partial fulfilment of the requirements
for the degree of MSc.

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December 2016

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DISCLAIMER

As the candidate’s supervisor, I have approved this thesis for submission

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PREFACE

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ABSTRACT

Tomato postharvest losses are the major constraints that limit optimum competitiveness and marketability of tomatoes. This becomes a serious threat since tomatoes are highly perishable, and lose quality at any stage of the supply chain. In this study, the effects of supply chain routes, pre-storage treatments and storage conditions on microbial quality were evaluated in ‘Nemo-Netta’ tomatoes harvested at pink maturity stage. The effects of supply chain routes, harvesting maturity stages, pre-storage treatments, pre-storage treatments, and storage conditions on physiological, biochemical and chemical quality of ‘Nemo-Netta’ tomatoes were also evaluated. The study also evaluated the combined effects of integrated postharvest technologies.

The effect of disinfecting tomatoes with different solutions (anolyte water, chlorinated water and hot water) or coating tomatoes (with Gum Arabic), on the microbiological quality of tomatoes during storage after transportation in non-refrigerated trucks along three different supply chain routes was evaluated (Chapter 3). Upon the arrival of tomatoes in Pietermaritzburg market, they had condensed droplets on the fruit surfaced which was speculated to be due to the differences in temperatures and relative humidity within truck during transportation. Droplets on the fruit surface became a conducive environment for microorganisms to proliferate. Pink-matured tomatoes with freedom from blemishes were treated, stored on either ambient (16 °C in winter / 25 °C in summer) or cold (11 °C), and sampled on day 0, 16 and 30 for quality assessment. An experiment was laid out as a factorial split-plot design with supply routes as main plots, storage conditions as subplots and random allocation of treatments within each subplot. An experiment was conducted in two seasons during winter harvest and during summer harvest.

The results revealed a highly significant difference ($P < 0.001$) in the microbiological population (log cfu cm^{-2}) and marketability (%) of tomatoes from different supply routes, storage environments, and treated with different disinfectants. Anolyte water was the most effective treatment in maintaining quality of tomatoes. It reduced the initial microbial load significantly ($P < 0.001$) to 3.779 log cfu cm^{-2}. This represented the second highest log reduction of 1.049 log cfu cm^{-2} when compared to untreated control which had 4.828 log cfu cm^{-2}. Furthermore, three-way interaction of supply route, disinfectants, particularly anolyte water with low temperature storage remained the most superior treatment in the microbial quality of pink-matured tomatoes. It reduced the initial microbial load significantly ($P < 0.001$) to 2.835 log cfu cm^{-2}. This represented the highest log reduction of 1.470 log cfu cm^{-2}, when compared to untreated samples. Anolyte water also maintained the highest percentage of the general marketability of pink-matured tomatoes, however a three-way interaction of supply route, disinfectants, particularly anolyte water with low temperature storage remained the most superior treatment in maintaining marketability of pink-matured tomatoes across all the supply routes.

The effect of disinfecting tomatoes with different solutions (anolyte water, and hot water) or coating tomatoes (with Gum Arabic), and their combinations on the physiological, chemical and biochemical quality of tomatoes during storage after transportation in non-refrigerated trucks along three different supply chain routes was evaluated in Chapter 4. Green, pink and red matured tomatoes with freedom from blemishes were treated, stored on either ambient (16/ 25 °C) or cold (11 °C), and sampled on day 0, 8, 16, 24 and 30 for quality assessment. An experiment was laid out as a factorial design, split-split plot with supply routes as main plots, maturity stages as subplots, storage conditions as sub-subplots and random allocation of treatments with each subplot. An experiment was conducted in two seasons during winter harvest and during summer harvest. The results revealed highly significant impact ($P < 0.001$) of individual technologies in maintaining quality, which was measured by number of parameters including colour, texture, TSS, physiological weight loss, respiration rate, total phenolic compounds, Total antioxidant capacity and general marketability. Furthermore, integrated technologies had more superiority in maintaining quality of tomatoes. Therefore anolyte water and Gum Arabic coating need to be researched further as potential substitutes of chemical treatments that are currently used by tomato industry.

ACKNOWLEDGEMENTS

I am thankful to God for giving me a good health, strength, and for His guidance in the preparation of this thesis. I sincerely thank my Supervisor, Prof. Tilahun Seyoum Workneh for his guidance during the preparation of this document. I thank Dr Milindi S Sibomana for his valuable technical advices in experiments pertaining to microbiological food safety analysis. I thank Prof. Stefan Schmidt for his valuable technical advices in experiments pertaining to microbiological food safety analysis. I thank Mrs Elsie Correia for accommodating me in her labs and for technical and even social support. I also thank Mr TC Nkosi for his technical advice in experiments pertaining to fruit chemical analysis.

I would like to thank PHI/ TPO for taking initiative in funding this project. Gratitude would also be sent to NRF for funding the researcher.

My heartfelt gratitude goes to my family for their endless prayers, emotional support and for permitting me to be away from home for my studies.

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1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) belonging to the family *Solanaceae* (Tigist *et al.*, 2012), is the second most important and widely consumed vegetable crop in the world after potatoes (Wilcox *et al*., 2003). It is also the second most widespread vegetable crop in South Africa, after potatoes (DAFF, 2013). In South Africa, tomatoes are planted in an area that covers about 6000 hectares, and are produced all over the country (i.e. in all nine provinces), with Limpopo being the major producing province. This is due to its morphological diversity combined with the soil and climatic conditions of South Africa which allows production in summer and winter (in frost free areas) (DAFF, 2013). Importance of tomatoes is due to their nutritional value (Wilcox *et al*., 2003). Tomatoes are the potential sources of carotenoids, mainly lycopene and β-carotene (Ali *et al.,* 2010). Consuming carotenoids from tomato is associated with reduction in the risk of cancer and incidence of heart diseases (Giovanelli *et al*., 1999; Ali *et al*., 2013). Tomatoes are also popular for being potential sources of fibre, Vitamin A and Vitamin C (ascorbic acid) (Arab and Steck, 2000).

Tomatoes are well-known for being susceptible to chilling injury when stored at temperatures below 12 ºC (Bailén *et al*., 2006; Kalantari *et al*., 2015). Membranes of most fruits contain phospholipids with fatty acids, which may be saturated or unsaturated, and these affect membrane fluidity. Unsaturated fatty acids are more fluid than saturated fatty acids, thus can withstand lower storage temperatures. However, tomatoes contain low degree of fatty acids unsaturation, thus sensitive to chilling injury (Fallik, 2004).This becomes a challenge when tomatoes have to undergo cold chain (< 12ºC) to maintain quality during transportation (Kalantari *et al*., 2015). Tomatoes are climacteric fruits, which defines their ripening pattern that is accompanied by a burst of ethylene production associated with a peak in the respiration rate (Alexander and Grierson, 2002; Wu, 2010; Klee and Giovannoni, 2011). Fruit respiration rate is inversely proportional to shelf life i.e. the higher the respiration rate, the shorter the fruit shelf life, which limits the marketing potential of tomatoes by reducing its shelf life.

Tomato fruits are normally harvested at three different maturity stages, i.e. mature green, pink, and red, depending on harvesting season and purpose (Kalantari *et al*., 2015). The stage of maturity at harvest is one of the major determinants of the storage life and quality of the fruit

(Alam *et al*., 2006). Getinet *et al.* (2008) reported that tomatoes harvested at mature-green stage maintained better chemical quality and marketability compared to samples harvested at turning and light red stage, stored under the same storage conditions. Teka (2013) argued that at green-maturity stage tomato is firmer than at other maturity stages thus most susceptible to mechanical injury as compared to medium ripe and red ripe fruits. Therefore, there are still opportunities for research pertaining to the relationship between maturity stage (green, pink, or red), and various pre-storage treatments to further the maintenance of fruit quality during the postharvest period.

Different researchers, especially in developing countries (Getinet *et al*., 2008; Ali et al., 2010, Ali *et al*., 2013; Sibomana *et al*., 2016), have reported postharvest quality losses in tomatoes. These losses may occur during harvest period, transportation, processing or storage (Wu, 2010). Reducing postharvest losses remains a major goal mainly due to food security issues need which to be alleviated worldwide, especially in the developing countries (Boyette *et al*., 1994; Pila *et al.*, 2010). Pila *et al.* (2010) reported that South Africa is among the subtropical countries that lose approximately 20-50% tomatoes between harvesting, transportation and consumption, compared to 5-10% that is lost in developed countries. Literature provides some information regarding reduction of these losses, however, they do not seem to fully resolve the problem, and attention was mostly paid to fruit in the market not the whole supply chain. This creates knowledge gaps with regards to the effects of postharvest practices in the tomato supply chain on fruit quality (Pila *et al.*, 2010). As a result, in the following research question is posed: what is the effect of different supply chain routes on the quality of tomato fruits?

Pre-storage treatments for maintaining tomato quality have included the use of different chemicals such as disinfectants, blanching treatments, coating, packaging and low temperature storage. All of them had some positive effects in maintaining tomato quality, however, their efficiency varies with maturity stages (Getinet *et al.,* 2008; Teka, 2013). The current major concern is with food safety and nutritional value; therefore, there is still a considerable interest in an alternative, safe, but effective pre-storage treatment for use by the fresh produce industry (Romanazzi *et al.,* 2015). There is currently a renewed and growing interest in the use of natural products for maintaining quality and extending the shelf life of fruits and vegetables (Ahmed *et al.,* 2012). Therefore, again there is knowledge gap as to which pre-storage treatment or treatment combination is most effective in maintaining quality and at which maturity stage.

Even though pre-storage treatments are used by the tomato industry, it is still essential to control temperature and relative humidity and gas composition during storage, because they are the major causes of fruit spoilage during ripening and storage (Bailén *et al.*, 2006; Workneh, 2010). Low temperature storage reduces physiological, biochemical and microbiological activities that occurs within a fruit, which result in fruit spoilage (Kader *et al*, 1989; Workneh and Woldetsadik, 2004; Workneh, 2010). Therefore in this study, the efficiency of cold storage temperature (11 °C) in tomatoes harvested at different maturity stages and treated with different pre-storage treatments.

Several studies have revealed that integration of different postharvest technologies is recommended to optimize fruit postharvest quality (Beckles, 2012). However, least have been done in attempting a holistic approach of minimising postharvest losses in tomatoes. Therefore, the literature below aims to review tomato postharvest losses, all factors affecting postharvest losses and technologies which have been used in South Africa and then suggest a potential holistic approach of integrated treatments that have a potential to reduce postharvest losses.

2. LITERATURE REVIEW

2.1 Introduction

Tomatoes are one of the most valuable crops, nutritionally, and its global consumption is higher than other fruits (Arthur *et al*., 2015). Its mineral nutrients are associated with the reduction of cancer and cardiovascular diseases. However, it is highly perishable and it has the shortest shelf life than all fruits. Developing countries experience high postharvest losses of tomatoes (Pila *et al*., 2010, Mashau *et al.*, 2012). According to Pila *et al*. (2010), approximately 40-50% of tomato fruit quality loss occurs in developing countries like South Africa due to poor postharvest handling. The latest statistical estimates revealed that the South African tomato supply chain experienced a loss of about 10.2% (loss ~ R 336 million) of total production in 2011, due to inadequate handling, transportation and storage (FAOSTAT, 2014). This is one of the major constraints affecting small and large scale farmers. Therefore this literature aims to quantify the postharvest losses that have been incurred in South African tomato industry, how can they be mitigated, factors that affect postharvest quality of tomatoes, potential technologies that have been used and currently in use by the industry to reduce postharvest losses.

2.1.1 Overview of tomato production and postharvest losses in South Africa

Tomato is the one of the most popular and valuable fruit globally (Beckles, 2012). It is the second most important and widespread fruit in South Africa, after potatoes (Wilcox, 2003; DAFF, 2013). Its morphological diversity enables production in all nine provinces of South Africa, where it contributed 18% of gross value of vegetable production in 2012 (DAFF, 2013). The major areas of tomato production in South Africa are: Limpopo, Mpumalanga (Low- and Middleveld), Pongola (in KwaZulu Natal), the southern parts of Eastern Cape and Western Cape (DAFF, 2013). Tomato production is dominated by commercial farmers who contribute 95% of the national tomato production, while small scale farmers only contribute 5%. FAOSTAT (2014) reported the latest statistics on total production of tomatoes in South Africa which approximated to 566180 tons from 7819 ha land during 2013.

Postharvest losses are reported to occur from the point of production through the marketing chain until reaching the consumers (Wu, 2010; Verhuel *et al*., 2015). These losses are more pronounced in tropical (or subtropical) areas where they account for more than half of fruit deterioration and quality loss, while only about 10% of fruits significantly lose quality in other regions (Kereth *et al*., 2013). An important challenge facing fresh produce companies is fruit quality loss that occurs during fruit distribution (Ali *et al*., 2010). These losses may occur during the harvest period, transportation, processing or during storage (Irtwange, 2006). Fruit postharvest losses may occur due to low levels of technology, low investment in food production systems and poor marketing (Prusky, 2011).

For the postharvest losses to be minimized, certain postharvest handling practices or technologies have to be adopted by producers (Beckles, 2012). Therefore, several pre-storage treatments such as anolyte water (Seyoum, 2003; Gil *et al*., 2009; Workneh *et al*, 2012), chlorinated water (Cengiz and Certel, 2014), hot water (Fallik, 2004), and edible coatings (Ali *et al*., 2013) have been used and have potential to reduce postharvest losses. As reported by Melkamu *et al*. (2008), as much as these treatments have showed a potential to prolong fruit quality, but they cannot substitute the effectiveness of low temperature and high relative humidity.

2.2 Factors influencing deterioration of tomato fruit quality and shelf life

Tomato continues with metabolic processes after harvest, and these processes cannot be stopped but can rather be controlled up to certain limits (Wu, 2010; Bapat *et al*., 2010). Therefore, to ensure maximized fruit quality, it is important to harvest fruit at the optimum maturity stage depending on harvesting purpose (Teka, 2013), and during the correct time of the day. Tomato quality deterioration after harvest occurs due to physiological deterioration, biochemical changes and microbiological growth that are taking place within the fruit (Workneh and Woldetsadik, 2004). Therefore, thorough knowledge of the physiology, biochemistry, and microbiology of tomato is essential for efficient selection and implementation of postharvest treatments (Workneh, 2010). There are many factors which affect the postharvest life of tomato fruit.

2.2.1 Pre-harvest factors

Pre-harvest factors significantly influence postharvest quality deterioration. Management practices including mineral nutrition, irrigation intervals and water quality, light intensity, training, pruning and duration of exposure to light are the major determinants of fruit quality and shelf life (Hewett, 2006). Managing these practices efficiently results in attaining healthy fruit with well-balanced levels of antioxidants, sugars, minerals and water, thus possess high potential to have longer shelf life (Hewett, 2006).

2.2.2 Environmental factors affecting tomato quality and shelf life

The most important environmental factors that affect fruit quality are temperature and relative humidity (Wu, 2010). Temperature, relative humidity and atmospheric composition are the major environmental factors that cause fruit deterioration since they control physiological, biochemical and microbiological changes (Workneh *et al*., 2009). The ripening process of tomato fruit is generally controlled with gas composition, temperature and relative humidity (Ali *et al.,* 2010). The impacts of each of these factors are discussed in details below.

Temperature

Temperature is the major environmental factor that determines the shelf life of horticultural commodities after harvest (Irtwange, 2006, Workneh and Osthoff, 2015; Aung and Chang, 2014). It controls all the factors affecting metabolic processes taking place within a fruit, hence fruit rate of deterioration. These include physiological factors, microbial factors and biochemical factors. Physiologically, high temperatures triggers ethylene production and increase the rate of fruit respiration, hence significantly affect metabolic processes taking place within the fruit (Workneh and Osthoff, 2015). Therefore, as temperature surrounding the fruit increases, so does the rate at which fruit respires. Wu (2010) reported that for every ten degrees increment in temperature, the rate of fruit respiration is approximately doubled, while Zagory and Kader (1988) reported that it may be doubled, tripled or even quadrupled. This was reported on number of horticultural produce, particularly fruit.

Microbiologically, temperature significantly affects microorganism growth during fruit storage (Seyoum *et al.*, 2011). Ambient temperature storage of carrots resulted in higher total aerobic bacteria counts being recorded than cold storage. This led to the conclusion that low temperatures during storage of fresh produce significantly control growth of microorganisms, while room temperature storage facilitates the proliferation of microorganisms (Seyoum *et al.*, 2011). Biochemically, higher storage temperatures in tomatoes enhance development of polygalacturonase activity resulting in fruit losing firmness. High temperatures stimulate the rate of tomato ripening, hence increased pectin and polygalacturonase activities, resulting in fruit softening (Yoshida *et al*., 1984). In addition, high temperatures activate enzymes which create off-flavours, and fruit discolouration during tomato fruit storage, hence reduce fruit marketability (Workneh *et al*., 2009; Workneh and Osthoff, 2015).

Therefore keeping tomatoes at low storage temperature (11 °C) could have a potential to reduce the rate of deterioration in tomatoes by slowing the rate of microbial growth and enzymatic activities that lead to fruit softening. Temperature is the key tool for sustaining quality and shelf life of horticultural commodities (Pinheiro *et al*., 2013a). To prolong the shelf life of tomatoes, ideally, low temperature should be effected immediately after harvest (to remove field heat), during transportation, storage and even at the market (Workneh and Osthoff, 2015). The first step in managing temperature for optimizing fruit quality is pre-cooling, which defines the quick removal of field heat from a horticultural commodity before shipment, storage and processing (Wu, 2010; Pinheiro *et al*., 2013a). The most common technologies used to pre-cool tomatoes are forced-air cooling and room cooling (Pinheiro *et al*., 2013b).

Relative humidity

Relative humidity is another environmental factor that is crucial in maintaining quality and extending shelf life of fresh fruits and vegetables. Increasing relative humidity causes the elevation of vapour pressure of the air surrounding the produce, hence reducing physiological weight of fresh produce (Workneh and Osthoff, 2015). The difference in the vapour pressure between the fresh commodity and the surrounding air cause moisture loss from wet produce to the air, resulting in fruit mass loss (Workneh and Osthoff, 2015). Generally, relative humidity must be kept between 90-95% to prevent moisture loss from a fresh produce (Irtwange, 2006). This ensures minimized fruit transpiration, hence mass loss. However for tomatoes, 85-95%

relative humidity is optimum, any further increment in relative humidity may promote fungal infection, due to formation of condensed water on the fruit surface (Pinheiro *et al*., 2013a), and resultant diseases (Prusky, 2011).

Atmospheric composition

Another effective method of maintaining quality and extending the shelf life of fresh produce is manipulation of gas composition around the fresh produce. Changing the concentration of gases surrounding a fresh produce significantly reduces the produce respiration rate, retards microbial growth and senescence, and hence extends shelf life and quality of produce. The condition whereby the new atmospheric composition has been created around the fruit by addition or removal of certain gases is termed modified atmosphere (MA) (Wu, 2010). The gas composition within the modified atmosphere differs from the normal atmosphere due to addition or removal of certain gases. The most critical gases to be manipulated in the atmosphere are oxygen, carbon dioxide and ethylene. This is due to their significant impact in the respiration rate of fresh produce. The respiration rate of a fruit is reduced by hindering ethylene production, reducing oxygen concentration and elevating levels of carbon dioxide around the produce (Waghmare, and Annapure, 2013).

2.2.3 Technical factors

Any form of damage that occurs mechanically in fruits, including bruising, cuts and surface scratches which result in fruit quality being reduced, falls under technical factors that causes fruit quality deterioration (Opara and Phathare, 2014). Horticultural products are inherently highly perishable (Wu, 2010), without any mechanical damage, which stimulates fruit rate of deterioration, for example a fruit wound enhances water loss (Li *et al.,* 2010), ethylene production, and respiration rate, hence quality deterioration (Wu, 2010). Fruit wounds enable the entrance of microorganisms thus hastens the rate of fruit decay (Arazuri, 2007; Prusky, 2011).

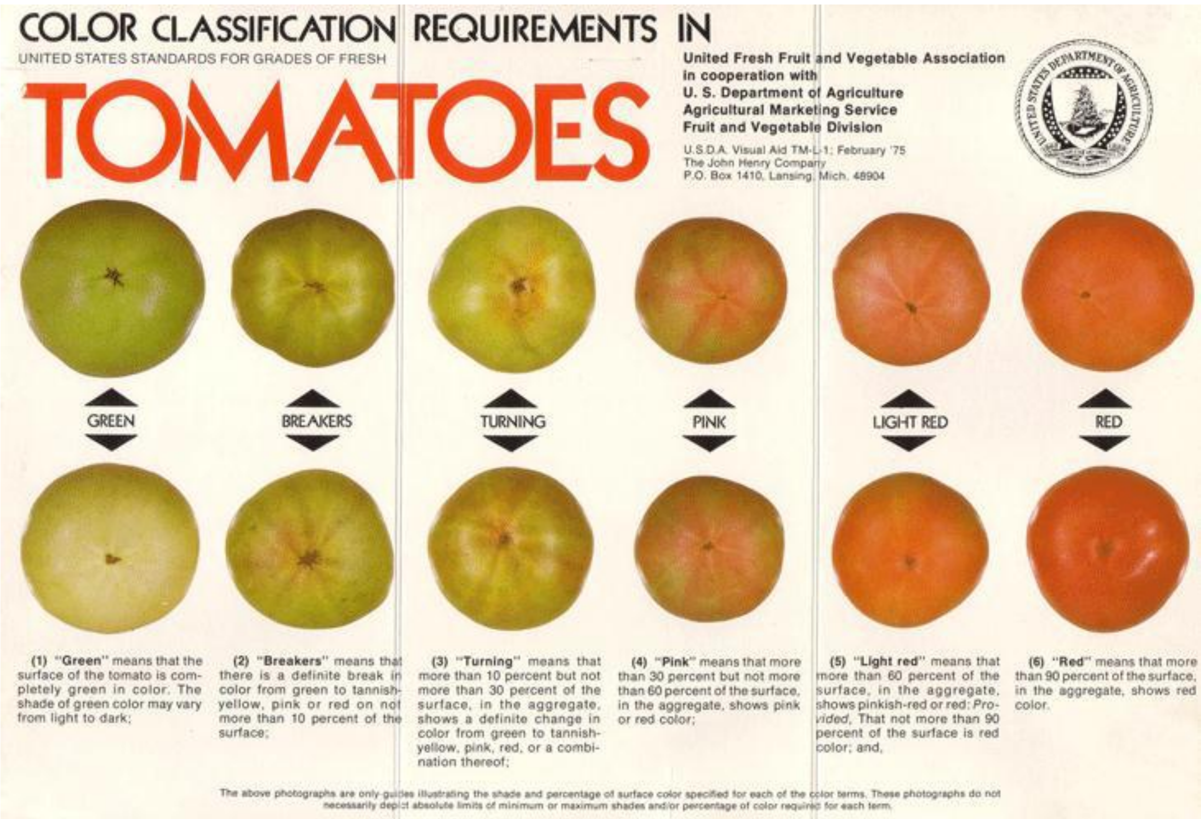
The major cause of postharvest quality deterioration of fruits and vegetables is mechanical damage. "It occurs mainly during harvesting, grading, handling and transportation" (Shafiur, 1999). Arazuri (2007) also reported that most mechanical activities affecting tomato quality occurs during the harvesting and transportation period. Among highly perishable horticultural commodities, tomato is very prone to mechanical damage (Arazuri, 2007). Bruising is the one of the major types of mechanical damage that affects fresh fruits and vegetables, by reducing fruit quality, hence marketability (Opara and Pathare, 2014). It can occur at any stage of the postharvest life of a fruit, from harvest, transportation, packaging, as well as storage (Mujtaba and Masud, 2014). Factors affecting the degree of mechanical damage of tomatoes include packaging material, handling method and dropping height (Van Zeebroeck *et al*., 2007; Workneh *et al*., 2009). The severity of these factors depends on tomato variety, maturity, shape, texture and date of harvesting (Van Zeebroeck *et al*., 2007). Therefore, quality maintenance should begin at harvest by applying proper handling practices which will result in reduced mechanical damages. Reduced mechanical damages will result in fruit not losing juice, thus reduced mass loss, and reduced chances of microbial attack since microorganisms use wounds and cracks to proliferate. In addition to that physiological and biochemical processes which lead to quality deterioration are enhanced in wounded fruit, therefore minimizing mechanical damages will slow these processes and result in fruit quality being maintained.

2.3 Harvesting

Harvesting plays a significant role in the shelf-life of tomatoes. The most important factors to be considered are the stage of maturity (Alam *et al*., 2006; Getinet *et al.*, 2008; Getinet *et al*., 2011; Teka, 2013; Parker and Maalekuu, 2013), time of harvesting (Wu, 2010; Clarkson *et al.*, 2005) and the method of harvesting (Bhattarai and Gautam, 2006; Getinet *et al.*, 2008). The method of harvesting includes an actual approach towards harvesting, whether harvesting will be done manually (by hands) or by machine (Getinet *et al.*, 2008). In South Africa, only tomatoes for fresh consumption are harvested by hands (DAFF, 2013). It also includes the way tomato fruits will be harvested, whether they will be harvested with or without stalk (Bhattarai and Gautam, 2006).

2.3.1 Maturity stage

Stage of maturity at harvest is one of the major determinants of the storage life and quality of a tomato fruit (Alam *et al*., 2006; Getinet *et al.*, 2011; Teka, 2013). The maturity stage at harvest is the major determining factor of several quality parameters of tomato during postharvest, including fruit firmness, sugars, soluble solids, pH, colour and acidity (Teka, 2013). In tomatoes, firmness and colour are the key determining features of maturity stage, and these features are also attractive to tomato consumers in the market (Gómez *et al*., 2006). Tomato maturity is generally divided into six stages, namely: Green mature stage, breaker stage, turning stage, pink stage, light red stage and red stage (López Camelo and Gómez, 2004). These stages are illustrated in Figure 2.1. In a commercial setup, farmers harvest tomatoes at different maturity stages depending on the harvesting seasons, i.e. with green samples being harvested mostly in summer and riper samples being harvested in winter (Sibomana *et al.*, 2016). According to Wang *et al.* (2011), tomato maturity is closely related to its surface colour, therefore visual analysis of tomato colour prior to harvesting is crucial.



COLOR CLASSIFICATION REQUIREMENTS IN
UNITED STATES STANDARDS FOR GRADES OF FRESH
TOMATOES

United Fresh Fruit and Vegetable Association
in cooperation with
U. S. Department of Agriculture
Agricultural Marketing Service
Fruit and Vegetable Division

U.S.D.A. Visual Aid TM-L-1; February '75
The John Henry Company
P.O. Box 1410, Lansing, Mich. 48904

(1) "**Green**" means that the surface of the tomato is completely green in color. The shade of green color may vary from light to dark;

(2) "**Breakers**" means that there is a definite break in color from green to tannish-yellow, pink or red on not more than 10 percent of the surface;

(3) "**Turning**" means that more than 10 percent but not more than 30 percent of the surface, in the aggregate, shows a definite change in color from green to tannish-yellow, pink, red, or a combination thereof;

(4) "**Pink**" means that more than 30 percent but not more than 60 percent of the surface, in the aggregate, shows pink or red color;

(5) "**Light red**" means that more than 60 percent of the surface, in the aggregate, shows pinkish-red or red: *Provided*, That not more than 90 percent of the surface is red color; and,

(6) "**Red**" means that more than 90 percent of the surface, in the aggregate, shows red color.

The above photographs are only guides illustrating the shade and percentage of surface color specified for each of the color terms. These photographs do not necessarily depict absolute limits of minimum or maximum shades and/or percentage of color required for each term.

Figure 2.1 Tomato stages during the ripening process, (after USDA, 2011)

Getinet *et al.* (2008) reported that tomatoes (three cultivars) harvested at mature green stage maintained better chemical quality and marketability compared to ones harvested at turning and light red stage, stored under same conditions. Fruit quality varied with cultivars, but fruit harvested at mature green stage maintained high total sugars, reducing sugars and other quality parameters, in both cultivars (Getinet *et al*., 2011). Teka (2013) argued that at green-mature stage, tomato was firmer than at other stages thus most susceptible to mechanical injury than medium ripe and red ripe fruits. Therefore, there is still debate between researchers about the exact time for harvesting tomatoes. Pinheiro *et al*. (2013a) also argued that tomatoes harvested **at** green mature stage are highly resistant to pathogen attacks when compared to ripe tomatoes.

2.3.2 Time of harvesting

According to Getinet *et al*. (2008) tomatoes must be harvested early in the morning by hand to minimize mechanical injury. Harvesting of perishable produce must take place during the coolest part of the day to minimize field heat (Wu, 2010). Clarkson *et al.* (2005) who conducted the same study in lettuce argued that, improved lettuce shelf life at the end of the day is also associated with additional assimilates accumulated during the harvesting day. No information has been found concerning harvesting at the end of the day, on tomato shelf life. This could be associated with the practices that need to be done after harvest e.g. pre-cooling, so producers secure their time of doing this by harvesting in the morning.

2.3.3 Harvesting method

To ensure optimum quality and extended shelf life, tomatoes must be harvested manually (by hands) to minimize mechanical injury (Getinet *et al*., 2008). Most postharvest losses that occur in tomato fruit are due to mechanical damage that occurs mainly during harvesting and storage (Arazuri, 2007). Mechanical injury that occurs in fresh fruits result in stimulated metabolic activities, hence hastened rate of fruit quality deterioration (Shafiur, 1999). Mechanically harvesting tomatoes result in elevated levels of bruising, and stimulate fruit quality loss (Li *et al*., 2010). Fruit quality maintenance also depends on the whether the fruit was harvested with stalk or without stalk. Bhattarai and Guatam (2006) reported that tomatoes harvested with stalk had longer shelf life than the ones harvested without stalk after storage under similar conditions. Therefore, harvesting method is important and needs to be considered when long shelf life of tomatoes is desired.

2.4 Locations and supply chain routes

The shelf life of fresh tomatoes depends on the distance, and road quality between the production and the consumption area which also significantly affect the quality of tomato during distribution (Roy *et al.*, 2008). Poor road quality influences tomato fruit quality significantly by causing injuries in the fruit surface which also increases the respiration rate and fruit transpiration (Mintem and Kyle, 1999). Temperature is a key factor that affects the rate of fruit respiration (Wu, 2010), therefore refrigerated trucks need to be adopted for maintaining quality of tomatoes (Roy *et al*., 2008). However, in many instances, refrigerated trucks are unaffordable for small scale farmers, especially in developing countries; therefore, these quality losses are continuously incurred (Mintem and Kyle, 1999). But integration of disinfectants, edible coatings and storage temperature may significantly reduce postharvest losses in tomatoes if applied immediately after fruit transport from the field to a packhouse (Ali *et al*., 2013; Workneh and Osthoff, 2010).

Travelling on gravel or poor roads causes fruits to shake, which results in some mechanical injury during transportation (Parker and Maalekuu, 2013). Mechanical injuries that take place in tomatoes during transportation are the major causes of fruit quality deterioration (Arazuri *et al.*, 2007). Injuries on the tomato fruit surface damage the membrane surrounding the fruit, thus resulting in fruit losing juice before it reaches the consumer (Arazuri *et al.*, 2007). Physiologically, any damage on the fruit surface results in stimulation of ethylene production, hence high rate of fruit respiration. It also stimulates the rate of water loss from the fruit, hence loss of firmness, glossiness, mass and subsequently economic returns, since fruits are sold on the mass basis (Wu, 2010). In addition, any scratch or cut in the fruit surface become a site of fungal infection and microbial growth which are proliferated under high temperature (Arazuri *et al.*, 2007; Prusky, 2011). Enzyme activities including peroxidase activity increase in response to high temperature, so as to resist further pathogenic infection (Workneh *et al*., 2012).

Mitigating postharvest losses

Ensuring prolonged postharvest shelf life of tomato starts from harvesting at the correct maturity stage depending on the harvesting purpose and season (Teka, 2013, Constán-Aguilar *et al.*, 2013). Prematurely harvested fruit has not yet attained sufficient carbohydrates to survive independently (Melkamu *et al.,* 2009). Tomatoes harvested at the right maturity stage, depending on harvesting purpose, usually have a potential to exhibit long shelf life, while overripe tomatoes have shortest shelf life. The short shelf life of overripe tomatoes is associated with low levels of protective antioxidants such as phenolic compounds, ascorbic acid etc. at overripe stage. Transportation is another factor that needs to be considered, because fruit lose quality during the transportation period, especially at a long distance (Roy *et al.*, 2008). In addition, roughness of a road might cause mechanical injuries, which significantly adds to fruit quality deterioration (Minten and Kyle, 1999). In most developed countries refrigerated trucks are used to maintain cold chain (Roy *et al.*, 2008), however in South Africa non-refrigerated trucks are only used to supply small supermarkets, such as Woolworths, Pick'n Pay, where small stocks are transported. The main supermarkets which are supplied in bulks still used non-refrigerated trucks. Therefore, higher temperatures (> 13 °C) of non-refrigerated trucks, which affect poor storage conditions, are normally used. High temperature storages stimulate the physiological, biochemical and microbiological activities that occurs within a fruit, which resulting in fruit spoilage (Kader *et al*, 1989).

2.6 Pre-storage treatments

The major role of pre-storage treatment is to control the agents of postharvest diseases prior to fruit storage. Pre-storage treatments are chosen on the basis of their efficiency in controlling fruit postharvest diseases, less interference with the environment as well as low hazards in human health. The most common pre-storage treatments that have been used to reduce fruit quality loss are chemicals and physical treatments (Workneh and Osthoff, 2015). There are many pre-storage treatments that have been shown to be effective in maintaining fruit quality, however, only commonly used and effective pre-storage treatments will be discussed in this section.

2.4.1 Chlorinated water

This is an effective disinfectant that is commonly used after washing fruits and vegetables mainly to control microbial load (Workneh *et al.,* 2012). Chlorinated water has been widely used in the fruit and vegetable postharvest industry. It has been used in different forms namely:

sodium hypochlorite, calcium hypochlorite and chlorine gas (Barth *et al.*, 2009), however it seems to be more effective in the calcium chloride form (Pila *et al.*, 2010). Chlorination represents one of the few chemical strategies effectively used in controlling postharvest losses of fruit and vegetables (Boyette *et al*., 1994). Chlorinated water is prepared by dissociation of sodium hypochlorite in water. Elemental chlorine or hypochlorites are quickly hydrolysed when added to water and usually result in hypochlorous acid and chloride ion. Hypochlorous acid is highly active in this disinfectant, however it is temperature and pH dependent (Wei *et al*., 1985). Therefore, for the efficiency this disinfectant to be maximized, the pH of water must be kept at 6.5-7 range (Barth *et al.,* 2009).

It is highly effective as a postharvest dipping treatment for tomatoes when containing 100 µg ml^{-1} free chlorine, which is prepared using 5% sodium hypochlorite (Nunes and Emond, 1999; Rogers *et al.,* 2006). It significantly reduced microbial load in bell peppers (Nunes and Emond, 1999), in tomatoes (Workneh *et al*., 2012) and reduced mancozeb residues in tomatoes (Cengiz and Certel, 2014). Its efficacy is enhanced when integrated with other effective postharvest handling practices (Workneh *et al.*, 2012). Chlorinated water is an effective pre-storage treatment, which poses only minor threats to human health and environment (Boyette *et al*., 1994). It also results in some off-flavours which hide the true taste of fruit or vegetable (Hassenberg *et al.*, 2008). It is relatively cheap (Boyette *et al*., 1994) thus affordable by small scale farmers.

2.4.2 Anolyte water

Anolyte water is also known as electrochemically activated water that is made up of an aqueous solution of sodium chloride (Workneh and Osthoff, 2015). Activation of water is defined as a change of molecular state of water from stable to metastable state (Seyoum *et al.,* 2003). Activated water is distinguished by having high physico-chemical and biological activity (Aider *et al*., 2012). Water may be activated and transferred to a non-equilibrium thermodynamic state using physico-chemical and biological methods (Aider *et al.,* 2012). Electrical activation is the most effective method of activating water, among all methods (Bahir, 1996). There are two types of electrically activated water, namely anolyte and catholyte. Anolyte water is characterized by having an oxidation-reduction potential (ORP) in the region of +1000 mV and catholyte an ORP of -8000 mV (Workneh and Osthoff, 2015). Anolyte water is also characterized by having a pH value that is in the acidic region, while catholyte has a pH value in the alkaline region (Workneh and Osthoff, 2015). It contains free radicals which gives it sporicidal and bactericidal activities, thus contains more antimicrobial effects. These features are beneficial for fruit protection against microbial effects, since fruits only contain antioxidants as a defence system (Aquastel, 2000).

Anolyte is advantageous for use in the postharvest industry of fruits and vegetables due to the fact that it is environmentally and eco-friendly (Seyoum *et al*., 2003; Workneh and Osthoff, 2015). Postharvest dipping of carrots in anolyte water significantly reduced growth of aerobic bacteria, moulds, yeasts and coliform bacteria in carrots (Seyoum *et al.*, 2003). Anolyte water is harmless to human health (Seyoum *et al.*, 2003) and is affordable by small and large scale farmers.

2.4.3 Hot water

Hot water treatment is well-known as an easy to use treatment. It is a reliable disinfectant, with very short treatment time (Fallik, 2004). Hot water has been extensively used in many vegetables and fruits of temperate, subtropical and tropical origin mainly for inhibiting spoilage during the postharvest period (Schirra *et al*., 2000). Hot water immersion technology has an economic advantage, for example it costs approximately 10% of a commercial vapour heat treatment system (Jordan, 1993). Hot water dipping treatment has also been used as a quarantine treatment mainly against Mexican fruit fly (Fallik, 2004). The temperature range of dipping water for quarantine purposes is 43-49 °C, however, the dipping period depends on commodity size (Fallik, 2004). Generally, the bigger the fruit, the longer the dipping period in order to optimize the disinfection. The efficiency of hot water disinfectant has been evidence in many different fruits, and it protects fruits against rot without affecting fruit quality parameters and marketability (Fallik, 2004).

Hot water disinfection is advantageous for being a simple, yet useful treatment which is applicable to a wide range of fruits and vegetables. Hot water not only works as a disinfectant, but is also beneficial in fruit and vegetable physiology by inhibiting biochemical processes leading to fruit ripening. Hot water appears to be one of the most promising postharvest treatments, since it inhibits accumulation of lycopene, chlorophyll degradation and reduces fruit metabolic processes (Pinheiro *et al*., 2013a). It protects fruits and vegetables against pathogen attack by inducing defence system around outer layers. It also protects fruits against chilling injury by inducing heat shock proteins (Fallik, 2004).

2.4.4 Edible coatings

An edible coating can be defined as a coating technique that involves application of a thin layer of a material that is suitable for consumption (González-Aguilar *et al*., 2010). This material serves as a barrier against different agents such as oxygen, moisture and water vapour, hence enabling protection on the surface of a horticultural commodity (González-Aguilar *et al*., 2010; Eca and Sartori, 2014). The major components of edible coatings are lipids, polysaccharides, pectin, starch derivatives, proteins and their combinations (Pinhiero *et al.*, 2013a. The most common compounds that are used to make edible coating are cellulose, chitosan, starch, alginate, beeswax and fatty acids. Gum Arabic is an example of edible coatings in current use. As an edible coating material, Gum Arabic has shown its effectiveness by significantly delaying ripening in cold stored apples (El-Anany *et al.* 2009) and prolonging shelf life and maintaining quality of green mature tomatoes during storage at ambient temperature (Ali *et al*., 2010). Ali *et al*. (2013) also reported that Gum Arabic edible coating significantly delayed the ripening process and maintained the antioxidant capacity of green matured tomatoes stored at 20 °C. Gum Arabic (GA) creates a barrier around the fruit, thus hinders the gaseous exchange, which result in the reduction in the respiration rate and ethylene production, hence maintaining quality and extending shelf life of tomatoes (Ali *et al*., 2010; Ali *et al*. 2013). GA is a mixture of polysaccharides and glycoproteins (Patel and Goyal, 2014). It also delayed ripening, maintained quality, antioxidant capacity, physico-chemical properties and significantly reduced microbial burden in pawpaw fruit during storage (Addai *et al.*, 2013). This edible coating has also recently been reported to affect significant delay in loss of physio-chemical properties of Carambola fruit (Gol *et al*, 2015), and also to maintain the physio-chemical and sensorial properties of pears (Cruz *et al*., 2015

Some studies have been done on evaluating the effectiveness of GA in maintaining quality and extending shelf life of tomatoes, however, none of them evaluated the physiological, biochemical, and microbiological response of tomatoes of different maturity stages to it. Gum

Arabic is harmless to human health, eco-friendly (Motlagh *et al.*, 2006), easy to apply and affordable, thus can be suitable for small scale and large scale farmers.

2.6 Assessment of fruit quality

Tomato fruit quality is assessed using various parameters, such as physical, chemical, biochemical, microbiological and sensory properties. This is due to the fact that all of these parameters are the components of fruit quality (Workneh, 2010).

2.6.1 Physical properties

Colour

Colour is the primary visual quality parameter of tomato that determines consumer purchasing decisions (López Camelo and Gómez, 2004; Batu, 2004). The fruit surface colour is the one of the key determining factors of fruit maturity stage (Wang *et al*., 2011). Getinet *et al*. (2008) note that tomato colour also serves as an indicator of when to harvest. It determines the ripeness and the shelf life of tomatoes (López Camelo and Gómez, 2004). The surface colour of a tomato fruit is influenced by many factors including light and storage temperature (Verhuel *et al.*, 2015). It is also affected by the maturity stage, storage period and atmospheric composition in the fruit surroundings (Baltazar *et al*., 2008).

The most common methods of assessing tomato fruit colour are colour charts and colorimeters. These instruments are used mainly to distinguish different ripening stages of tomato fruits (Baltazar *et al*., 2008). Van Zeebroeck *et al*. (2007) reported that the lack of uniformity in tomatoes bias the colorimeter test results. One of the main instruments currently used for assessment of tomato colour, non-destructively, is the Raman spectroscopy technique (Saad *et al*., 2014). There are three main colour changes during tomato fruit development, namely; green, orange and red. Green colour (high chlorophyll) is degraded for the accumulation of carotenoids, mainly ß-carotene (orange colour), which is also degraded for the accumulation of lycopene (red colour) (Pinhiero *et al*., 2013a). Tomato ripening stages are classified according to Gierson and Kader (1986) in Table 2.1 below.

Table 2.1 The ripening stages of tomato fruit (Gierson & Kader, 1986)

Ripening stages	**Class**	**Description**
1	Mature green	100% light-to dark-green, but mature
2	Breaker	First appearance of external pink, red or greenish yellow colour; not more than 10%
3	Turning	Greenish-yellow colour; not more than 10% (>10%) but not more than 30% red, pink or orange-yellow
4	Pink	(>30%) but not more than 60% pinkish or red
5	Light-red	(>60%) but not more than 90% red
6	Red	(>90%) red; desirable table ripeness

All percentages refer to both colour distribution and intensity.

Firmness

Fruit firmness defines a force required as an input on the fruit surface to cause tissue collapse (Wann, 1996). It is one of the most important quality parameters that determines marketability and shelf life of tomatoes (Wann, 1996; Batu, 2004). It is determined by many factors including the structure of the cell wall, cuticle properties and cell's turgor (Chaib *et al.,* 2007, Chapman *et al*., 2012). Crookes and Grierson (1983) reported that loss of tomato fruit firmness during ripening is associated with the separation of the primary cell wall and the middle lamella. Firmness of a tomato fruit tissue during ripening is mainly controlled by the cell wall integrity as well as the enzymatic softening that takes place due to the ripening process (Wann, 1996). Workneh (2009) reported that increasing temperature results in the loss of fruit firmness due to the activation of enzymes that enhance degradation of cell walls. Therefore, it is essential to control storage temperature in order to sustain tomato quality and shelf life. Measuring fruit firmness is the best method to be used in monitoring fruit softening and bruising effects during harvest and postharvest handling (Valero *et al*., 2007). Batu (2004) reported that for a tomato fruit to be acceptable and remain competitive in supermarket shelves its firmness must be greater than 1.46 N/mm.

2.6.2 Physiological properties

Ethylene production and respiration rate

According to Wu (2010), tomatoes are climacteric fruits, so their ripening process is characterized by high accumulation of ethylene as a ripening hormone, which then triggers the high respiration rate, hence high rate of fruit quality deterioration. Effective postharvest handling of fruits and vegetables is thus associated with reducing their respiration rate, because it is inversely proportional to the fruit shelf life (Irtwange, 2006; Singh *et al*., 2013). Therefore, fruit quality and shelf life can be assessed by the rate of ethylene production and respiration rate (Irtwange, 2006; Wu, 2010; Workneh *et al*., 2012). The respiration rate of tomatoes is measured using gas analysers (Singh *et al.,* 2013).

Mass loss

The fresh mass of tomato fruit is dominated by water. Most fresh fruits are harvested while they contain approximately 70-95% of water thus have maximum fresh mass (Pinheiro *et al.,* 2013b). Organic compounds only contribute about 6%, of which skin and seeds contribute 1% (Turhan and Seniz, 2009). Physiological mass loss occurs as a result of fruits continuously losing water through transpiration, resulting in softening, shrinkage, and fading appearance. (Irtwange, 2006; Pinheiro *et al*., 2013b). The fruit physiological mass loss is greatly influenced by the storage temperature and relative humidity surrounding the produce (Workneh, 2010). Storage of fruit at high temperatures and low relative humidity results in the fruit respiration rate being elevated which causes physiological mass loss (Workneh *et al*., 2009). This cause significant losses economically, since tomatoes and other fresh produce are sold on the mass basis. It also result in the marketability based on appearance being reduces, since mass loss result in fruit shrinking and dull surface, thus unattractive to consumers.

2.6.3 Chemical properties

Chemical composition of tomato fruit is the major determinant of fruit maturity and quality) Chemical composition in tomato defines the amount and the proportion of different chemical compounds contained within the fruit mainly glucose, fructose, proteins, fibre, ash and moisture content Assessment of tomato fruit quality is done by evaluating chemical compounds such as total soluble solids (degree brix), acidity, sugars, citric acid and other organic acids (Suárez *et al.,* 2008a). The major components of tomato flavour with highest contribution quantitatively are chemical properties (Suárez *et al*., 2008b). This is due to the fact that tomato ripening and quality deterioration is characterized by a series of qualitative and quantitative changes in chemical composition.

Total soluble solids (TSS)

Total soluble solids (TSS) are important parameters in assessing maturity and quality of many fruits and vegetables (Kader, 1999). TSS is measured using a digital refractometer which expresses the results in degree brix (ºBrix), indicative of the TSS percentage (Kader, 2008; Beckles, 2012). ºBrix defines the ratio of the total soluble solids to water in a solution (Pothula *et al.,* 2014). Sucrose, glucose and fructose are the major components of the TSS, and major determinants of fruit flavour (Suárez *et al.*, 2008a; Kola *et al.*, 2015). These sugars contain the majority of the total dry matter content of tomato and increases with fruit ripening stage and quality (Parker and Maalekuu, 2013). TSS denotes the dry matter content of tomato fruit and it is inversely proportional to the fruit size (Beckles, 2012). The increment of sugars with ripening stages of tomato is associated with metabolism of carbohydrates, proteins and lipids (Lira *et al*., 2016). Tomato fruit flavour is determined by the amount of sugars (glucose, fructose and sucrose) and acids contained in it (Turhan and Serniz, 2009). The proportion of glucose and fructose is higher than the one for sucrose in tomatoes (Georgelis and Scott, 2004; Suárez *et al.*, 2008a). The best flavour of tomatoes occurs as a result of high sugars which result in high TSS and relatively high acids content, because too high acid contents results in sour tomatoes (Turhan and Serniz, 2009). Total soluble solids are good indicators of quality in fresh produce such as fruits and vegetables.

Citric acid

This is the major primary acid found in tomato fruit, and it is responsible for giving sourness in tomato fruit (Georgelis and Scott, 2004). Tomato is known as one of the highly acidic fruits with a pH range between 4 and 4.5 (Cheema *et al.*, 2015). Acidity in tomatoes makes it less susceptible towards bacteria, yeast and moulds as compared to other vegetables, (Workneh, 2010). Citric acid is measured together with other acids such as malic acid contained in tomatoes by using a pH meter. The pH meter measures citric acid as total acidity, however these results are reliable since citric acid is the dominant organic acid in tomato fruit (Shahnawaz *et al*., 2012). Tomato fruit pH at harvest is the major determinant of quality and shelf life (Mohammed *et al*., 1999).

Lycopene

Lycopene is a red compound responsible for red colour in tomato fruit. It is present in high concentrations in tomatoes and most tomato products (Viskelis *et al.*, 2008), comprising approximately 80-90% of pigments in ripe tomatoes (Shi, 2000). Lycopene has been recognized for being the most functional and beneficial carotenoid in tomatoes just because of its compounds that provide protection against cancer and heart disease (Viskelis *et al.*, 2008; Javanmardi and Kubota, 2006). The degradation of lycopene, therefore, does not only affect tomato fruit appearance (colour) or flavour, but it also affects nutritional quality of tomatoes (Shi, 2000). Lycopene concentration varies with different tomato cultivars, stage of maturity, harvesting seasons and management during a growing season. Stahl and Sies (1996) reported that lycopene is also known as a potential antioxidant which is also involved in delaying oxidation of membrane lipids (Javanmardi and Kubota, 2006). It achieves this by quenching the reactive oxygen species such as singlet oxygen (Shi, 2000). The measurement of lycopene is therefore important to assess nutritional quality of tomatoes.

Antioxidant activity

Antioxidant activity of tomatoes can be defined as the ability to inhibit the activities of the reactive oxygen species (ROS) and delay oxidation of membrane lipids, hence sustain fruit quality of tomatoes (Javanmardi and Kubota, 2006; Gómez-Romero *et al*., 2007). The major antioxidants found in tomatoes are carotenoids (mainly lycopene and β-carotene), phenolic compounds and ascorbic acid (Javanmardi and Kubota, 2006; Toor and Savage, 2006; Gómez-Romero *et al*., 2007). Consuming tomatoes provides the benefits of these antioxidants which are essential and beneficial in the human body. Antioxidants use different mechanisms to achieve this; they may quench the reactive oxygen species or scavenge the peroxyl radicals (Martínez-Valverde *et al.*, 2002). The antioxidant activity of tomatoes generally increases during low temperature storage, which is associated with metabolism of phenolic compounds during ripening (Javanmardi and Kubota, 2006).

2.6.4 Biochemical properties

Biochemical activities that take place during the postharvest life of fruits and result in the loss of fruit firmness, discolouration, and development of off-flavours are all controlled by enzymes (Workneh, 2010). There are many enzymes involved in fruit quality; however, the most important enzymatic activities in sustaining tomato fruit appearance, quality and shelf life are polyphenol oxidase, peroxidase activity (POX) and polygalacturonase (PG) activity. These enzymes are responsible for almost all biochemical and chemical changes that occur in fruit and result in quality deterioration. Monitoring of these enzymes (or their activity) is therefore important to evaluate fruit quality.

2.6.5 Microbiological properties

Microorganisms cause approximately 15% of postharvest decay in fruits and vegetables (Workneh, 2010). The shelf life of fresh fruit and vegetables is dependent on the microbial population within and on the surface of each produce during harvesting (Teka, 2013). Bacteria and fungi are the key microorganisms that jeopardize quality of fruit and vegetables. Therefore, the postharvest life of tomatoes is estimated based on the total number of microorganisms during harvest, handling and storage. Microorganisms are sourced anywhere during the fresh produce growing season and during the postharvest operations. Therefore, monitoring of microbial population in the form of colony forming units (CFU) provides good indicators of tomato quality after harvest (Workneh, 2010).

2.7 Discussion and summary

Tomatoes are very important and nutritious fruits worldwide (Viskelis *et al.*, 2008). Its consumption is higher than all other fruits (Arthur *et al.*, 2015). Postharvest losses of about 40-50% have been reported in developing countries, mainly between harvesting and consumption (Pila *et al.*, 2010). One of the major factors affecting tomato postharvest losses is supply chain routes. During fruit transportation there are vibrations in the trucks, and the severity and effect of the vibration is determined by the road quality and distance travelled (Parker and Maalekuu, 2013). These vibrations affect fruits by causing bruising and other mechanical damages. This leads to cuts, bruises and other mechanical damages which lead to loss of fruit juice (Arazuri, 2007). These mechanical damages affect fruit physiologically, by speeding up the rate of ethylene production, respiration and transpiration; hence fruit quality deterioration before arrival at the market (Arazuri, 2007). In addition to that, any form of cut or scar becomes the site of fungal infection and site of microbial growth. Severity of mechanical damages is determined by the transporting distance.

The severity of mechanical damages that occur during fruit postharvest life varies with fruit maturity stage. Teka (2013) reported that green-matured fruits are firmer that pink- and red-matured fruits, thus more susceptible to mechanical injuries. In addition to mechanical damages, all physiological, biochemical and microbiological factors leading to fruit deterioration also vary with fruit harvesting maturity stage. Tomato cultivars harvested at green maturity stage showed high marketability and retained better chemical quality when compared to samples harvested at turning and red maturity stage (Getinet *et al.,* 2008) although physiological processes such as ethylene production and respiration are generally higher in green-matured fruit than pink- and red-matured fruit (Wu, 2010).

Several practices such as blanching, low temperature storage, coating, and disinfectants have shown positive results in retaining quality of tomatoes after harvest (Teka, 2013). However, some of these treatments were not cost effective especially for developing countries with emerging farmers. Pre-storage treatments have shown potential in reducing tomato fruit deterioration rate, mainly by controlling postharvest diseases before fruit storage (Workneh, 2010). This is due to the fact that approximately 15% of postharvest diseases are caused by microbial decay. Selection of pre-storage treatments is no longer based on only the effectiveness in controlling diseases, but minimal residues and environmental friendliness (Workneh, 2010). Anolyte water treatment, Gum Arabic coating, hot water treatment and chlorinated water are promising pre-storage treatments in maintaining shelf life of tomatoes (Workneh, 2010; Getinet *et al*., 2008; Ali *et al*., 2010, Ali *et al*., 2013).

In the literature review, different technologies were reviewed and discussed as potential options to be used to minimize tomato postharvest losses and extend tomato shelf life. The most critical point noted about the technologies is that they possess different techniques (modes of action) which however lead to the same goal of extending the shelf life of tomatoes. Furthermore, it has been noted that effectiveness of these technologies varies with tomato fruit harvesting maturity stages. Documented information with regards to minimizing tomato postharvest losses only start from the packhouse, while losses start during harvesting. Therefore, after reviewing literature, it has been noted that there are knowledge gaps in managing the whole tomato supply chain, which might help, reduce these losses. There is insufficient information on the effects of harvesting, handling and transporting tomatoes in fruit quality and shelf life. Furthermore, literature regarding the effect of the integration of the pre-storage treatments with low temperature in prolonging shelf life of tomatoes of different maturity stages is not adequately documented in South Africa. Therefore, this study aims to fill that gap, by evaluating the effect of the supply chain routes and pre-storage treatments in the (1) microbiological; (2) physiological, biochemical properties of tomatoes, and (3) to evaluate the most suitable harvesting maturity stage that will minimize postharvest losses.

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3. EVALUATION OF THE EFFECTS OF THE SUPPLY CHAIN ROUTES AND PRE-STORAGE TREATMENTS ON THE MICROBIAL QUALITY OF TOMATOES

ABSTRACT

The effect of disinfecting tomatoes with different solutions (anolyte water, chlorinated water and hot water) or coating tomatoes (with Gum Arabic), on the microbiological quality of tomatoes during storage after transportation in non-refrigerated trucks along three different supply chain routes was evaluated. Pink-matured tomatoes with freedom from blemishes were treated, stored at either ambient (16/ 25 °C) or cold (11 °C), and sampled on day 0, 16 and 30 for quality assessment. An experiment was laid out as a split-plot factorial design, with supply chain routes as main plots, storage conditions as sub-plots and random allocation of treatments within each sub-plot. There was highly significant difference ($P < 0.001$) in the microbiological population (log cfu cm^{-2}) and marketability (%) of tomatoes from different supply routes, storage environments, and treated with different disinfectants. Anolyte water was the most effective treatment, it reduced the initial microbial load significantly ($P < 0.001$) to 2.835 log cfu cm^{-2}, and it also limited the microbial growth to 3.419 log cfu cm^{-2} during day 16, which was the lowest microbial population. This represented the highest log reduction of 1.470 log cfu cm^{-2}, when compared to untreated samples which had 4.828 log cfu cm^{-2}. Furthermore, three-way interaction of supply route, disinfectants, particularly anolyte water with low temperature storage remained the most superior treatment in maintaining marketability of pink-matured tomatoes. Therefore, since all these factors (routes, treatments and storage) are crucial in sustaining fruit quality, postharvest treatment integration is recommended to be researched further as a potential substitute to chemical disinfectants used in tomatoes and other fruit industries.

Key words: Tomatoes, postharvest losses, supply routes, maturity stages, treatments, storage

3.1 INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is popular among vegetable crops due to the dietary and health benefits that it entails (Perveen *et al*., 2015). The tomato fruit contains antioxidants, mainly lycopene and β-carotene which are important for human nutrition (Bramley, 2002, Ali et al., 2010). Lycopene is well known for contributing to the prevention of different cancers, mainly lung, stomach and prostate cancer (Perveen *et al.*, 2015), while β-carotene is an important precursor of vitamin A, which has been identified as important for eyesight (Bramley, 2002). Moreover, tomato fruit also contains vitamin C, important for the formation of a protein called collagen, which is responsible for giving structure of bones, muscles and cartilage (Bramley, 2002). Postharvest losses have been continuously reported in this crop, especially in developing countries mainly during transporting and storage (Ali *et al*., 2010, Sibomana *et al*., 2016). Pre-harvest factors that influence fruit losses after harvest include; manure fertilized fields, quality of irrigating water and inappropriate seeding (Heaton and Jones, 2008).

Approximately 15% of postharvest decay is caused by microorganisms in fruit and vegetables (Liplap *et al*., 2014). These losses occur between harvesting and consumption periods, and decay is the major cause of these losses (James and James, 2010). The most active groups of microorganisms in reducing quality of fruit and vegetables are bacteria, yeasts and moulds (Shi and Maguer, 2000, Workneh and Osthoff, 2015). Barth *et al*. (2009) reported that fruit and vegetables provide a conducive environment for multiplication of microorganisms. Moreover, tomatoes can host foodborne pathogens which may cause serious threats when ingested (Heaton and Jones, 2008).

Quality and shelf life of fresh produce is dependant on the microbial population at harvest (Teka, 2013), as well as during storage and marketing. Even though decay-causing microorganisms may be present during harvesting, but fruit deterioration predominantly manifests during fruit transportation and storage (Barth *et al.*, 2009). Travelling on gravel or poor quality roads causes vibrations which may result in mechanical injuries in fruit (Parker and Maalekuu, 2013). Any scratch or cut on the fruit surface as a result of mechanical damage, becomes a site of microbial infection or fungal growth, hence reducing fruit quality (Prusky, 2011).

Much work has been done to develop novel methods to control postharvest decay in tomatoes (Workneh *et al*., 2011, Teka, 2013). Postharvest dips in chlorinated water were found effective in reducing microbial load and limiting microbial growth in bell peppers (Nunes and Emond, 1999) and in tomatoes (Workneh *et al*., 2012). Anolyte water disinfectant was also effective in reducing postharvest decay in carrots (Seyoum et al., 2011b), and hot water in tomatoes (Fallik, 2004, Pinheiro *et al.,* 2013). The study aims to evaluate the effect of supply chain routes and pre-storage treatments on the microbial load and marketability of pink-matured tomatoes.

3.2 MATERIALS AND METHODS

3.2.1 Site description

Fresh tomatoes, cv. 'Nemo-Netta', of pink maturity stage were harvested or sourced from three different commercial farms in Limpopo province, South Africa. Tomatoes from different sites were grown in open-fields with staking. Site 1 Pontdrift (PD) region (22° 21' 67" S, 29° 16' 67 E), 266 km to the pack-house and a further 827.1 km to the Pietermaritzburg market. Site 2 Letaba Municipality (LM) (22° 19' 48''S, 30° 28' 19 E), in Musina Rural, 229.6 km to pack-house and further 827.1 km to Pietermaritzburg market. Esmé 4 (EF) region (23° 49' 04" S, 30° 18' 11 E) which is about 270 km to the Rietpol pack-house (23.8962° S, 29.4486° E) and further 827.1 km to the Pietermaritzburg market. Fruit at the pink mature stage were selected for this study, because in the South African market tomatoes at this stage are the most valuable economically. Fruit were hand-harvested to reduce mechanical injury. Uniformity in colour and size was ensured to reduce experimental bias. Only fruits that are free from blemishes were selected for experimentation, and fruits with any sort of mechanical injuries, defects, or bruises were discarded.

3.2.2 Experimental design

The experimental design constituted a factorial type, split-plot in a randomized complete block design, with specific factors as 3 harvest sites (supply chain routes), 5 pre-storage treatments, (Anolyte water, chlorinated water, hot water treatment, Gum Arabic coating and the control), 2 storage conditions (ambient and cold storage) and the three sampling dates. Arrangement of factors was in a form of split-plot design with supply chain routes as main plots, storage conditions as sub-plots and random allocation of treatments within each sub-plot.

3.2.3 Transportation packaging

The tomatoes were transported in non-refrigerated trucks from the harvesting area to the storage area. The crates used for transporting the fruit were made of UV-stabilised impact modified polypropylene, with double-walled corners and a 478 kg capacity (Mpact, Johannesburg, South Africa). The dimensions of the crate consisted of an internal area of 1267 mm x 1067 mm and a depth of 400 mm, with 640 air vents located in the side panels and floor. The boxes used in transporting the fruit were corrugated boxes with a 6.5 kg capacity (Mpact, Johannesburg, South Africa). The corrugated boxes had dimensions of 390 mm x 240 mm and a height of 140 mm. The boxes had 4 air vents on the side panels and 4 air vents in the bottom panel. The crates were stacked 4 high with data loggers, to measure temperature and relative humidity during transport, placed on top of the tomatoes in the bottom, middle and top crate. The boxes were stacked 4 across x 3 wide x 13 high, and one data logger was placed on top of the fruit in a box in the bottom, the middle and the top row.

3.2.4 Postharvest treatments

Tomatoes were treated, upon arrival in Pietermaritzburg, with (ca. 150 mg/L free chlorine) or Gum Arabic (10% w/v) for 3 min, or hot water (42 °C) for 30 min, or anolyte water for 5 min as specified by Workneh *et al*. (2012). The targeted chlorine concentration was between 100-200 mg/L, as recommended by the current tomato industry for disinfection of fresh produce effectively.

Anolyte water treatment

Ready-to-use neutral anolyte water was supplied in 25-litres plastic containers by Radical Waters (Midrand, South Africa). Preparation of the solution involved mixing 5 % Sodium Chloride (NaCl) in potable water and an ionizing generator operating at a pressure of 50 kPa, which results in the production of anolyte and catholyte solutions. A neutral pH anolyte was produced by mixing approximately 10 % of the resultant catholyte solution with the anolyte solution. The plastic containers were used to prevent loss of charged ions in the solution (Workneh *et al.*, 2012). The neutral anolyte solution was delivered and used within 2 days of production to avoid loss of ionic properties. After dipping treatments, samples were surface dried and then packed into clean tomato cartons.

Gum Arabic coating

Gum Arabic coating was sourced from AEB Africa (Pty) Ltd, Cape Town, South Africa. AEB Africa (Pty) Ltd provide Gum Arabic in the form of Arabinol HC with 40% pure Gum Arabic (GA). Gum Arabic (GA) (10% w/v) coating was made by diluting Arabinol HC (contains 40% GA) with distilled water using adjusted calculations to make it 10% w/v GA. About 15 litres of anolyte water solution was used and 45 fruit were dipped per unit time. Fruit were dipped for 3 min and air-dried on the surface before staorage.

Chlorinated water

Chlorinated water was prepared by dissolving calcium hypochlorite granules (Frexus® CH, Arch Chemicals, Johannesburg, South Africa) in deionized water at ambient temperature. Manual dosing, as per manufacturer's instructions, was performed by adding 3.3 g of the $Ca(ClO)_2$ granules to 15 L of deionized water, to attain a free chlorine concentration of 150 mg/L, with the biocidal agent being hypochlorous acid. Frexus® CH is an approved, SANS 1853, South African Bureau of Standards. 2001. SANS 1853 Ed. 1.01: Disinfectants and Detergent-Disinfectants for use in the Food Industry. South African Bureau of Standards, Pretoria, South Africa.

Hot water treatment (HWT)

The water bath was prepared by adding about 25 litres of water, adjusted to 42 °C and left for 15 minutes to stabilize. About 45 tomato fruit of similar maturity stage were immersed in the hot water for 30 minutes and then removed. Immediately upon removal, they were cooled under running cold tap water (Fallik, 2004), coated with GA, and allowed to surface dry before they were taken to a storage environment.

3.2.5 Environmental conditions during fruit storage

Fruit were then divided into two groups, and stored either at ambient temperature (approximately 16 °C in winter or 25 °C in summer) or in a controlled temperature unit (set at 11°C). Data loggers (HOBO® data logger temp/RH/2 ext channels, U12-013) were used to monitor a change in temperature inside the cold room, relative humidity was not controlled during storage. Data loggers were placed in the shelf at cold room and on the table at ambient storage.

3.2.6 Data collection

Three fruit per treatment were sampled immediately after complete surface drying (day 0), on day 16, and on day 30. This study involved tomato quality assessment based on the surface burden of total aerobic bacteria and marketability.

3.2.7 Microbial analysis

Briefly, each tomato was weighed and washed in a sterile plastic bag with 30 ml peptone water (per L distilled water; 8.5 g NaCl and 1 g peptone, pH=7) for 5 min. One millilitre of the peptone water in the bag was then, aseptically, pipetted into a 9 mL test tube of sterile peptone water. Decimal dilutions were made by pipetting 1 mL of the mixture from first up to the sixth test tube (10^{-6} dilution). The dilutions were thoroughly mixed (1 minute, Fisherbrand Whirlimixer model CM-1, Fisher Scientific, Massachusetts, USA), and spread-plating was done after aseptically transferring 100 µL from each dilution into petri dishes with plate count agar (Merck, Germany). Plating was duplicated, which resulted in 12 petri-dishes per fruit sample. After plating, petri-dishes were incubated at 28 °C for 48 hours, followed by colony counting according the ISO 4832 method (ISO, 2006). The most effective treatment was noted by counting the number of colony forming units (CFU) and determining the CFU per cm^{-2} of tomato surface and per gram of tomato fresh weight, the best treatments were noted by having a low aerobic bacteria burden in this regard.

3.2.8 Percentage Marketability

In addition to microbial analysis, fruit were also assessed visually in terms of being marketable or non-marketable. Fruit were rated on the basis freedom from any form of defects, i.e. bruising, diseases, physiological disorders, and fungal infection. Fruit with any sort of defects were rated as unmarketable, since it can no longer be sold. Fruit with freedom from blemishes were rated as marketable. Marketability percentage was calculated using Equation 1.

$$Percentage\ marketability = \frac{Marketable\ fruit}{Total\ number\ of\ fruit} \times 100 \quad (1)$$

3.2.9 Data analysis

Data analysis was done by using Genstat® 17th Edition (VSNI, Hempstead, United Kingdom), performing a general analysis of variance (ANOVA) and considering 5% levels of statistical significance. Comparisons of means was done by using the Duncan’s multiple range test.

3.3 RESULTS AND DISCUSSION

3.3.1. Air temperature and relative humidity during transportation

The duration between harvesting and storage was approximately 21 hours. Temperatures were generally lower in the truck during transportation of the winter harvested tomatoes, compared to summer (Table 3.1). On the other hand, the relative humidity in truck was generally higher in fruit harvested in winter and lower in the ones harvested in summer. During winter harvest, variation in temperatures in trucks from different sites did not vary significantly.

Table 3.1 Average temperature and relative humidity in trucks during transportation of tomatoes after winter and summer harvests.

Routes	Winter harvest		Summer harvest	
	Temperature (°C)	Relative Humidity (%)	Temperature (°C)	Relative Humidity (%)
Pontdrift	19.70	72.36	20.96	71.20
Letaba	20.27	64.79	28.83	43.33
Esmé4	18.66	81.35	22.43	35.85

3.3.2 Microbiological changes

Surface burden of total aerobic bacteria

The microbiological quality of pink matured tomatoes varied significantly ($P < 0.001$) with the supply routes. This resulted in difference in the surface microbial burden upon arrival and during storage (Table 3.2 and Table 3.3). Generally, the microbial burden was highest in fruit from Esmé4, followed by fruit from Pontdrift, then Letaba Municipality. This occurred in both seasons (summer and winter) and it was detected upon the evaluation of the initial sampling of microbial load (day 0), as well as during the storage period (day 16 and day 30). Esmé4, as noted previously, represented the longest supply route from harvest to storage. Overall, the shortest supply route, from Letaba Municipality, showed the lowest surface burden as noted even in the control (untreated) tomatoes. Microbial burden has been primarily associated with the nature of a crop, production site and the management practices used. This involves cultivar, climate, i.e. average temperatures, soil, relative humidity and rainfall during production.

Berrueta *et al.* (2016) reported that microbial growth is hastened by high temperatures and frequent rainfall. The final microbial load after harvest is also influenced by irrigation systems, water quality, fertilizer, pesticides and fungicides.

The effect of supply chain routes in fruit quality is associated with the mechanical damages that occur in fruit due to vibrations in a trucks during transportation (Parker and Maalekuu, 2013a). Severity of the mechanical damages is associated with the road quality, truck speed and the distance from production to marketing site (Sibomana *et al*., 2016). Any sort of scars, bruises or cuts in the fruit surface becomes a site of microbial attack (Prusky, 2011). Berrueta *et al.* (2016) reported that microbial growth is hastened by high temperatures and frequent rainfall, and high relative humidity (Seyoum *et al*., 2011). Therefore, the difference in the effect of the supply chain routes is also associated with variation in temperatures and relative humidity within trucks during fruit transportation (Seyoum *et al*., 2011, Berrueta *et al*., 2016).

The number of colony forming units dropped significantly ($P < 0.001$) following fruit disinfection with all disinfectants and coating (anolyte water treatment, chlorinated water, hot water treatment and / coated with Gum Arabic), however, anolyte water became the most effective disinfectant. The rate of microbial growth was not suppressed to the same extent with different disinfectants and coating. The results revealed highly significant ($P < 0.001$) difference between different disinfectants and coating in reducing the initial microbial load and slowing down the rate of microbial growth. The microbial burden generally increased during the storage, however, their proliferation varied significantly with disinfectants used. Anolyte water treatment had an the highest effect in reducing the number of CFUs observed during plate counts, followed by chlorinated water, hot water, Gum Arabic, and then control. These results are in accordance to those reported by (Seyoum *et al.*, 2011), whereby anolyte water treatment was the best treatment in reducing initial microbial load and slowing down the rate of microbial growth in carrots.

Storage temperature was the most important factor that significantly ($P < 0.001$) reduced the microbial proliferation on the fruit surface. There was highly significant ($P < 0.001$) difference between the number of CFUs observed from fruit that were stored at cold room (11 °C) and those stored at ambient temperature (25 °C for summer and 16 °C for winter). These results are in line with (Seyoum *et al*., 2011), whereby storage temperature significantly ($P < 0.05$)

reduced the rate of microbial growth in carrots. Hot water treatment and Gum Arabic coating had less effect in reducing microbial load and slowing down microbial growth, however, their impact was significantly different ($P < 0.001$) from the control (untreated). Hot water caused some skin burns on pink-matured tomatoes, which affected fruit marketability. This revealed the sensitivity of pink-matured tomatoes towards higher blanching temperatures or longer blanching duration. The microbial population was significantly ($P < 0.001$) higher in summer than in winter. Similar results of higher microbial populations in summer than winter were reported by (Edwards *et al.*, 1999).

The integration of postharvest treatments (disinfectants/ coating and storage), had a significant impact ($P < 0.001$) on the surface microbial burden of tomatoes harvested in summer and stored for 30 days (Table 3.2 and Table 3.3). Integrating anolyte water treatment with low storage temperature (11 °C) has been the best treatment for fruit that were harvested in summer (Table 3.2). This is due to the fact that it reduced the initial microbial load significantly ($P < 0.001$) to 2.835 log cfu cm^{-2}, and it also limited the microbial growth to 3.419 log cfu cm^{-2} during day 16, which was the lowest microbial population (Table 3.2). This represented the highest log reduction of 1.470 log cfu cm^{-2}, when compared to untreated samples which had 4.828 log cfu cm^{-2}. In winter, integration of postharvest treatments reduced microbial load, however the difference between them was not significant ($P > 0.05$). Only the interaction between supply chain routes and treatments had significant difference ($P < 0.05$) in microbial load during the winter harvest. This was due to the low winter temperatures which confounded the effect of integration of treatments, particularly storage. However, anolyte water treated fruit remained the best in terms of having the lowest microbial load and lower microbial growth during storage across the different supply chain routes and in both storage environments.

Table 3.2 The effect of supply chain routes, pre-storage treatments and storage temperatures on the log cfu cm^{-2} of pink-matured tomatoes harvested in summer and stored for 30 days.

	log cfu cm^{-2}		
	Day 0	Day 16	Day 30
Pontdrift, Control, Ambient	5.928 ^{ab}	5.972 ^{a}	6.005 ^{ab}
Letaba, Control, Ambient	4.828 ^{efg}	5.012 ^{i}	5.503 ^{defgh}
Esmè4, Control, Ambient	6.033 ^{a}	6.043 ^{a}	6.067 ^{a}
Pontdrift, Gum Arabic, Ambient	5.512 ^{abcd}	5.576 ^{cd}	5.841 ^{abcde}
Letaba, Gum Arabic, Ambient	4.554 ^{fgh}	4.661 ^{j}	5.363 ^{efgh}
Esmè4, Gum Arabic, Ambient	5.745 ^{abcd}	5.770 ^{b}	5.797 ^{abcdef}
Pontdrift, Hot Water, Ambient	5.678 ^{abcd}	5.519 ^{cde}	5.697 ^{abcdefg}
Letaba, Hot Water, Ambient	4.305 ^{ghij}	4.605 ^{j}	5.437 ^{defgh}
Esmè4, Hot Water, Ambient	5.500 ^{abcd}	5.568 ^{cd}	5.607 ^{abcdefg}
Pontdrift, Chlorine, Ambient	5.321 ^{cde}	5.384 ^{fg}	5.438 ^{defgh}
Letaba, Chlorine, Ambient	4.170 ^{hij}	4.395 ^{k}	4.729 ^{ijk}
Esmè4, Chlorine, Ambient	5.392 ^{bcde}	5.486 ^{def}	5.529 ^{cdefgh}
Pontdrift, Anolyte, Ambient	4.118 ^{hij}	4.416 ^{k}	4.385 ^{jk}
Letaba, Anolyte, Ambient	3.779 ^{j}	3.955 ^{m}	4.542 ^{jk}
Esmè4, Anolyte, Ambient	4.864 ^{ef}	4.945 ^{i}	5.106 ^{hi}
Pontdrift, Control, Cold	5.774 ^{abcd}	5.802 ^{b}	5.880 ^{abcd}
Letaba, Control, Cold	4.305 ^{ghij}	4.379 ^{k}	5.303 ^{gh}
Esmè4, Control, Cold	5.811 ^{abc}	5.965 ^{a}	5.982 ^{abc}
Pontdrift, Gum Arabic, Cold	5.467 ^{abcd}	5.504 ^{cde}	5.538 ^{bcdefgh}
Letaba, Gum Arabic, Cold	4.174 ^{hij}	4.225 ^{l}	4.817 ^{ij}
Esmè4, Gum Arabic, Cold	5.563 ^{abcd}	5.614 ^{c}	5.688 ^{abcdefg}
Pontdrift, Hot Water, Cold	5.353 ^{bcde}	5.439 ^{efg}	5.584 ^{bcdefg}
Letaba, Hot Water, Cold	4.059 ^{hij}	4.176 ^{l}	5.357 ^{fgh}
Esmè4, Hot Water, Cold	5.353 ^{bcde}	5.456 ^{efg}	5.548 ^{bcdefgh}
Pontdrift, Chlorine, Cold	5.191 ^{de}	5.241 ^{h}	5.327 ^{fgh}
Letaba, Chlorine, Cold	3.854 ^{ij}	4.005 ^{m}	4.510 ^{jk}
Esmè4, Chlorine, Cold	5.227 ^{cde}	5.354 ^{g}	5.398 ^{efgh}
Pontdrift, Anolyte, Cold	3.902 ^{hij}	4.030 ^{m}	4.304 ^{k}
Letaba, Anolyte, Cold	2.835 ^{k}	3.419 ^{n}	4.407 ^{jk}
Esmè4, Anolyte, Cold	4.410 ^{fghi}	4.385 ^{k}	4.595 ^{jk}
Route (A)	<0.001	<0.001	<0.001
Treatment (B)	<0.001	<0.001	<0.001
Storage (C)	<0.001	<0.001	<0.001
A×B	<0.001	<0.001	<0.001
A×C	0.004	<0.001	NS
B×C	<0.001	<0.001	NS
A×B×C	<0.001	<0.001	NS

Means followed by the same letter(s) are not significant: Duncan's multiple range test ($P < 0.05$)

The LSD value = 0.2807, C.V = 5.3, S.E = 0.282

Table 3.3 The effect of supply chain routes, pre-storage treatments and storage temperatures on the log cfu cm^{-2} of pink-matured tomatoes harvested in winter and stored for 30 days

Treatment combination	log cfu cm^{-2}		
	Day 0	Day 16	Day 30
Pontdrift, Control, Ambient	5.623 ^{a}	5.619 ^{a}	5.689 ^{a}
Letaba, Control, Ambient	4.556 ^{efghi}	4.766 ^{bcd}	4.679 ^{de}
Esmè4, Control, Ambient	5.219 ^{abcd}	5.171 ^{ab}	5.453 ^{abc}
Pontdrift, Gum Arabic, Ambient	4.698 ^{cdefg}	4.712 ^{bcdef}	5.612 ^{a}
Letaba, Gum Arabic, Ambient	4.803 ^{bcdef}	4.728 ^{bcde}	4.052 ^{gh}
Esmè4, Gum Arabic, Ambient	5.287 ^{abc}	5.291 ^{ab}	5.379 ^{abc}
Pontdrift, Hot Water, Ambient	5.069 ^{abcde}	5.076 ^{abc}	5.283 ^{abc}
Letaba, Hot Water, Ambient	4.165 ^{fghijk}	4.021 ^{fghijklmn}	4.016 ^{gh}
Esmè4, Hot Water, Ambient	5.092 ^{abcde}	5.146 ^{ab}	5.512 ^{ab}
Pontdrift, Chlorine, Ambient	4.535 ^{efghi}	4.460 ^{cdefghi}	5.311 ^{abc}
Letaba, Chlorine, Ambient	3.883 ^{ijkl}	4.055 ^{efghijkl}	3.929 ^{gh}
Esmè4, Chlorine, Ambient	4.069 ^{ghijk}	4.127 ^{defghijk}	5.212 ^{abc}
Pontdrift, Anolyte, Ambient	4.277 ^{fghijk}	4.270 ^{defghij}	4.983 ^{bcd}
Letaba, Anolyte, Ambient	3.737 ^{kl}	3.706 ^{jlkmn}	3.305 ^{ij}
Esmè4, Anolyte, Ambient	3.899 ^{ijkl}	4.051 ^{efghijklm}	5.055 ^{bcd}
Pontdrift, Control, Cold	5.405 ^{ab}	5.430 ^{a}	5.522 ^{ab}
Letaba, Control, Cold	4.458 ^{efghij}	4.422 ^{cdefghi}	4.661 ^{def}
Esmè4, Control, Cold	5.294 ^{abc}	4.678 ^{bcdefg}	5.446 ^{abc}
Pontdrift, Gum Arabic, Cold	4.631 ^{defg}	4.456 ^{cdefghi}	5.359 ^{abc}
Letaba, Gum Arabic, Cold	4.218 ^{fghijk}	3.955 ^{hijklmn}	4.179 ^{fgh}
Esmè4, Gum Arabic, Cold	4.579 ^{efgh}	4.624 ^{bcdefgh}	4.974 ^{bcd}
Pontdrift, Hot Water, Cold	4.110 ^{ghijk}	4.226 d^{efghij}	5.234 ^{abc}
Letaba, Hot Water, Cold	3.934 ^{hijkl}	3.986 ^{ghijklmn}	4.039 ^{gh}
Esmè4, Hot Water, Cold	4.057 ^{ghijk}	4.099 ^{defghijk}	4.954 ^{cd}
Pontdrift, Chlorine, Cold	4.319 ^{fghijk}	4.301 ^{defghij}	4.998 ^{bcd}
Letaba, Chlorine, Cold	3.743 ^{kl}	3.698 ^{jklmn}	3.688 ^{hi}
Esmè4, Chlorine, Cold	3.791 ^{jkl}	3.905 ^{ijklmn}	5.014 ^{bcd}
Pontdrift, Anolyte, Cold	4.067 ^{ghijk}	3.974 ^{hijklmn}	4.368 ^{efg}
Letaba, Anolyte, Cold	3.398 ^{l}	3.497 ^{klmn}	3.103 ^{j}
Esmè4, Anolyte, Cold	3.318 ^{l}	3.371 ^{lmn}	4.331 ^{efg}
Route (A)	<0.001	<0.001	<0.001
Treatment (B)	<0.001	<0.001	<0.001
Storage (C)	<0.001	<0.001	<0.001
A×B	0.012	0.032	NS
A×C	NS	NS	NS
B×C	NS	NS	NS
A×B×C	NS	NS	NS

Means followed by the same letter(s) are not significant: Duncan’s multiple range test ($P < 0.05$)

The LSD value = 0.4485, C.V =13.5, S.E = 0.6454

3.3.3 Subjective quality analysis for marketability

The percentage of marketable fruit remained high during the first week of storage, and only dropped significantly during the second week (day 16). The results for sampling revealed highly significant difference ($P < 0.001$) between marketability percentages of fruit from the different supply chain routes. Generally, fruit from Letaba municipality had the highest percentage marketability than other routes, followed by fruit from Pontdrift, then Esmè4 (Table 3.4 and 3.5). This could be associated with minimal effects of factors affecting fruit quality during transportation, i.e. reduced mechanical injuries that occur as result of poor road quality, high truck speed, and distance to market (Roy *et al.*, 2008); Parker and Maalekuu, 2013). Arazuri *et al*., (2007) reported that the mechanical injuries that takes place in tomatoes during transportation are the major causes of tomatoes fruit quality detrioration. Minten and Kyle (1999) also reported that vibrations due to poor road quality affect fruit quality significantly by causing injuries in the fruit surface, which end up hastening fruit respiration rate and transpiration. This affect the appearance of a fruit, and also transpiration reduce fruit mass, hence economic returns since tomatoes are sold on the mass basis.

Tomato fruit percentage marketability was sustained following fruit disinfection with anolyte water treatment, chlorinated water, hot water treatment and / coated with Gum Arabic (Table 3.4 and 3.5). There was a significant ($P < 0.001$) difference between fruit that were treated with disinfectants/ coating and the control treatment. Anolyte water sustained the highest percentage marketability across all the different supply chain routes, followed by chlorinated water, hot water, Gum Arabic coating, and then the control. This occurred in both seasons (summer and winter), and there was highly significant difference ($P < 0.001$) in the marketability of fruit that were harvested in summer compared to the winter harvest. Generally, fruit marketability percentage was higher in winter than in summer. This could be associated with the difference in the effects of the average temperatures for summer and winter, since temperatures are higher in summer than in winter (Minten and Kyle, 1999, Wu, 2010).

Tomato fruit quality (quality indicating parameters that were measured) also varied significantly ($P < 0.001$) with the storage temperature. Fruit from ambient storage generally had lower marketability than fruit from cold storage. This could be due to the factors such as temperature, relative humidity and gas composition, which directly affect fruit metabolic processes (such as respiration, ethylene production and transpiration) thus enhance fruit quality deterioration. Temperature affects all the metabolic processes leading to fruit quality deterioration (Aung and Chang, 2014, Workneh and Osthoff, 2015). Therefore, low storage temperatures (< 12 °C) are suitable for tomato storage in order to slow down the fruit metabolic activities, maintain fruit quality and extend the shelf-life (Pinheiro *et al.*, 2013b).

Integration of postharvest treatments (disinfectants/ coating and storage), had highly significant difference (P < 0.001) in the marketability percentage of pink matured tomatoes stored for 30 days (Table 3.4 and 3.5). Integration of pre-storage treatments and storage conditions had significant difference (P < 0.001) in sustaining marketability of tomatoes during day 16 and 30 of both harvesting seasons. Tomatoes which were disinfected and stored at cold room retained Integration of supply routes with higher marketability than the ones stored at ambient. Similar results were reported by (Cengiz and Certel, 2014) whereby disinfection treatments followed by cold storage further extended the shelf life of different tomato varieties. Pre-storage treatments had significant difference (P < 0.001) in sustaining marketability of tomatoes during day 16 and 30 of both harvesting seasons. Integration of supply routes with storage environment also sustained tomato marketability, significantly during day 16 and 30 of both harvest seasons. Getinet *et al.* (2011); Wu (2010); Nunes and Emond, 1999) reported that integration of practices such as harvesting at appropriate maturity stages and ideal storage environment can possibly extend the shelf life of tomatoes by reducing the rate of ripening.

Furthermore, integration of supply routes, pre-storage treatments and storage environment had highly significant impact (P < 0.001) in sustaining marketability of tomatoes during day 16 and 30 of both harvest seasons. Fruit harvested in winter from Letaba Municipality, treated with anolyte water, and stored at 11 °C were the best during all the sampling dates with the highest marketability percentage of 44% and 42.5% during day 30 of winter and summer harvests, respectively. This also symbolise the superiority of the combined effects of different postharvest treatments. Similar results were reported by (Seyoum *et al.*, 2011), whereby disinfecting carrots with anolyte water followed by cold storage had significant impact in extending shelf life. Therefore similar features of treatment combination make effective in extending shelf life of tomatoes.

Table 3.4 The effect of supply chain routes, pre-storage treatments and storage temperatures on marketability of pink-matured tomatoes harvested in winter and stored for 30 days.

Treatment combination	Marketability (%)		
	Day 0	Day 16	Day 30
Pontdrift, Control, Ambient	100^{a}	40.0 ^{n}	1.0 ^{o}
Letaba, Control, Ambient	100^{a}	49.0 ^{l}	2.5 ^{mno}
Esmè4, Control, Ambient	100^{a}	32.5 ^{p}	2.5 ^{mno}
Pontdrift, Gum Arabic, Ambient	100^{a}	40.0 ^{n}	2.5 ^{mno}
Letaba, Gum Arabic, Ambient	100^{a}	60.0 ^{i}	4.5 ^{kl}
Esmè4, Gum Arabic, Ambient	100^{a}	30.0 ^{q}	5.0 ^{k}
Pontdrift, Hot Water, Ambient	100^{a}	42.5 ^{m}	5.0 ^{k}
Letaba, Hot Water, Ambient	100^{a}	54.0 ^{k}	3.3 ^{lm}
Esmè4, Hot Water, Ambient	100^{a}	50.0 ^{l}	5.0 ^{k}
Pontdrift, Chlorine, Ambient	100^{a}	60.0 ^{i}	5.0 ^{k}
Letaba, Chlorine, Ambient	100^{a}	58.3 ^{j}	6.0 ^{k}
Esmè4, Chlorine, Ambient	100^{a}	35.0 ^{o}	3.7 ^{lm}
Pontdrift, Anolyte, Ambient	100^{a}	42.5 ^{m}	7.5 ^{j}
Letaba, Anolyte, Ambient	100^{a}	62.5 ^{h}	7.5 ^{j}
Esmè4, Anolyte, Ambient	100^{a}	55.0 ^{k}	5.8 ^{k}
Pontdrift, Control, Cold	100^{a}	90.0 ^{d}	20.0 ^{f}
Letaba, Control, Cold	100^{a}	82.5 ^{e}	20.0 ^{f}
Esmè4, Control, Cold	100^{a}	62.5 ^{h}	7.5 ^{j}
Pontdrift, Gum Arabic, Cold	100^{a}	100 ^{a}	10.0 ^{i}
Letaba, Gum Arabic, Cold	100^{a}	97.5 ^{b}	20.0 ^{f}
Esmè4, Gum Arabic, Cold	100^{a}	97.5 ^{b}	17.5 ^{g}
Pontdrift, Hot Water, Cold	100^{a}	72.5 ^{g}	37.5 ^{b}
Letaba, Hot Water, Cold	100^{a}	100 ^{a}	22.2 ^{e}
Esmè4, Hot Water, Cold	100^{a}	75.0 ^{f}	12.5 ^{h}
Pontdrift, Chlorine, Cold	100^{a}	75.0 ^{f}	30.5 ^{c}
Letaba, Chlorine, Cold	100^{a}	90.0 ^{d}	32.5 ^{c}
Esmè4, Chlorine, Cold	100^{a}	92.5 ^{c}	22.5 ^{e}
Pontdrift, Anolyte, Cold	100^{a}	100 ^{a}	32.5 ^{c}
Letaba, Anolyte, Cold	100^{a}	100 ^{a}	44.0 ^{a}
Esmè4, Anolyte, Cold	100^{a}	97.5 ^{b}	22.5 ^{e}
Route (A)	NS	<0.001	<0.001
Treatment (B)	NS	<0.001	<0.001
Storage (C)	NS	<0.001	<0.001
A×B	NS	<0.001	<0.001
A×C	NS	<0.001	<0.001
B×C	NS	<0.001	<0.001
A×B×C	NS	<0.001	<0.001

Means followed by the same letter(s) are not significant: Duncan's multiple range test ($P < 0.05$)

The LSD value = 1.36, C.V = 6.1, S.E = 0.8333

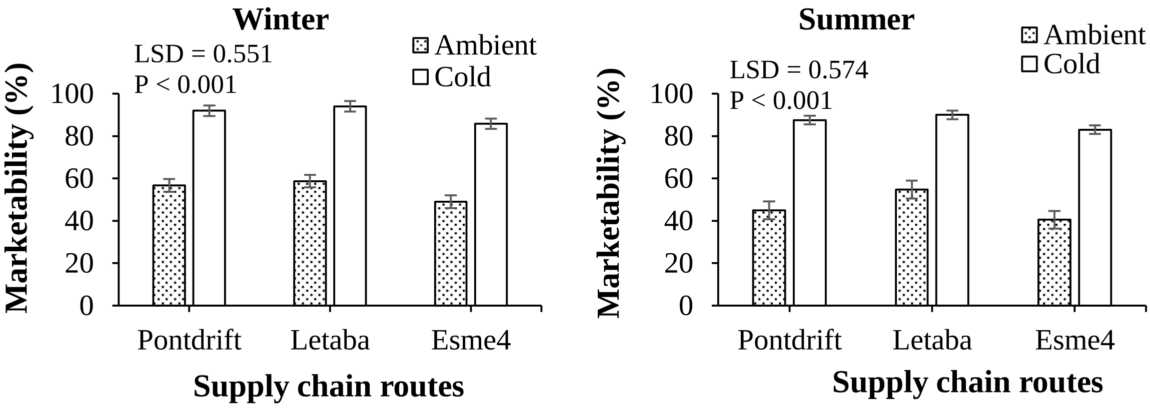
Table 3.5 The effect of supply chain routes, pre-storage treatments and storage temperatures on marketability of pink-matured tomatoes harvested in summer and stored for 30 days.

Treatment combination	Marketability (%)		
	Day 0	Day 16	Day 30
Pontdrift, Control, Ambient	100^{a}	49.0 ^{p}	2.5 ^{n}
Letaba, Control, Ambient	100^{a}	52.5 ^{o}	3.3 ^{mn}
Esmè4, Control, Ambient	100^{a}	60.0 ^{lmn}	1.0 ^{o}
Pontdrift, Gum Arabic, Ambient	100^{a}	60.0 ^{lmn}	4.5 ^{lm}
Letaba, Gum Arabic, Ambient	100^{a}	61.0 ^{m}	10.5 ^{i}
Esmè4, Gum Arabic, Ambient	100^{a}	40.0 ^{r}	2.5 ^{n}
Pontdrift, Hot Water, Ambient	100^{a}	54.0 ^{o}	0.0 ^{o}
Letaba, Hot Water, Ambient	100^{a}	50.0 ^{p}	8.50 ^{j}
Esmè4, Hot Water, Ambient	100^{a}	42.5 ^{q}	5.0 ^{l}
Pontdrift, Chlorine, Ambient	100^{a}	58.0 ^{n}	7.0 ^{k}
Letaba, Chlorine, Ambient	100^{a}	65.0 ^{k}	12.3 ^{h}
Esmè4, Chlorine, Ambient	100^{a}	60.0 ^{mn}	5.0 ^{l}
Pontdrift, Anolyte, Ambient	100^{a}	62.5 ^{l}	7.5 ^{kj}
Letaba, Anolyte, Ambient	100^{a}	65.0 ^{k}	13.5 ^{h}
Esmè4, Anolyte, Ambient	100^{a}	42.5 ^{q}	2.5 ^{n}
Pontdrift, Control, Cold	100^{a}	82.5 ^{h}	20.0 ^{f}
Letaba, Control, Cold	100^{a}	92.5 ^{e}	20.0 ^{f}
Esmè4, Control, Cold	100^{a}	86.7 ^{g}	7.5 ^{jk}
Pontdrift, Gum Arabic, Cold	100^{a}	97.5 ^{abcd}	10.0 ^{i}
Letaba, Gum Arabic, Cold	100^{a}	100 ^{a}	20.0 ^{f}
Esmè4, Gum Arabic, Cold	100^{a}	97.5 ^{abd}	17.5 ^{g}
Pontdrift, Hot Water, Cold	100^{a}	100 ^{a}	37.5 ^{c}
Letaba, Hot Water, Cold	100^{a}	75.0 ^{i}	22.5 ^{e}
Esmè4, Hot Water, Cold	100^{a}	72.5 ^{j}	12.5 ^{h}
Pontdrift, Chlorine, Cold	100^{a}	89.7 ^{f}	42.5 ^{a}
Letaba, Chlorine, Cold	100^{a}	92.5 ^{e}	32.5 ^{d}
Esmè4, Chlorine, Cold	100^{a}	75.0 ^{i}	22.5 ^{e}
Pontdrift, Anolyte, Cold	100^{a}	100 ^{a}	22.5 ^{e}
Letaba, Anolyte, Cold	100^{a}	100 ^{a}	42.5 ^{a}
Esmè4, Anolyte, Cold	100^{a}	97.5 ^{ad}	22.5 ^{e}
Route (A)	NS	<0.001	<0.001
Treatment (B)	NS	<0.001	<0.001
Storage (C)	NS	<0.001	<0.001
A×B	NS	<0.001	<0.001
A×C	NS	<0.001	<0.001
B×C	NS	<0.001	<0.001
A×B×C	NS	<0.001	<0.001

Means followed by the same letter(s) are not significant: Duncan's multiple range test ($P < 0.05$)

The LSD value = 1.28, C.V = 5.2, S.E = 0.7853

The results generally revealed an expected, negative (inverse), relationship between the total microbial burden and fruit marketability. The increase in microbial burden resulted in fruit marketability being significantly (P < 0.001) reduced. These results are in line with the ones reported by (Teka, 2013) who stated that microbial load in tomatoes are major determinant of fruit quality and consumer's safety after consuming fruit. The higher the microbial load on the fruit surface, the higher the chances of fruit being infected by microbial contamination (Teka, 2013). Generally, marketability % was higher during winter harvest, than summer, and there was highly significant difference (P < 0.001) between the marketability % of fruit harvested in winter and in summer (Figures 3.1a and 3.1b). Fruit treated with anolyte water reflected a better condition compared to fruit treated with other treatments. They were shiny, firmer, with no surface blemishes (Table 3.6). Chlorine treated fruit were also looking good, however they possessed some surface defects. Gum Arabic treated fruit were also attractive, but less attractive than the ones treated by anolyte water. Hot water treated tomatoes possessed surface burns thus less attractive. Control (untreated) fruit were also unattractive, mainly due to shrinkage and being dull and also exhibited surface blemishes.



(a) (b)

Figure 3.1 The effect of supply chain routes and harvesting seasons in the marketability of tomatoes under ambient and cold storage conditions during day 16.

Table 3.6 The effect of pre-storage treatments and storage temperatures on an overall percentage marketability of pink-matured tomatoes harvested in summer and stored for 30 days

Treatments	Storage	Final state of marketability during day 30	Rating
Anolyte water	Ambient	Red shiny, firm, no blemishes	Good
	Cold	Red shiny, firm, no blemishes	Excellent
Chlorine	Ambient	Red shiny, firm, surface blemishes	Good
	Cold	Red shiny, firm, surface blemishes	Good
Gum Arabic	Ambient	Red shiny, firm, no blemishes	Good
	Cold	Red shiny, firmer, no blemishes	Good
HWT	Ambient	Orange-red shiny, soft, surface burn	Poor
	Cold	Orange-red shiny, soft, surface burn	Fair
Control	Ambient	Red dull, shrinkage, blemishes	Poor
	Cold	Red dull, shrinkage, blemishes	Fair

The level of marketability started from *'Fair', 'Good'* and *'Excellent'*. Fruit that were rating *'Poor'* were unmarketable.

3.4 CONCLUSIONS

Higher microbial surface load resulted in tomato fruit marketability being significantly reduced. Different disinfectants significantly reduced the initial microbial load and the growth of the microbial burden throughout the storage period. Anolyte water was the most effective disinfectant with the highest reduction. It significantly reduced the initial microbial load, and also reduced the rate of microbial growth during storage. Furthermore, the three-way interaction, i.e. integration of fruit sourced from Letaba Municipality with anolyte water treatment and low temperature storage was the best treatment combination in terms of extending the shelf life of pink-matured tomatoes. Supply routes involve crop genome, growing site i.e. environmental effects and management practices during the growing season, plus handling and transportation effects on fruit quality. While disinfectants and storage conditions are applied directly to slow down the rate of quality deterioration. Therefore, since all these factors (routes, treatments and storage) are crucial in sustaining fruit quality, postharvest treatment integration is recommended to be researched further as a potential substitute to chemical disinfectants used in tomatoes and other fruit industries.

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4. EVALUATION OF THE EFFECTS OF THE SUPPLY CHAIN ROUTES, MATURTY STAGES AND PRE-STORAGE TREATMENTS ON THE POSTHARVEST QUALITY OF TOMATOES

ABSTRACT

Tomato climacteric nature limits its shelf life. In this study, the effects of three supply routes (Pontdrift, Letaba, Esmé4), three maturity stages (green, pink, red), four pre-storage treatments (anolyte water, Gum Arabic (GA), Anolyte water + GA, hot water treatment + GA, control/ untreated) and two storage conditions (ambient 16/ 25 °C and cold 11 °C) were evaluated in tomato 'Nemo-netta' quality. A factorial split-split design was selected as the experimental design with three supply routes as main plots, three maturity stages as sub-plots, two storage conditions as sub-sub-plots, and a random allocation of five pre-storage treatments within sub-sub-plots. Three replications of 15 fruit per replicate were used in each treatment. Tomato quality was assessed on Days 0, 8, 16, 24 and 30. Quality assessment involved colour (hue angle), texture, physiological weight loss (%) respiration rate, total soluble solids (TSS), total phenolic compounds (TPC), total antioxidant capacity (TAC), and overall marketability percentage.

The results generally revealed a positive effect of the postharvest treatments in extending the shelf life of tomatoes. All individual technologies had a significant ($P < 0.05$) effect in maintaining quality and extending shelf life of tomatoes. Tomatoes from Letaba Municipality were of optimum quality upon the arrival, and became the best in terms of maintaining quality throughout the storage period. In terms of maturity stages, green matured harvested tomatoes maintained highest quality across different supply routes. Anolyte water was the most effective treatment in maintaining the quality of tomatoes of different maturity stages, at different storage conditions and across different supply routes, followed by GA coating. In addition, this treatment was effective in reducing the rate of respiration, mass loss, the rate of colour change, maintaining high levels of TPC and TAC. Their individual effects were significant ($P < 0.001$) in maintaining the tomato quality. However, integration of number of treatments gave more

superior results. Therefore these findings suggest that the holistic approach is most efficient in extending shelf life of tomatoes.

4.1 Introduction

Tomato (*Solanum lycopersicum* L.) remains one of the most widely consumed vegetables worldwide due to its dietary and health benefits (Willett, 2010, Perveen *et al.*, 2015). It contains antioxidants, which are associated with a reduction of cancer and cardiac diseases (Ali *et al.*, .2013). However, the perishability of tomato fruit limit its postharvest life (Salas *et al*., 2013). This is due to tomatoes being characterised as climacteric fruit (Carrari and Fernie, 2006). Climacteric fruits are characterised by elevated metabolic processes such as high respiration rate, ethylene production and mass loss leading to hastened fruit deterioration (Zapata *et al*., 2008). Moreover, during tomato fruit ripening there are drastic changes in the fruit chemical composition which affect the colour, texture, pH, soluble solids and antioxidants, mainly phenolic compounds (Bailén *et al*., 2006). If these compositional changes go unchecked, it could result in rapid deterioration in the fruit quality (Fagundes *et al*., 2015).

Several researchers have reported serious postharvest quality losses of tomatoes, especially in developing countries (Ali *et al*., 2010, Ali et al., .2013, Sibomana et al., 2016). The latest statistical estimates revealed that the South African tomato supply chain experienced a loss of 10.2% (R 336 million) of total production in 2011, due to inadequate handling, transportation and storage (FAOSTAT, 2014). Several attempts have been made using different postharvest treatments, mainly low temperature, chemical disinfectants, edible coatings and blanching. (Teka, 2013). However, many of the research studies have focused on the individual effects of these treatments on the postharvest quality of tomatoes (Alimi *et al*., 2016). Generally, low temperature storage has been regarded as the most effective postharvest treatment during the supply chain of different fruit and vegetables (Wu, 2010). However, tomatoes are chilling sensitive, i.e. they develop chilling injury (CI) when exposed to storage temperatures below 12 °C (Zapata *et al.,* 2008). The effect of low storage temperatures on the quality of fruit varies according to the maturity stage. Polenta *et al*. (2007) found that for mature green tomatoes, temperatures above 13 °C) was suitable. Verheul *et al*. (2015b) discovered that at the breaker stage, suitable temperatures must be within a range of 10 to13 °C. There is limited research in South Africa on the effect of the supply chain routes on the postharvest quality of tomatoes.

Furthermore, there is a dearth of information regarding the combined effects of different postharvest treatments in the tomato industry.

Several practices such as blanching, low temperature storage, coating, and disinfectants have shown positive results in retaining quality of tomatoes after harvest (Teka, 2013). However, some of these treatments were not cost effective especially for developing countries with emerging farmers. Pre-storage treatments have shown potential in reducing the rate of tomato deterioration, mainly by controlling postharvest diseases before fruit storage (Workneh, 2010). This is due to approximately 15% of postharvest diseases being attributed to microbial decay. Selection of pre-storage treatments is no longer based solely on the effectiveness in controlling diseases, but also on minimal residues and environmental friendliness (Workneh, 2010). Anolyte water treatment, Gum Arabic coating, hot water treatment and chlorinated water are promising pre-storage treatments in maintaining shelf life of tomatoes (Getinet *et al*., 2008; Ali *et al.*, 2010; Workneh, 2010; Ali *et al*., 2013). Therefore, this study aims to evaluate the effects of individual and combined postharvest treatments in maintaining the quality and extending the shelf life of tomatoes at the different harvesting maturity stages of green, pink and red.

4.2 Materials and Methods

4.2.1 Site description

Fresh tomatoes, cv. ‘Nemo-netta’, of green, pink and red maturity stages were harvested or sourced from three different farms in the Limpopo province, South Africa. The Pontdrift region (PD) (22° 21' 67" S, 29° 16' 67 E), Letaba Municipality (LM) (23.5° S, 30.25° E), and Esmé 4 region (EF) (23° 49' 04" S, 30° 18' 11 E). Fruit were hand-harvested to reduce mechanical injury. Uniformity in colour and size was ensured to reduce experimental bias. Only fruit that were free from blemishes were selected for experimentation, and those with any sort of mechanical injuries, defects, or bruises were discarded. The selected fruit samples were then subjected to different pre-storage treatments, either anolyte water only, Gum Arabic (GA) only, Anolyte water + GA, hot water + GA, and control/ untreated. For each treatment in each maturity stage, half the number of treated samples was kept at cold room (11 °C) and the remaining half was kept at ambient (25 °C) storage.

4.2.2 Experimental design

A randomised complete block design was selected with three harvest sites (supply chain routes), three maturity stages (green, pink and red-matured), five pre-storage treatments, (Anolyte water, Gum Arabic (GA), Anolyte water + GA, hot water + GA, and control), two storage conditions (ambient and cold storage) and the storage period with five sampling days (Days 0, 8, 16, 24, 30). Factors were arranged in a split-split plot design with supply chain routes as main plots, maturity stages as sub-plots, storage conditions as sub-sub-plot and random allocation of treatments within each sub-sub-plot.

4.2.3 Transportation packaging

The tomatoes were transported in non-refrigerated trucks from the harvesting areas to the storage area in Pietermaritzburg. The crates used for transporting the fruit were made of UV-stabilised impact modified polypropylene, with double-walled corners and each crate had a capacity of 478 kg (Mpact, Johannesburg, South Africa). The dimensions of the crate consisted of an internal area of 1267 mm × 1067 mm and a depth of 400 mm, with 640 air vents located in the side panels and floor. The boxes used in transporting the fruit were corrugated boxes with a 6.5 kg capacity (Mpact, Johannesburg, South Africa). The corrugated boxes had dimensions of 390 mm × 240 mm and a height of 140 mm. The boxes had 4 air vents on the side panels and 4 air vents in the bottom panel. The crates used for transporting the fruit were made of UV-stabilised impact modified polypropylene, with double-walled corners and each crate had a capacity of 478 kg.The boxes were stacked 4 across × 3 wide × 13 high, and one data logger was placed on top of the fruit in a box in the bottom, the middle and the top row.

4.2.4 Postharvest treatments

Tomatoes were treated upon arrival in Pietermaritzburg with chlorinated water (150 mg.L^{-1} free chlorine) (Nunes and Emond, 1999) or Gum Arabic (10% w/v) for 3 minutes (Ali *et al*., 2013), or hot water (42 °C) for 30 min (Fallik, 2004), or anolyte water for 5 minutes as specified by Workneh *et al*. (2012). The targeted chlorine concentration was between 100-200 mg.L^{-1}, as recommended by the current tomato industry for disinfection of fresh produce effectively.

4.2.4.1 Anolyte water treatment

Ready-to-use neutral anolyte water was supplied in 25-litre plastic containers by Radical Waters (Midrand, South Africa). Preparation of the solution involved mixing 5% sodium chloride (NaCl) in potable water and an ionizing generator operating at a pressure of 50 kPa, which results in the production of anolyte and catholyte solutions. A neutral pH anolyte was produced by mixing approximately 10% of the resultant catholyte solution with the anolyte solution. The plastic containers were used to prevent loss of charged ions in the solution (Workneh *et al*., 2012). The neutral anolyte solution was delivered and used within 2 days of production to avoid loss of ionic properties. After dipping treatments, samples were surface dried and then packed into the normal tomato cartons.

4.2.4.2 Gum Arabic coating

Gum Arabic (GA) coating is a natural coating material derived from exudates of the Acacia tree. It was sourced from AEB Africa (Pty) Ltd, Cape Town, South Africa. AEB Africa provided GA in the form of Arabinol HC with 40% pure GA. GA (10% w/v) coating was made by diluting Arabinol HC (contains 40% GA) with distilled water using adjusted calculations to make it 10% w/v GA (Ali *et al*., .2013, Ali et al., 2010). About 15 litres of the anolyte water solution was used to dip the tomato fruit for a time of 3 minutes. The treatments were anolyte water, the combination of anolyte water and GA, combination of hot water treatment (42 °C for 30 min) and GA, and the control (untreated).

4.2.4.3 Hot water treatment (HWT)

The water bath was prepared by adding about 25 litres of water, adjusted to 42 °C and left for 15 minutes to stabilize. About 45 tomato fruit of similar maturity stage were immersed in the hot water for 30 minutes and then removed. Immediately upon removal, they were cooled under running cold tap water (Fallik, 2004), coated with GA, and allowed to surface dry before they were taken to a storage environment.

4.2.4.4 Treatment combinations

The combination treatment that involves anolyte water and GA was achieved by immersing the fruit in the anolyte water before being coated with GA. The combination treatment that involved the HWT and GA was achieved by dipping the fruit in hot water (42 °C for 30 min) before they were coated with GA.

4.2.5 Environmental conditions during fruit storage

Fruit were then divided into two groups, and stored either at ambient temperature (16 °C in winter or 25 °C in summer) or in a controlled temperature unit (set at 11°C). Data loggers (HOBO® Data loggers, IOS 17025 Calibration Lab, United States) were used to monitor a change in temperature inside the cold room. Relative humidity was not controlled during storage. Three fruit per treatment were sampled for physicochemical analysis immediately after treatment on Day 0, thereafter on Days 8, 16, 24 and day 30.

4.2.6 Data collection

This study involved tomato quality assessment based on the fruit physical properties (appearance, firmness and colour), physiological properties (respiration rate and mass loss), and chemical properties (total soluble solids, total phenolic compounds and antioxidant activity).

4.2.6.1 Physical properties

Colour

Three replications of three fruit per replicate were used. Tomato surface colour was analyzed by measuring a hue angle (h°) with a Minolta Chroma meter (Minolta CR-300, Ramsey, NJ, USA) at three different points located in the equatorial area a fruit (Dominguez *et al*., 2012).

Firmness

Tomato firmness was measured using the texture analyzer (Instron Universal Testing Machine (Model 3345), Buck, United Kingdom) fitted with two flat plates, according to the method used by Dominguez *et al.* (2012). The maximum deformation percentage, while applying a 10 N force at speed of 25 mm.min^{-1} was recorded.

4.2.6.2 Physiological properties

Respiration rate

The fruit respiration rate (CO_2 production per hour) was measured during the storage period using the infrared gas analyser respirometer (EGM-4 Environmental Gas analyser, PP Systems, Massachusetts, USA as conducted by Dominguez *et al.* (2012). Each fruit per treatment was weighed, volume determine (using the water displacement method) and incubated for 15 minutes, in a 1 litre jar. The carbon dioxide (CO_2) emission was then measured using an infrared gas analyser. The respiration rate could then be calculated by taking into consideration the mass and volume of the fruit, volume of the container, head space, CO_2 in the empty container and the CO_2 after fruit incubation for 15 minutes.

$$\text{Respiration } CO_2 = \frac{(P_{partial}\, CO_2^{f} - P_{partial}\, CO_2^{in})V_v}{100 \times W \times (t^f - t^i)} \qquad (4.1)$$

Where, $P_{partial}\, CO_2$ = the partial pressure of CO_2 emitted by fruit

V_v = Volume of void or head space = ($V_{container} - V_{fruit}$)

W = Weight of fruit sample (kg)

T = time (h)

Superscripts *in* and *f* = initial and final, respectively

Percentage weight loss

Tomato samples were weighed on day zero (i.e. upon receipt) and at the end of each storage interval. The difference between the initial and the final fruit weight was considered as the total weight loss during each storage interval. The weight loss percentage was then calculated on the initial weight (wet basis) using the method applied by AOAC (1984). The weight loss percentage was determined by using Equation 4.2 (Pirovani *et al.*, 1997):

$$Weight\ loss(\%) = \frac{Initial\ weight - Final\ weight}{Initial\ weight} \times 100 \tag{4.2}$$

4.2.6.3 Chemical properties

Total soluble solids

The total soluble solid (TSS) content was determined by using the method used by Ali *et al.* (2010). Tomato fruit juice was extracted and filtered through muslin cloth (Subramanian *et al.,* 2006). The TSS of each sample fruit juice was then determined by adding a juice droplet on the lens of a digital refractometer (Atago Palette- PR32, Tokyo, Japan) as determined by Ali *et al.* (2010).

Total phenolic content

Total phenolic contents in tomato fruit was determined by the Folin-Ciocalteau (FC) reagent procedure as determined by Singleton and Rossi (1965) with modifications. A 0.1 mL of fruit sample from each of the 3 fruit in each treatment was mixed with 0.5 mL FC reagent along with 1.5 mL of 7% sodium carbonate solution. Distilled water was added to to make a final solution volume of 10 mL. The mixture was then incubated at 40 °C for 2 hours, and the absorbance was then recoded at 750 nm using a UV-VIS Spectrophotometer (Varioskan Flash Multimode Reader, Thermo Fisher Scientific, USA). The final results were expressed in mg of Gallic acid equivalent to 100 g of fresh weight of fruit sample.

Antioxidant activity

For an efficient measurement of antioxidant activity in tomatoes a method involving organic radical producers such as 2,2'-azino-bis or 3-ethylbenzothiazoline-6-sulphonic acid (ABTS), 1,1-diphenyl-2-picrylhydrazyl (DPPH), Phospholipase C (PLC) assay or Ferric Reducing Antioxidant Power (FRAP) assay must be used (Ali *et al.*, 2013). In addition to either of these named methods, the method using metal ions for oxidation was used (i.e. FRAP). Several authors prefer no reliability in one method, and both groups should be considered for attaining the most precise results (Gómez-Romero *et al.*, 2007). Therefore, in the current study, DPPH and FRAP methods were used as they showed to be reliable and efficient in measuring antioxidant activity of tomatoes (Ali *et al*., 2013).

4.2.6.4 Measurement of antioxidant capacity

FRAP assay

The FRAP reagent contained 2.5 mL of 10 mM 2,4,6-Tripyridyl-s-triazine (TPTZ) solution in 40 mM hydrochloric acid along with 2.5 mL of 20 mM $FeCl_3$ and 25 mL of 0.03 mM acetate buffer having pH 3.6 (Benzie and Strain, 1996). The reaction mixture consists of 40 µL of fruit extract from each fruit 3 fruit in each treatment was mixed with 3 mL of FRAP reagent followed by incubation at 37 °C for 4 minutes. Absorbance was recorded at 593 nm using UV-VIS Spectrophotometer (Varioskan Flash Multimode Reader, Thermo Fisher Scientific, USA) and the results were expressed as the concentration of antioxidant having a ferric reducing activity equivalent to 1 $mg.g^{-1}$ ferrous sulphate ($FeSO_4$) of fresh weight of fruit sample. The range for standard was 0 to 1 mg. g^{-1} of ferrous sulphate ($FeSO_4$), and $R^2 = 0.723$, which showed certain level of precision.

DPPH Assay

Total antioxidant capacity was also measured through determining the free radical scavenging effect on 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical, according to the method described by Elez-Martínez and Martín-Belloso (2007) with some minor modifications. Prior to analysis, 25 mg /L of DPPH solution was freshly prepared by dissolving in 100% (v/v) methanol. Cuvette was filled with 3 mL of DPPH solution. Then 5 µL of sample from each of 3 fruit from each treatment was added into the cuvette and mixed well by using the same pipette tip. The mixture was left to react for 15 minutes. The absorbance was measured at 515 nm wavelength using UV-VIS Spectrophotometer (Varioskan Flash Multimode Reader, Thermo Fisher Scientific, USA) against a blank of methanol without DPPH. Results were expressed as a percentage decrease with respect to the absorption value of reference DPPH solution. This was obtained by subtracting the absorbance of a tomato extract solution from the absorbance of a DPPH assay.

4.2.6.5 Marketability percentage

Fruit were assessed visually in terms of being marketable or non-marketable. Fruit were rated on the basis of freedom from any form of defects, i.e. bruising, diseases, physiological disorders, and fungal infection. Fruit with any sort of defects were rated as unmarketable, since it can no longer be sold. Fruit with freedom from blemishes were rated as marketable. Marketability percentage was calculated using Equation 4.2.

$$Percentage\ marketability = \frac{Marketable\ fruit}{Total\ number\ of\ fruit} \times 100 \qquad (4.2)$$

4.2.7 Data analysis

Data analysis was done by using Genstat® 17th Edition (A VSNI product), analysis of variance (ANOVA) under 5% levels of significance. Comparison of means was done by using the Duncan’s multiple range test.

4.3 Results and Discussion

Temperature during the storage

Storage temperatures varied significantly ($P < 0.05$) with seasons. Ambient storage temperatures fluctuated just above 15 °C in winter, with an average storage temperature of 16°C (Figure 4.1a). In summer, storage temperatures had non frequent fluctuations above 20 °C with an average storage temperature of 23°C (Figure 4.1b). The cold storage temperature was kept at 11 °C, and it was efficient for both seasons. Tomatoes of different maturity stages responded differently to these storage conditions, but generally, cold storage led to better quality tomatoes of all maturity stages and across all the supply routes. This could be associated with the potential of low temperatures slowing down the metabolic processes such as respiration, transpiration, and ethylene production taking place in tomato fruit, thereby slowing down the rate of deterioration (Workneh *et al.*, 2012). Similar results were reported by Singh *et al.* (2013), whereby cold storage temperature reduced the rate metabolic processes particularly respiration, and extended shelf life of tomatoes. Workneh and Osthoff (2015) also reported that temperature is the most important environmental factor, which can be manipulated to slow down tomato metabolic processes, consequently extending the shelf life.

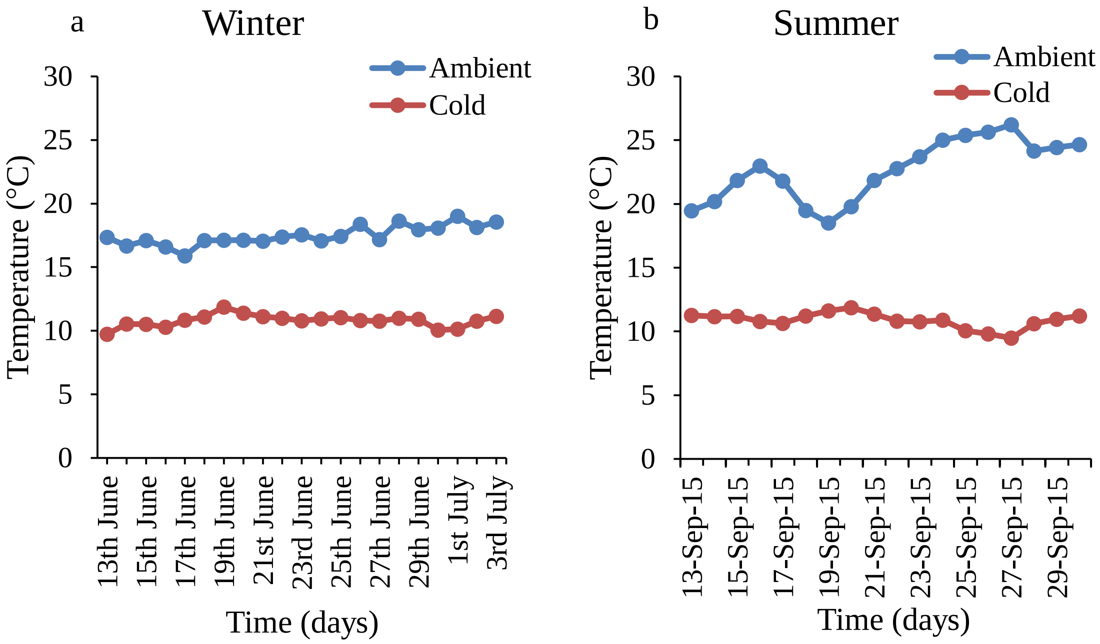

Figure 4.1 Variation in storage temperatures during winter (a) and summer seasons (b)

4.3.1 Colour

The full layout of all treatment combinations as per experimental design is presented in Appendix F and analysis of variance in Appendix I. Discussed below are typical examples outlining the key findings on tomato colour. The results revealed highly significant difference ($P < 0.001$) between the hue angle of tomatoes harvested in different seasons, across all different supply routes. Generally, fruit that were harvested in winter had higher hue angle than the ones harvested in summer (Figure 4.3a). Similar results were shown in Figures 4.3, 4.4 and 4.5 for the different maturity stages, storage conditions and across different supply routes. This implies that the rate of tomato fruit ripening was slower in winter than in summer, which resulted in fruit harvested in winter having longer shelf life. The grand mean hue angle for the winter harvest and summer harvest was 45.95 and 44.28, respectively (Figure 4.3a). The results revealed a highly significant ($P < 0.001$) difference between the hue angle of tomatoes from different supply routes, with the average hue angle being highest in fruit from Pontdrift, Letaba Municipality and then Esmè4. The average hue angle of tomatoes was 46.89; 45.83; and 42.62 for tomatoes from Pontdrift, Letaba Municipality and Esmè4, respectively (Figure 4.3d).

The hue angle also varied significantly ($P < 0.001$) with fruit maturity stages. Green-matured tomatoes had the highest average hue angle (53.78), followed by pink (43.13), then red (38.42) (Figure 4.3c). Similar results were reported by Wang *et al*. (2011) whereby the tomato hue angle was continuously decreasing with fruit ripening. Viskelis *et al*. (2008) also reported a significant ($P < 0.05$) reduction in the hue angle of different tomato cultivars as they turn from green to red-ripe. Cold storage environment significantly ($P < 0.001$) reduced the rate of ripening, colour change or hue angle reduction. Similar results were reported by Tilahun (2010), whereby cooling system significantly ($P < 0.05$) reduced the rate of colour change thus ripening in tomatoes of different maturity stages. The average hue angle of cold stored fruit was 54.17 while fruit from ambient storage had 36.06. The hue angle was observed to reduce over time. The highest rate of colour change occurred during the first 8 days of storage. This applied in both storage conditions with the rate of colour change being higher at ambient than at cold room conditions.

The rate of colour change or hue angle reduction significantly ($P < 0.001$) varied with pre-storage treatments. HWT + GA was a leading treatment in terms of delaying rate of hue angle reduction, followed by anolyte water + GA, GA only, anolyte water only, and then the control (Figure 4.2). Therefore, according to the hue angle results, HWT + GA combination treatment is most effective in delaying the physiological, biochemical and chemical processes associated with tomato colour change (ripening). Contrastingly, the marketability and firmness test revealed anolyte water as the best treatment in delaying tomato ripening process. HWT + GA delayed ripening process especially in green-matured tomatoes. However, it caused irregular ripening (Figure 4.2). On the other hand, green-matured tomatoes treated with anolyte water had fast rate of colour change i.e. quick hue angle reduction (Figure 4.2 a). However, these tomatoes resulted in the longest shelf life of 4 and 7 additional days at ambient and cold storage, respectively. Similar pattern applied to green matured tomatoes stored at cold conditions, however, the rate of colour change was slow.

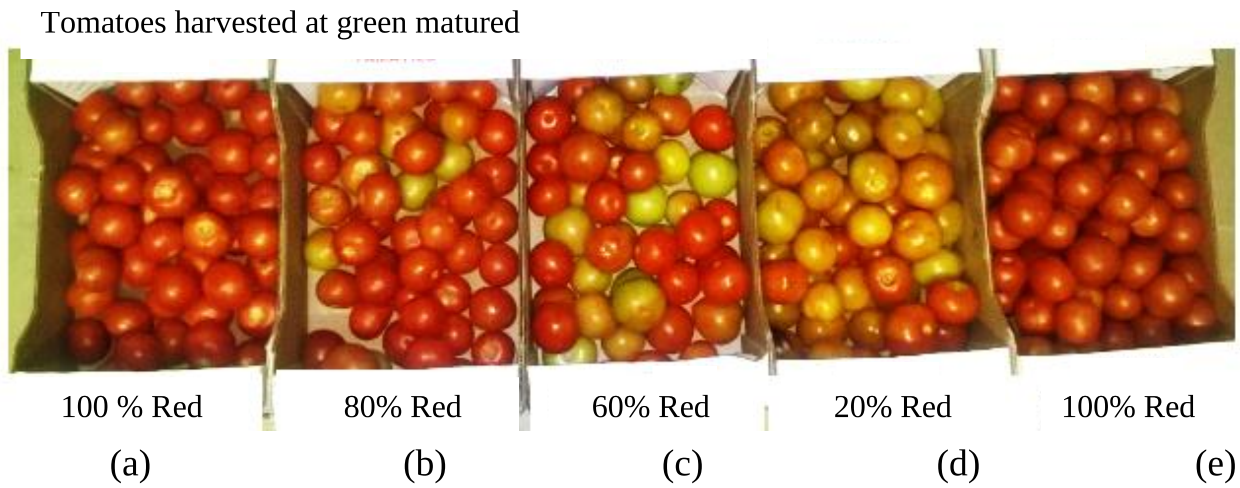

Figure 4.2 Colour change in tomatoes from Letaba Municipality (EM) with treatments: a=Anolyte water treatment, b = Gum Arabic Coating, c = Anolyte+ GA, d = HWT+GA and e = Control, during day 8 of sampling at ambient storage

Integrated treatments involving tomatoes harvested at green maturity, pre-storage treatments and cold storage conditions resulted in the rate of hue angle reduction being reduced significantly. These findings were most superior to the effects individual technologies involved. This resulted in an idea that, a holistic approach could be the better approach in sustaining quality and extending shelf life of tomatoes.

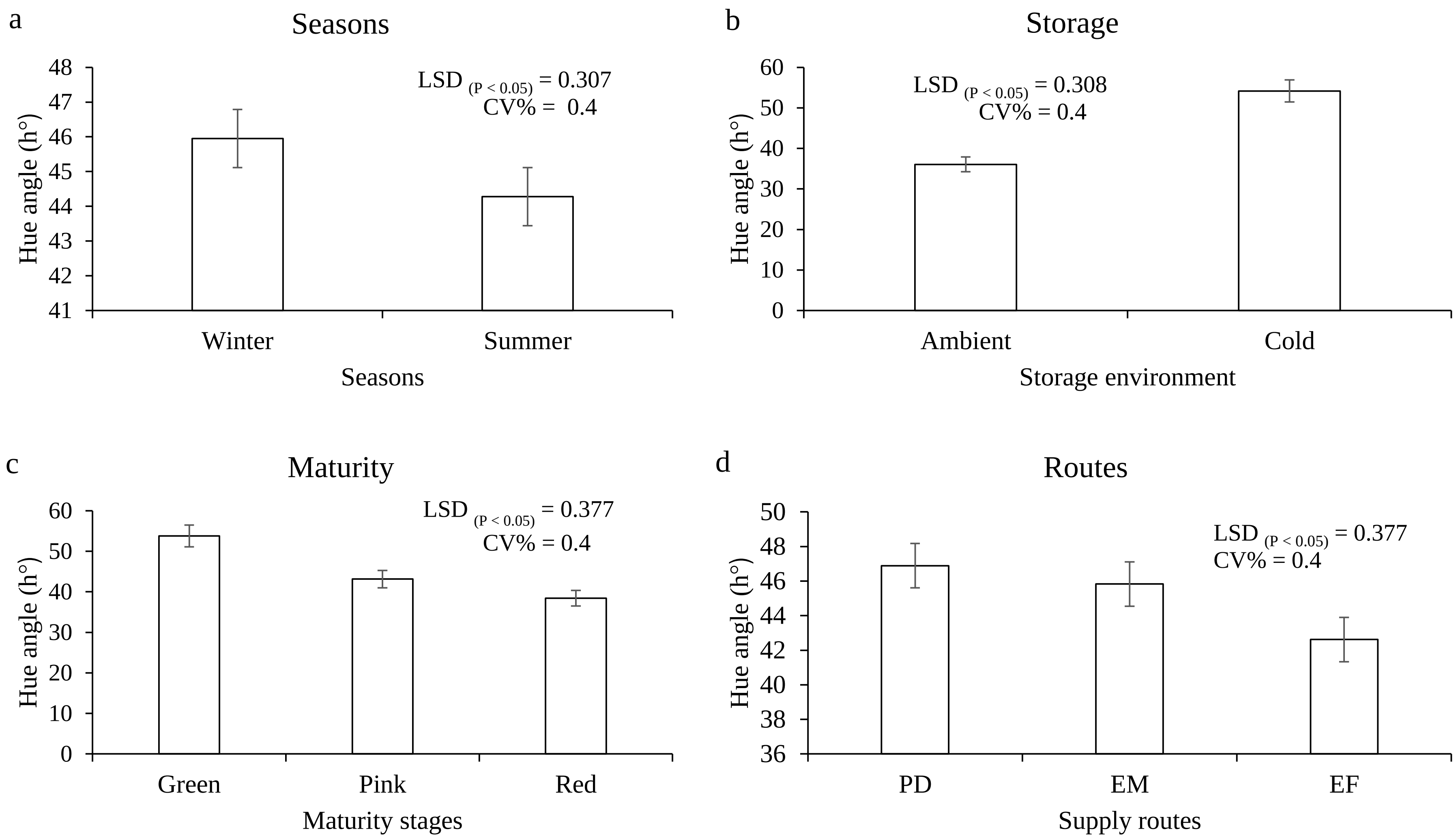

Figure 4.3 The effect of harvesting seasons (a), storage condition (b), maturity stage (c), and supply routes (d) on the colour (hue angle)

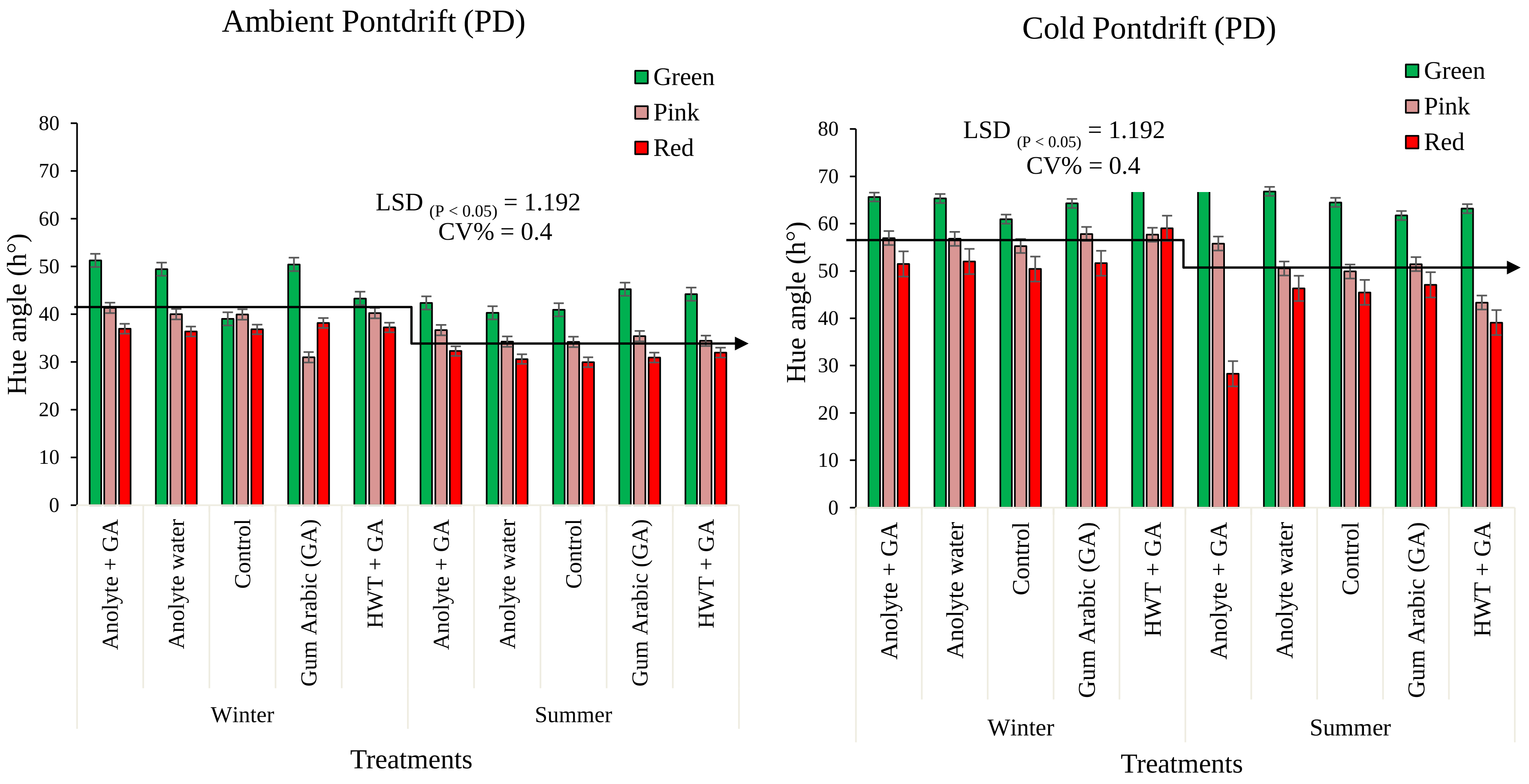

Figure 4.4 The effect of pre-storage treatments and storage conditions on the colour (hue angle) of tomatoes of different maturity stages from Pontdrift region

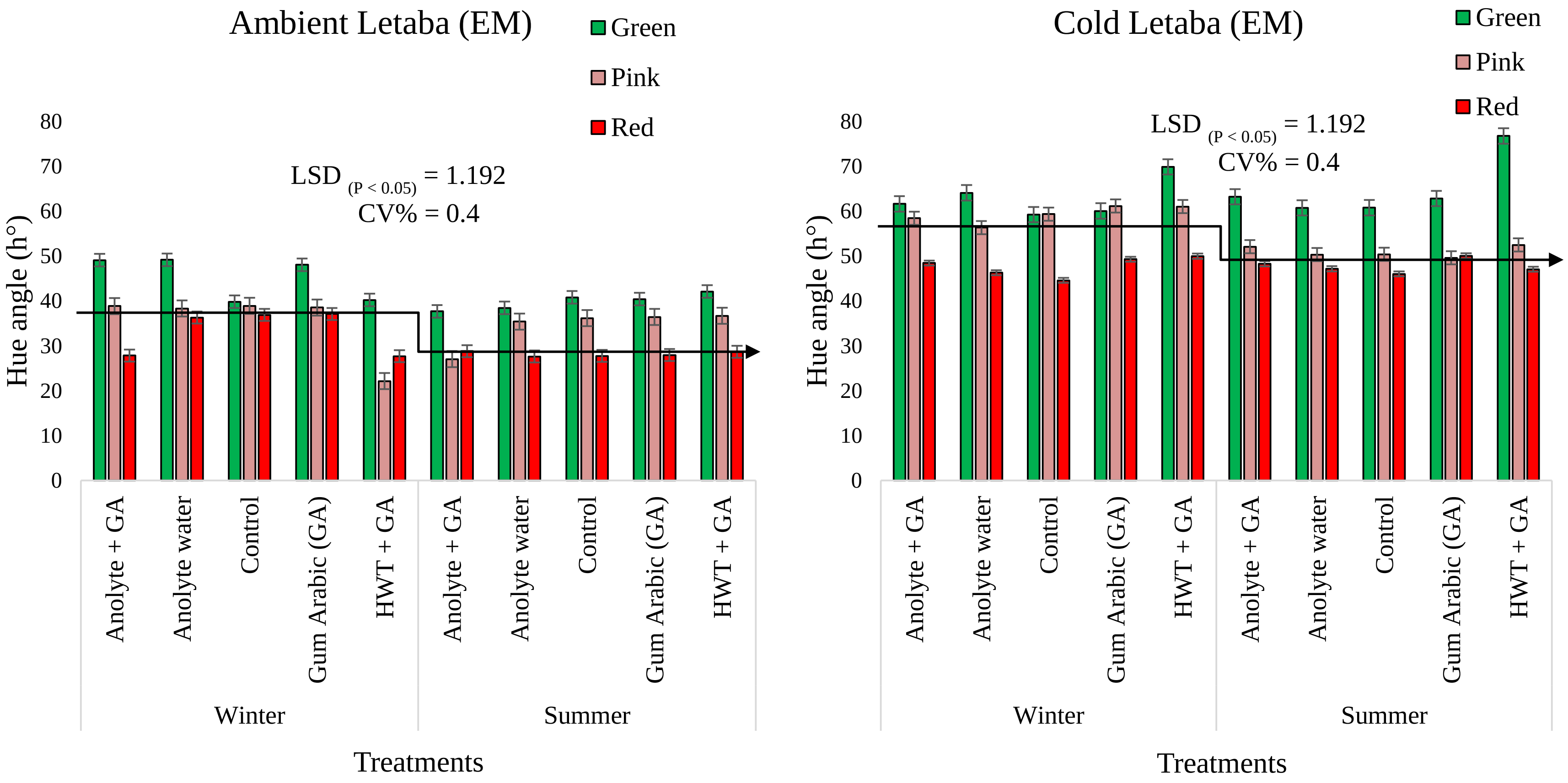

Figure 4.5 The effect of pre-storage treatments and storage conditions on the colour (hue angle) of tomatoes of different maturity stages from Letaba Municipality

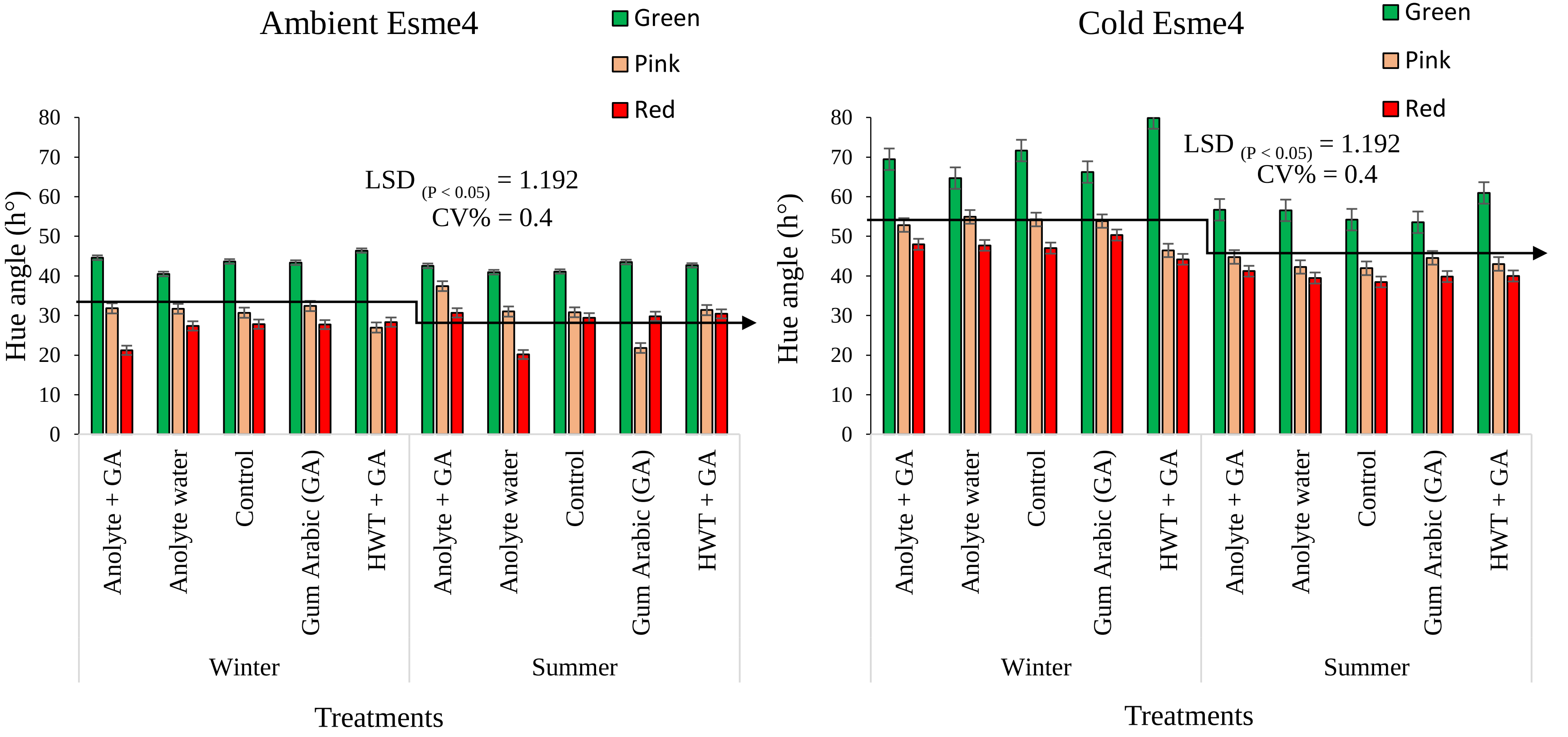

Figure 4.6 The effect of pre-storage treatments and storage conditions on the colour (hue angle) of tomatoes of different maturity stages from Esmé4 region

4.3.2 Firmness

The full layout of all treatment combinations as per experimental design is presented in Appendix B and analysis of variance in Appendix I. Discussed below are the key findings on the fruit firmness. The tomato firmness varied with harvesting seasons (Figure 4.7a and b). A comparison on Day 0 revealed that tomatoes that were harvested in winter were firmer than those harvested in summer. Supply chain routes had a significant ($P < 0.001$) impact on the firmness of tomatoes. Fruit from Letaba municipality (EM) were the firmest, followed by fruit from Pontdrift (PD), then fruit from Esmé4 (EF) (Figure 4.8b). Verheul *et al*. (2015b) reported the significant effect of temperature, light and relative humidity on different tomato quality parameters including firmness during fruit transportation over a long distance. The quality and shelf life of fresh tomatoes depends on the distance and road quality between the production and the processing area (Roy *et al*., 2008). These results positively correlates with the findings presented by Roy *et al*. (2008), since distribution of our current supply routes, i.e. Esmè4 is furthest from Pietermaritzburg market, and Letaba Municipality is closest.

Tomato firmness varied significantly ($P < 0.001$) with fruit storage conditions, with fruit store under cold storage being firmer than those stored at ambient conditions. Similar results were reported by Tilahun (2010), where tomatoes stored under a cooling system remained firmer than those stored at ambient conditions. As expected, the tomato firmness varied significantly ($P < 0.05$) with the harvesting maturity stage, whereby fruit harvested at the green maturity stage were firmer than the ones harvested at pink and red maturity stages (Figure 4.7). Similar results were reported by (Parker and Maalekuu, 2013). These findings were common across all three supply routes and under both storage conditions. Texture also varied significantly ($P < 0.001$) with the pre-storage treatments used to disinfect or coat tomato fruit. The HWT + GA combination treatment was the best treatment in terms of sustaining tomato fruit firmness. The HWT + GA combination treatment retained an average of 21.20 N and 20.24 N under cold and ambient storage conditions, respectively, compared to the control which retained 20.40 and 17.37 N under the same conditions. This occurred across all three supply routes. The HWT + GA combination treatment was a leading treatment, followed by anolyte water + GA, GA only and then anolyte water which resulted in firmer fruit under cold storage Similarly under ambient conditions, the HWT + GA combination treatment was still the best treatment in terms of maintaining tomato fruit firmness, which was followed by anolyte water only, GA only and anolyte water + GA (Figure 4.8a).

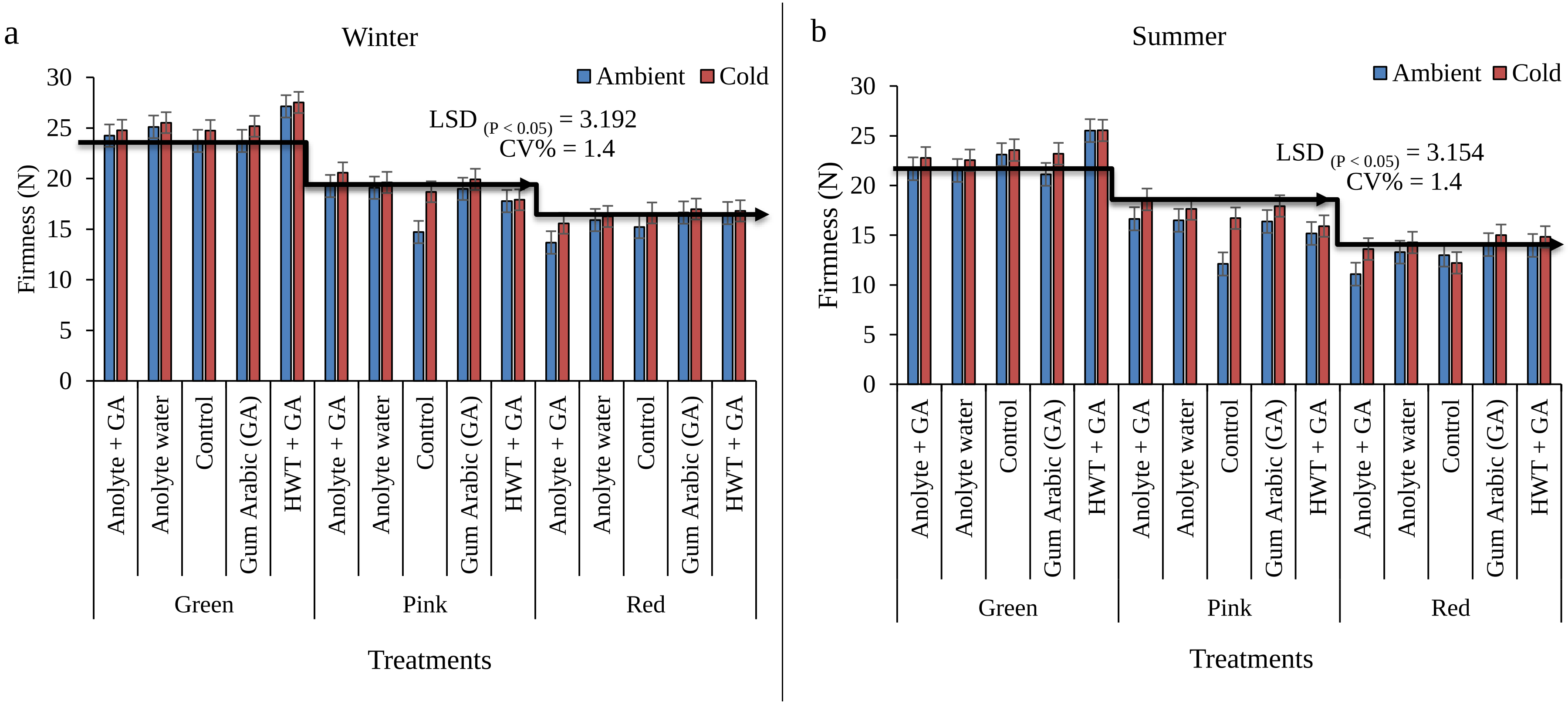

Figure 4.7 The effect of pre-storage treatments and storage condition on firmness of tomatoes harvested at different maturity stages in winter (a) and summer (b).

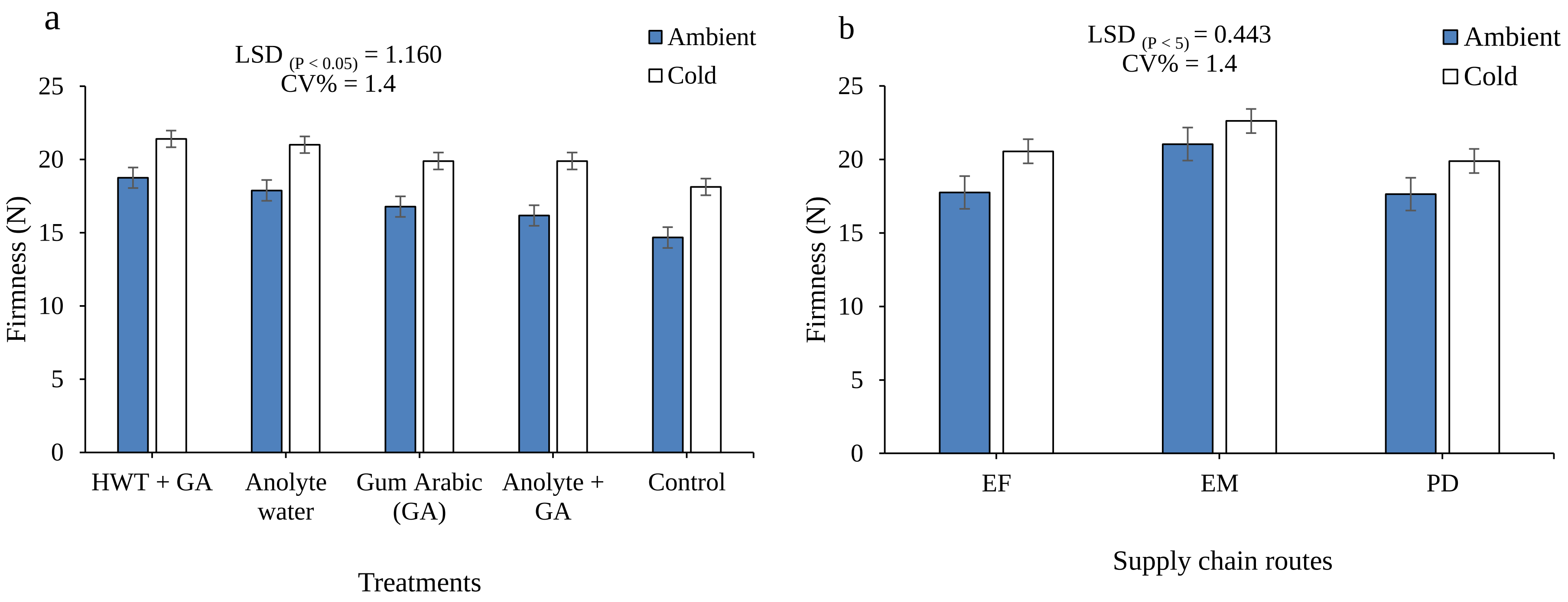

Figure 4.8 The effect of pre-storage treatments (a), supply routes (b), and storage conditions in tomato texture during day 16

4.3.3 Physiological weight loss

The means of treatments are presented in Appendix C and analysis of variance in Appendix I. Anolyte water and GA had had a highly significant ($P < 0.001$) influence on the physiological weight loss (PWL) of tomatoes. Fruit harvested in summer had a 2.87 % higher PWL when compared to fruit harvested in winter (data not shown). This could be due to the difference in the average temperatures between the winter and summer growing seasons and after harvest. During postharvest handling the average temperatures were 16 °C and 23 °C in winter and summer, respectively. Temperatures are generally higher in summer than in winter, which has the potential to induce stress in tomatoes during the growing season and to also hasten fruit deterioration after harvest (Verheul *et al.*, 2015a). The percentage mass loss also varied significantly ($P < 0.001$) with the supply chain routes, with tomatoes from Letaba Municipality experiencing the lowest physiological weight loss followed by Pontdrift, then Esmé4. This could be associated with the nature of tomatoes, conditions during the growing season, and conditions during transportation, mainly temperature and relative humidity. Roy *et al*. (2008) reported that the shelf life of tomatoes depends on the distance and road quality between the production area and consumption area. Tomato distribution through gravel or poor roads causes fruit to shake, which results in mechanical injuries and tomatoes lose juice through those minor injuries (wounds) and result in mass loss (Parker and Maalekuu, 2013).

Tomato fruit PWL also varied significantly ($P < 0.001$) with the storage conditions used. Fruit that were stored under cold storage conditions (11 °C) had lower PWL than the ones stored at ambient (16 °C in winter or 25 °C in summer), with an average of 4.84% and 10.07% for cold and ambient storage, respectively. Storage conditions of fresh highly perishable products like tomatoes are dependent on the storage temperature and relative humidity (Wu, 2010, Workneh and Osthoff, 2015). Therefore, the tomato fruit PWL is greatly influenced by a storage temperature and relative humidity surrounding the produce (Tilahun, 2010). Within the storage conditions tomato mass loss varied significantly with the harvesting maturity stages, green, pink and red. In general, the mass loss was the highest in green matured tomatoes, followed by pink, then red. This could be associated with the high rate of metabolic processes taking place in green-matured tomatoes, compared to pink and red. However, the mass loss of tomatoes of different maturity stages also varied significantly ($P < 0.001$) with their storage conditions. Under ambient storage, tomatoes harvested at green maturity had highest mass loss %, followed by the ones harvestsd at pink, then red (Figure 4.9a and c). They achieved this by having an average PWL % of 10.62, 9.70, and 9.68, for tomatoes harvested at green , pink and red maturity stages, respectively. However, under cold storage, tomatoes harvested at red maturity had the highest PWL, of 5.62%, followed by the ones harvested at pink maturity with 4.90%, then green maturity with 3.99% (Figure 4.9b and d). Tomato fruit mass loss can be attributed to the rate of transpiration as well as respiration (Pinheiro *et al*., 2013).

Within different maturity stages tomato mass loss varied significantly with pre-storage treatments. Anolyte water and the combination of anolyte water + GA coating were the best treatments in reducing the rate of fruit mass loss. GA and HWT did not do well in terms of reducing PWL (Figure 4.13). However, their positive impact was significantly ($P < 0.05$) different from the control (untreated) tomatoes. Anolyte water was found to be the most effective treatment in reducing the rate of physiological weight loss in of tomatoes, however, its mode of action was not anderstood since its a disinfectant.

Integration of pre-storage treatments and storage conditions resulted in a highly significant ($P < 0.001$) reduction in the PWL of tomatoes. The efficacy of the combined treatments was detected in tomatoes of different maturity stages and across all the supply routes. As mentioned previously, the pre-storage treatments suuch as anolyte water and Gum Arabic coating under cold storage conditions significantly ($P < 0.001$) reduced the mass loss in tomatoes. Integrated treatments resulted in more superior results, specifically in tomatoes harvested at the green maturity stage. Therefore, the results on the the effects of a three-way interaction between the harvesting maturity stage (green), pre-storage treatments anolyte water and Gum Arabic and cold storage conditions resulted in the most superior results in terms of reducing the rate of mass loss in tomatoes (Figure 4.10, 4.11 and 4.12, for green, pink and red, respectively). These treatments induced a highly significant ($P < 0.001$) impact in reducing tomato PWL. Similar results were reported by (Tilahun, 2010) whereby the efficiency of integrating pre-storage treatments and storage conditions significantly reduced mass loss and sustained quality in tomatoes.

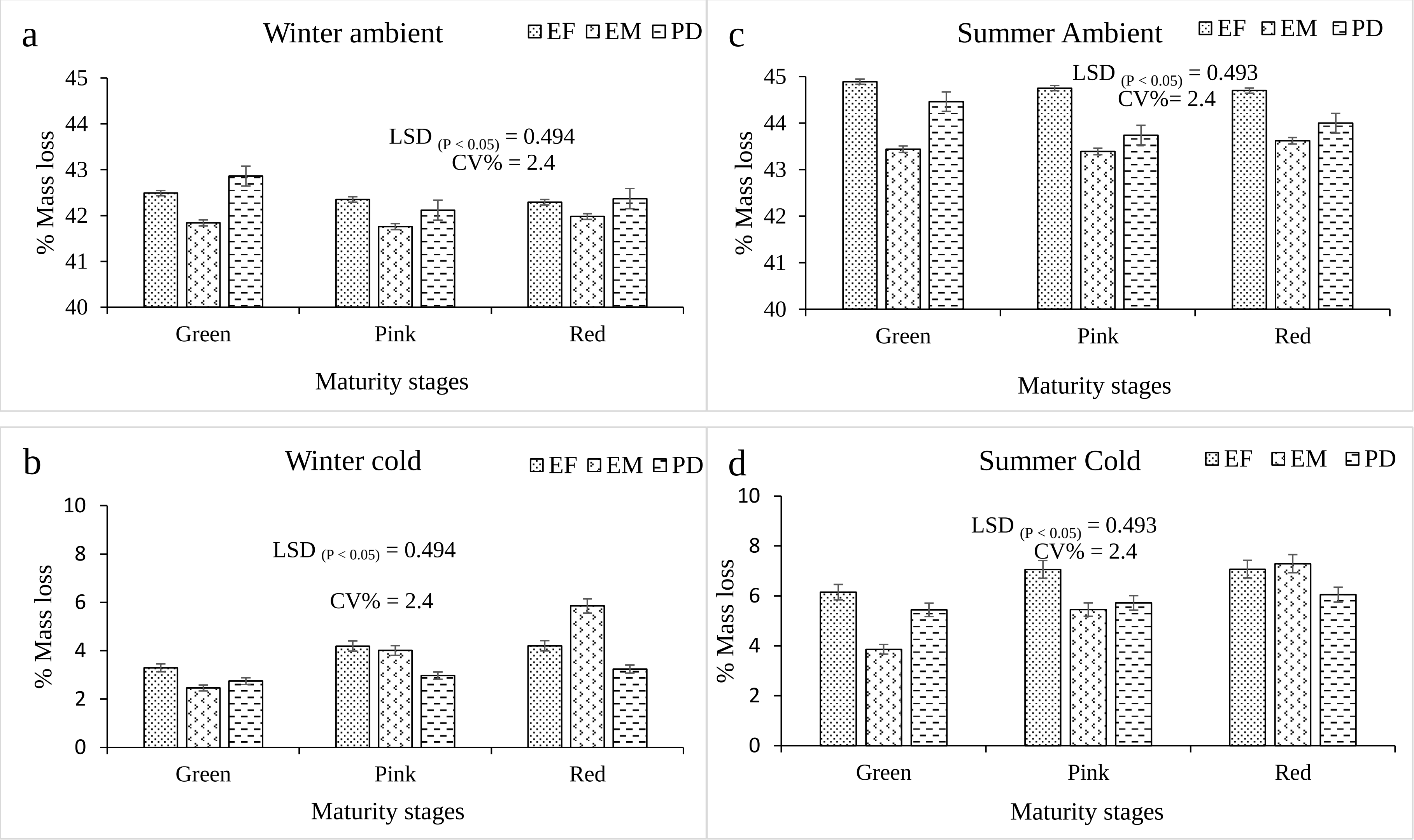

Figure 4.9 The effect of supply routes, maturity stages and storage conditions on mass loss of tomatoes harvested in different seasons

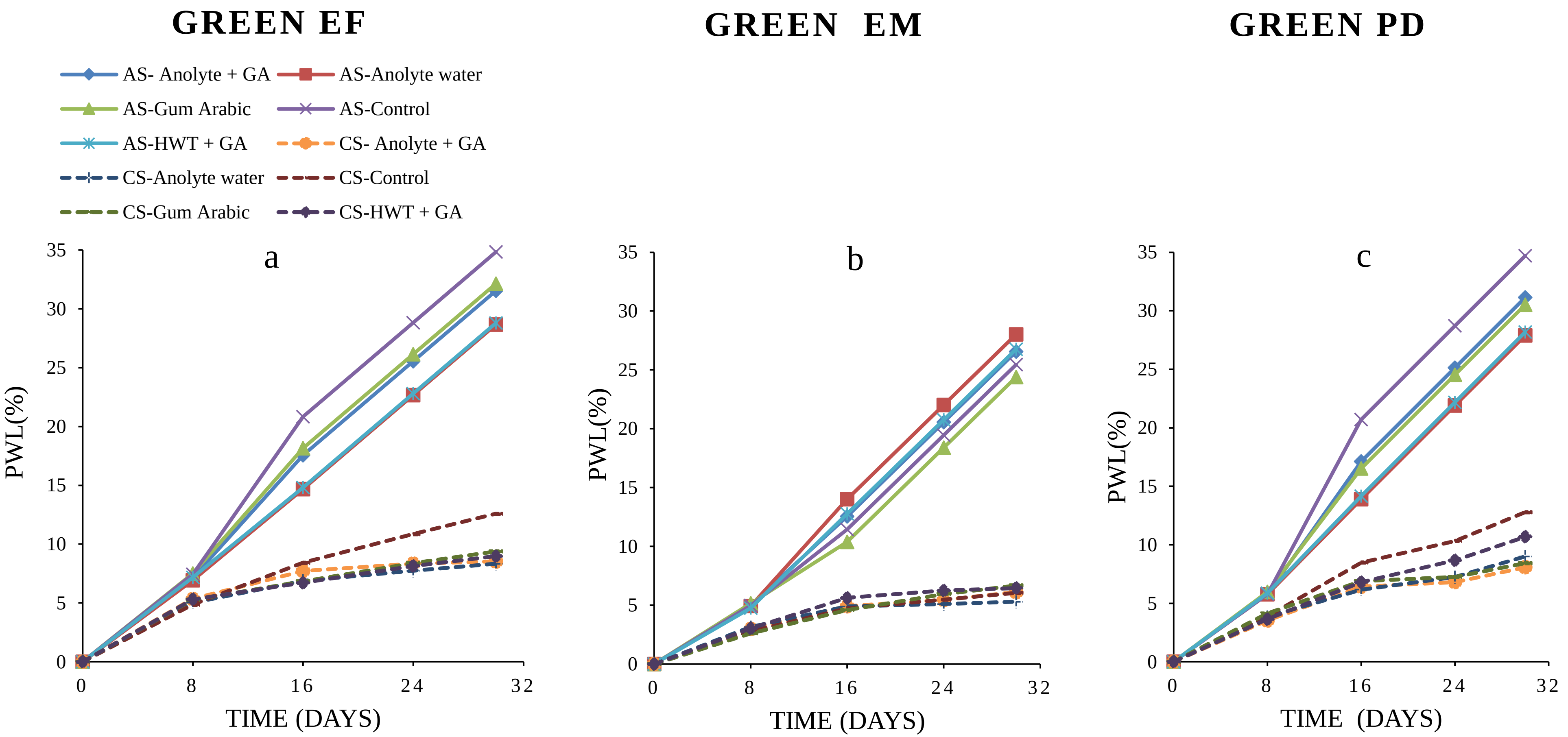

Figure 4.10 The interaction effects of pre-storage treatments and storage conditions on mass loss of pink-matured tomatoes from different supply routes (LSD ($P < 0.05$) = 1.743, CV% = 2.4)

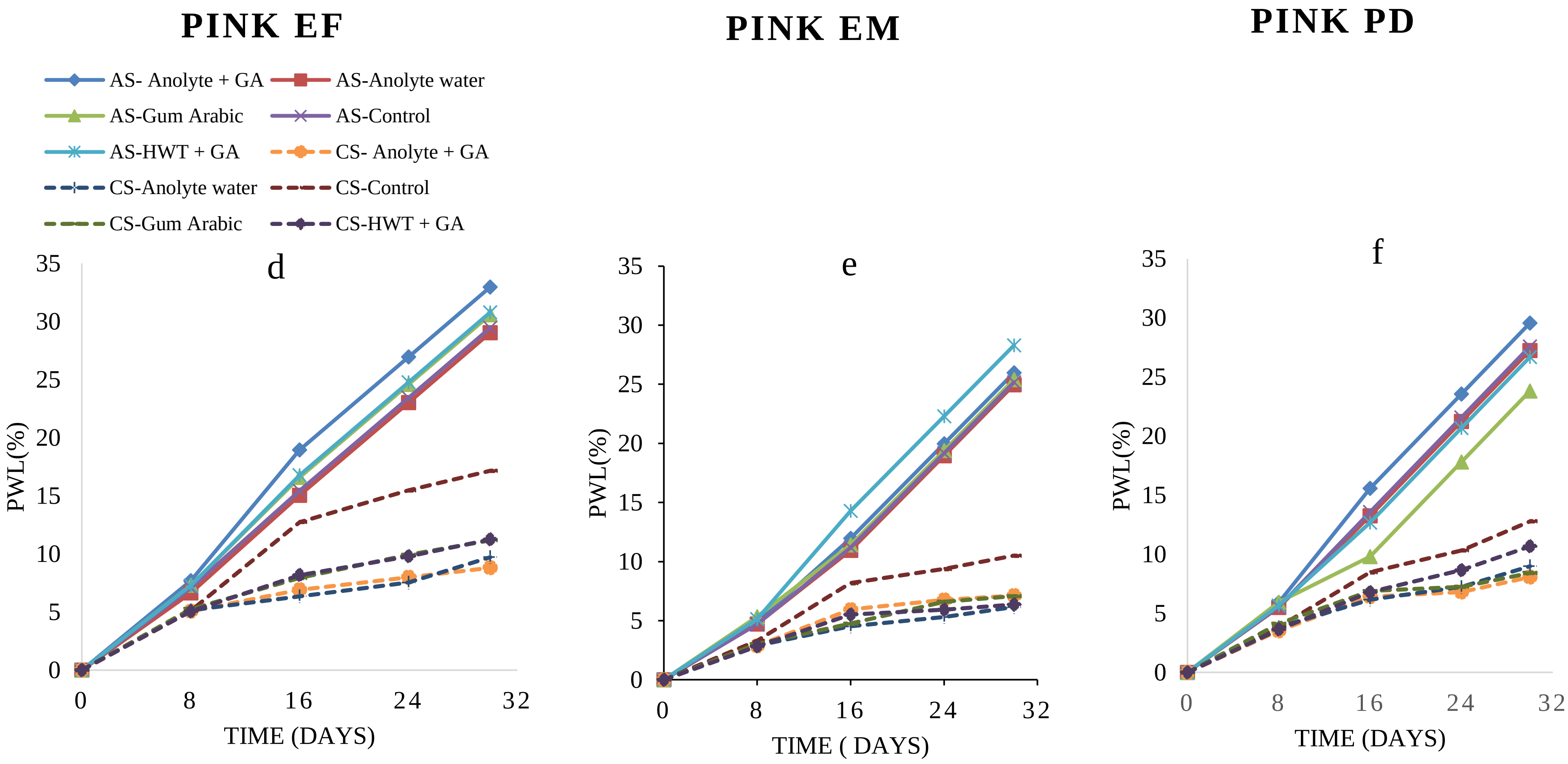

Figure 4.11 The interaction effect of pre-storage treatments and storage conditions on mass loss of pink-matured tomatoes from different supply routes (LSD ($P < 0.05$) = 1.743, CV% = 2.4)

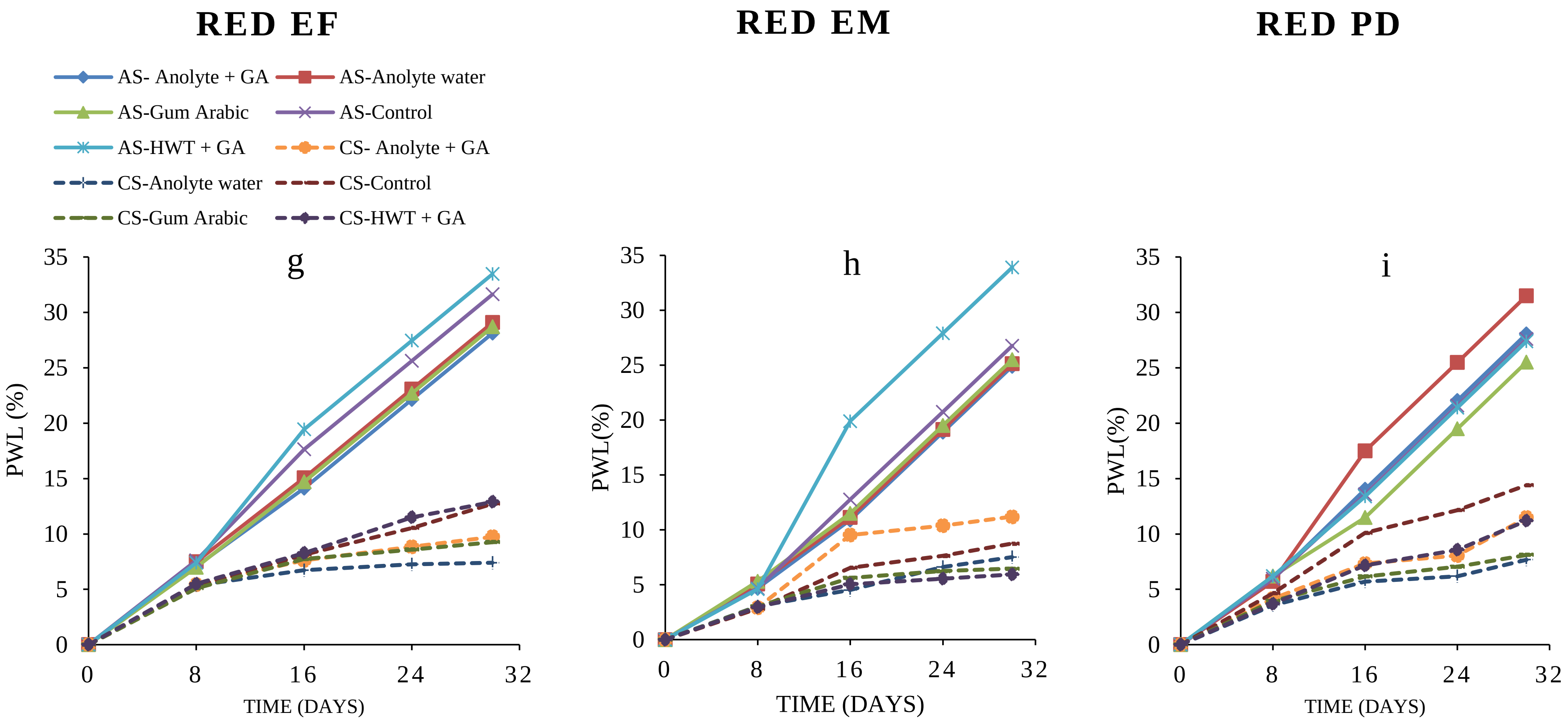

Figure 4.12 The interaction effect of pre-storage treatments and storage conditions on mass loss of red-matured tomatoes from different supply routes (LSD ($P < 0.05$) = 1.743, CV% = 2.4)

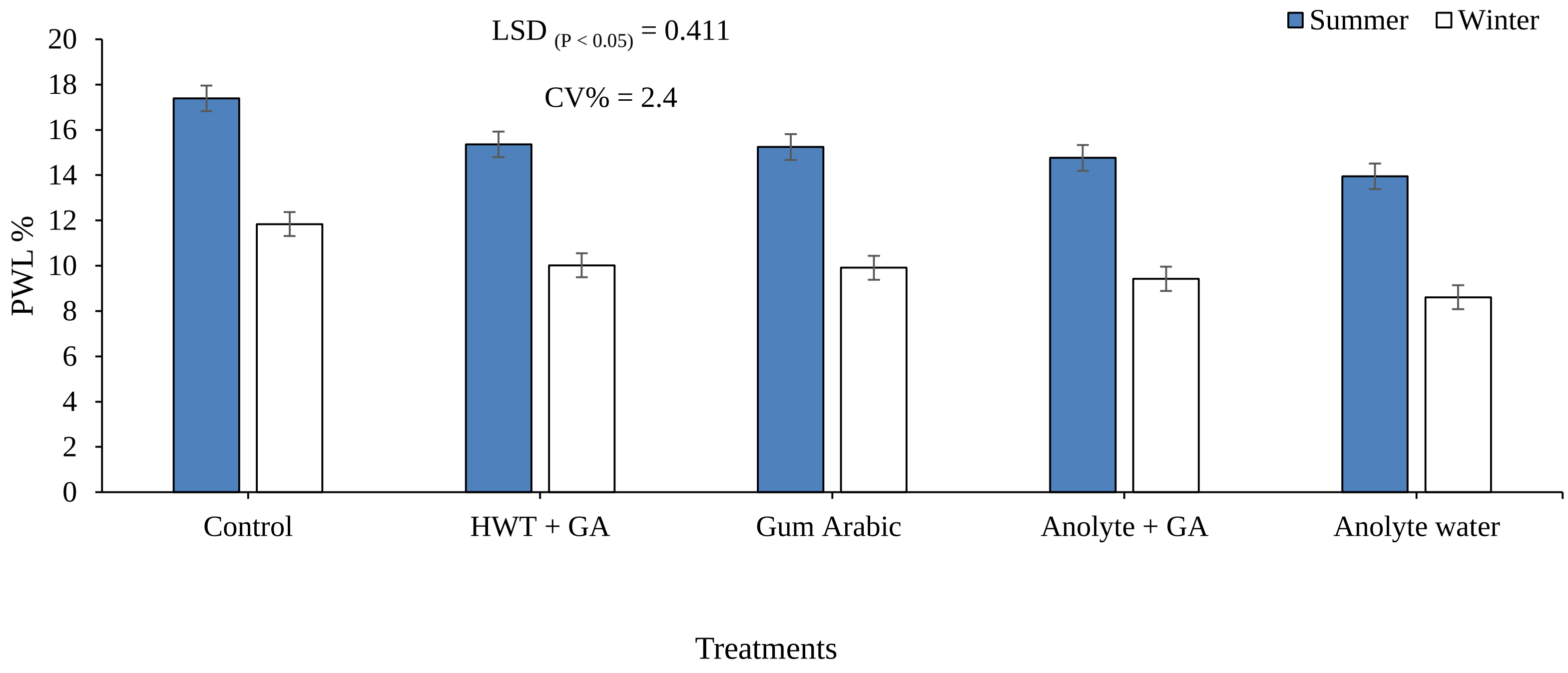

Figure 4.13 The overall effect of pre-storage treatments and storage conditions in mass loss % of tomato fruit of different harvest season

4.3.4 Respiration

The changes in the respiration rate of sample tomatoes for all combination treatments as per the experimental design are presented in Appendix D and analysis of variance in Appendix I. Tomato respiration varied significantly ($P < 0.001$) with the harvesting seasons. Fruit harvested in summer had higher respiration rates than tomatoes harvested in winter. With regard to the harvest seasons, tomato respiration rate varied significantly ($P < 0.001$) for the supply routes. Fruit from Letaba Municipality had the lowest respiration rate, followed by fruit from Esmé4, then fruit from Pontdrift. Tomatoes from Letaba Municipality, Esme4 and Pontdrift had an average respiration rate of 9.81, 12.26, and 15.44 mL $CO_2.kg^{-1}.hr^{-1}$, respectively. Within the supply routes, tomato respiration rate varied significantly ($P < 0.001$) with the harvesting maturity stages. Green matured fruit had the highest respiration rate followed by pink, and then red matured tomatoes. However, there was no significant ($P > 0.05$) difference in the respiration rate of pink and red matured tomatoes. Upon the tomato fruit arrival, the average respiration rate was 18.54, 15.69 and10.94 mL $CO_2 .kg^{-1}.hr^{-1}$, for green, pink and red matured tomatoes, respectively. The respiration rate increased on Day 8 of sampling, reaching the climacteric peak, then declined therafter.

The maturity stages combined with storage conditions had significant ($P < 0.001$) influenced the rate of respiration. Tomatoes from cold storage, generally, had lower respiration rates than fruit from ambient storage. At ambient storage, a climacteric peak was experienced on the 8th day of sampling for all the maturity stages. The climacteric peak was highest in tomatoes harvested at green maturity, followed by pink. Tomatoes harvested at red ripe stage had the lowest respiration rate. Under cold storage, the climacteric peak was observed on Day 8 only in pink and red matured tomatoes. Tomatoes harvested at green maturity stage experienced a delayed climacteric peak which only occurred during the 16th day of storage. This could be associated with the levels of ethylene emitted which were not yet sufficient to trigger the climacteric rise in the green-matured tomatoes (Calegario *et al*., 2001). Green-matured tomatoes had the highest climacteric peak under cold storage (27.55 mL $CO_2.kg^{-1}.hr^{-1}$). No significant climacteric rise in pink and red matured tomatoes. Similar results were reported by Calegario *et al*. (2001), whereby little or no climacteric rise was experienced in pink stage and red ripe tomatoes under cold storage.

Tomato respiration rate also varied significantly ($P < 0.001$) with the pre-storage treatments used prior to fruit storage. GA coating was the most effective treatment in reducing the rate of respiration across different maturity stages (Figure 4.14) and under both storage conditions. Similar results were reported by (Ali *et al.*, 2010) whereby GA coating significantly delayed the rate of respiration in tomatoes. The combination of pre-storage treatments and storage conditions significantly ($P < 0.001$) reduced the respiration rate of tomatoes with anolyte water disinfection treatment and HWT + GA being the most effective treatments under cold storage.

Furthermore, the integration of postharvest treatments had a highly significant ($P < 0.001$) impact in reducing the rate of respiration. Tomatoes from Letaba Municipality treated with GA and stored at cold storage had lowest respiration rate and retained the longer shelf life across all harvesting maturity stages. This could be associated with fruit quality status upon arrival, particularly the rate of respiration, which is a function of the temperature and relative humidity inside the truck. High temperatures after harvest stimulates the rate of metabolic and enzymatic activities taking place within tomato fruit, thus reduce fruit quality (Workneh and Osthoff, 2015). Rising temperatures within the tomato fruit surroundings result in the rate of respiration being stimulated (Singh *et al.*, 2013).

Respiration describes the process whereby accumulated organic materials (carbohydrates, fats and proteins) are broken down into simpler substances i.e. carbon dioxide and water, with a release of energy (Workneh e*t al.*, 2012, Hailu *et al.*, 2013, Workneh and Osthoff, 2015). This process basically defines the rate at which carbohydrate reserves are consumed for accumulation of energy in the form of ATP, which is necessary to power metabolic processes leading to ripening. Therefore, during respiration, food reserves are continuously consumed within a fruit, and this enhances the rate of senescence (Hailu *et al*., 2013). Irtwange (2006) discussed that the rate of fruit quality deterioration is directly proportional to the fruit respiration rate. This is due to the fact that the produce is no longer connected to the source of photosynthates; rather it is fully dependent on its own accumulated food reserves (Wu, 2010). So, the higher the rate at which accumulated carbohydrate reserves are used, the quicker the rate of fruit senescence. Therefore, the two-way interaction of cold storage and two of Gum Arabic involving treatments (i.e. Gum Arabic alone and HWT + GA) were the most effective treatments in reducing the rate of respiration in fruit of different maturity stages across different supply routes (Figure 4.13). On average, reduced the respiration rate by 3.3 and 2.8 ml CO_2

/kg.hr when compared to the control. This induced a potential of these pre-storage treatments to extend shelf life of tomatoes. The superiority of these pre-storage treatments was more enhanced in tomatoes stored under cold storage. This defines the additional superiority of integrating treatments as most efficient technology to be adopted by tomato industry, instead of investing more in individual treatments.

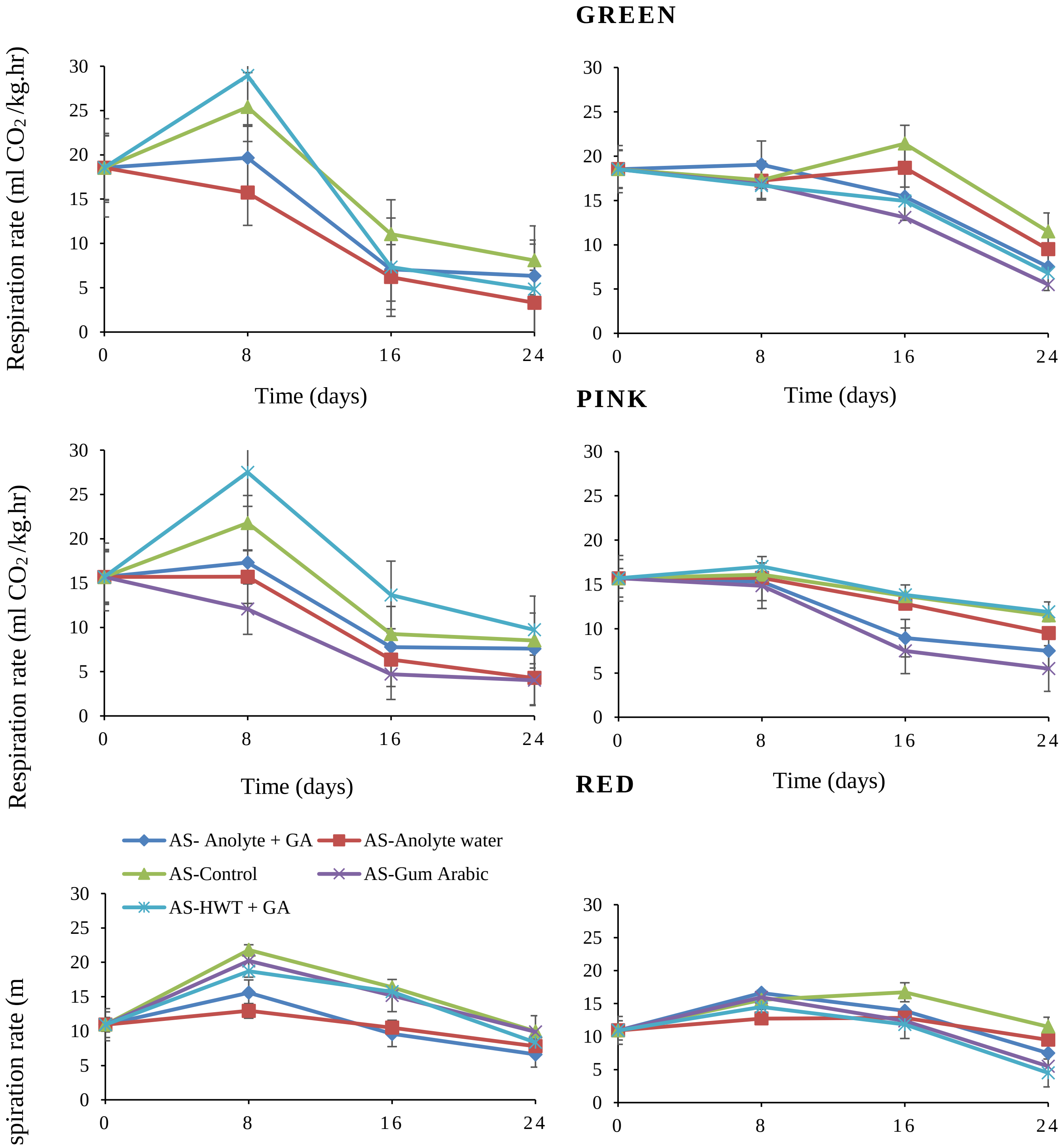

Figure 4.14 The interaction effects of pre-storage treatments and storage conditions on the respiration rate of tomatoes of different maturity stages (LSD $_{(P < 0.05)}$ = 1.356, CV% = 1.7)

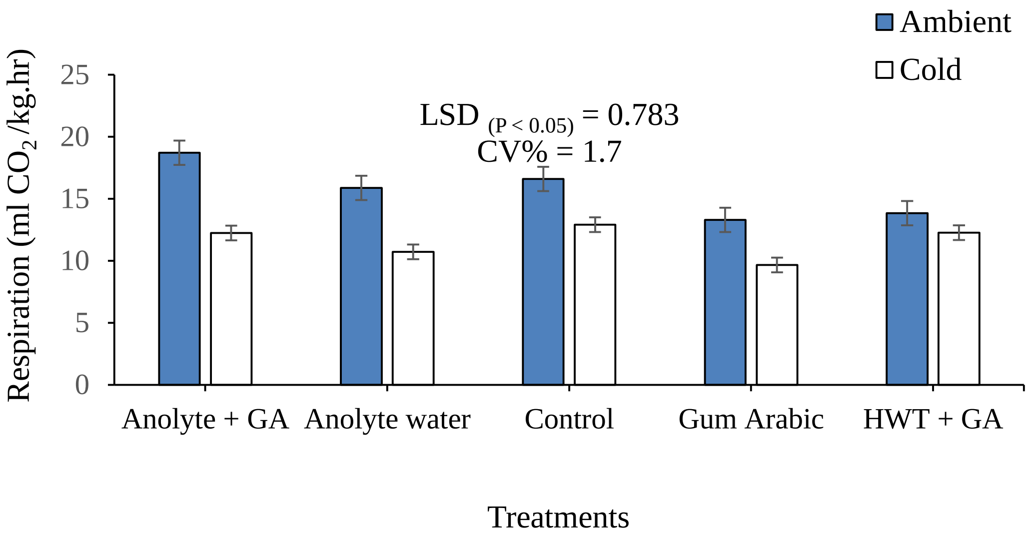

Figure 4.15 The interaction effects of pre-storage treatments and storage conditions on the rate of respiration during day 16

4.3.5 Total soluble solids

The full layout of all combination treatments as per experimental design for the total soluble solids (TSS) is presented in Appendix E and analysis of variance in Appendix I. The results on TSS revealed a highly significant ($P < 0.001$) difference in tomatoes of different harvest seasons, with the TSS being higher in summer harvested than in winter harvested tomatoes. This could be associated with the variation in temperatures during the growing seasons as well as postharvest of summer and winter harvested tomatoes. TSS also varied significantly ($P < 0.001$) with the supply routes, with tomatoes from Esmé4 region having the highest TSS, followed by Pontdrift, then Letaba Municipality. TSS in tomatoes are associated with accumulation of sugars and other organic compounds as sign of fruit ripening (Hailu *et al*., 2013). Therefore, high TSS in tomatoes from Esmé4 region indicated their ripening status, which was a bit further than fruit from other supply routes. Similar results were also reported by Suárez *et al*. (2008) who reported a continuous rise in TSS during tomato ripening. (Pothula et al., 2006) defined a °Brix as ratio of soluble solids in a solution. Soluble solids are made up of sucrose, glucose and fructose as the major components, and they increase as fruit ripens (Suárez *et al.*, 2008). (Lira *et al.*, 2016) increment of sugars with ripening stages of tomato is associated with the metabolism of carbohydrates, proteins and lipids.

Tomatoes of different supply routes also varied significantly ($P < 0.001$) with their storage condition, with fruit from cold storage having lower soluble solids than the ones from ambient (Figure 4.16). With regard to the storage conditions, the TSS varied significantly ($P < 0.001$) with the harvesting maturity stages, with fruit harvested at red-maturity stage having the highest TSS, followed by pink, then green matured. Similar results were reported by Moneruzzaman *et al*. (2008), whereby TSS of was highest in red-matured tomatoes and lowest in green matured tomatoes. This was advantageous in green-matured tomatoes since it resulted in tomatoes achieving longer shelf life than pink and red-matured tomatoes, however, tomatoes harvested at green maturity never achieved the levels of soluble solids and other assimilates accumulated by tomatoes harvested at pink- and red maturity stages. This is due to the fact that they were terminated from their source while still green, and after termination there are not additional assimilates that are accumulated, instead, the ones that were already accumulated are degraded for ripening to occur.

Tomatoes of different maturity stages were also significantly ($P < 0.001$) affected by the pre-storage treatments used as disinfectants or coating. Anolyte water only resulted in the favourable accumulation of optimal TSS without compromising fruit quality. Contrary to this, the combination of HWT + GA coating, and Anolyte water +GA were the most effective treatments in delaying chemical and biochemical processes leading to quick accumulation of soluble solids (Figure 4.15). Furthermore, the TSS were also significantly ($P < 0.001$) affected by the combined effects harvesting maturity stages, supply routes, pre-storage treatments and storage conditions. All two-way, three-way and four-way interactions had highly significant ($P < 0.001$) effects in delaying chemical and biochemical quality changes leading to quick hike in tomato TSS content (Table 5.9). This was advantageous in further extending the shelf life of tomatoes, since accumulation of TSS is associated with hastened biochemical and chemical processes leading to fruit quality deterioration. Individual postharvest technologies had significant effect in delaying the chemical and biochemical changes leading to quick rate of accumulation of soluble solids and ripening. However, the integration of these treatments resulted in a more effective treatment by slowing down the rate of accumulation of TSS, maintained quality and extended shelf life further. This was due to the significant impact induced by the combined effects of more than one technology instead of a single technology. For instance application of pre-storage treatments and using cold storage conditions resulted in superior results than each of individual technologies.

Reducing the onset of physiological, biochemical and chemical processes, which lead to the accumulation of TSS and ripening is more advantageous in green matured tomatoes, especially when a longer shelf life is desired (e.g. under long distance shipment or export conditions). However, nutritionally, it is not advantageous because, the levels of soluble solids which are sugars and other nutritious organic compounds and even levels of antioxidants such as carotenoids will never reach the level that they would reach if tomatoes were harvested at pink or red ripe stage. A similar trend was observed for tomatoes that are allowed to ripen on the vine compared to those allowed to ripen while detached (Parker and Maalekuu, 2013). Therefore, integration of postharvest technologies is very efficient in extending shelf life of tomatoes across all the maturity stages, however the efficiency decreases with ripening status, i.e. integrated technologies are less efficient in red than pink tomatoes.

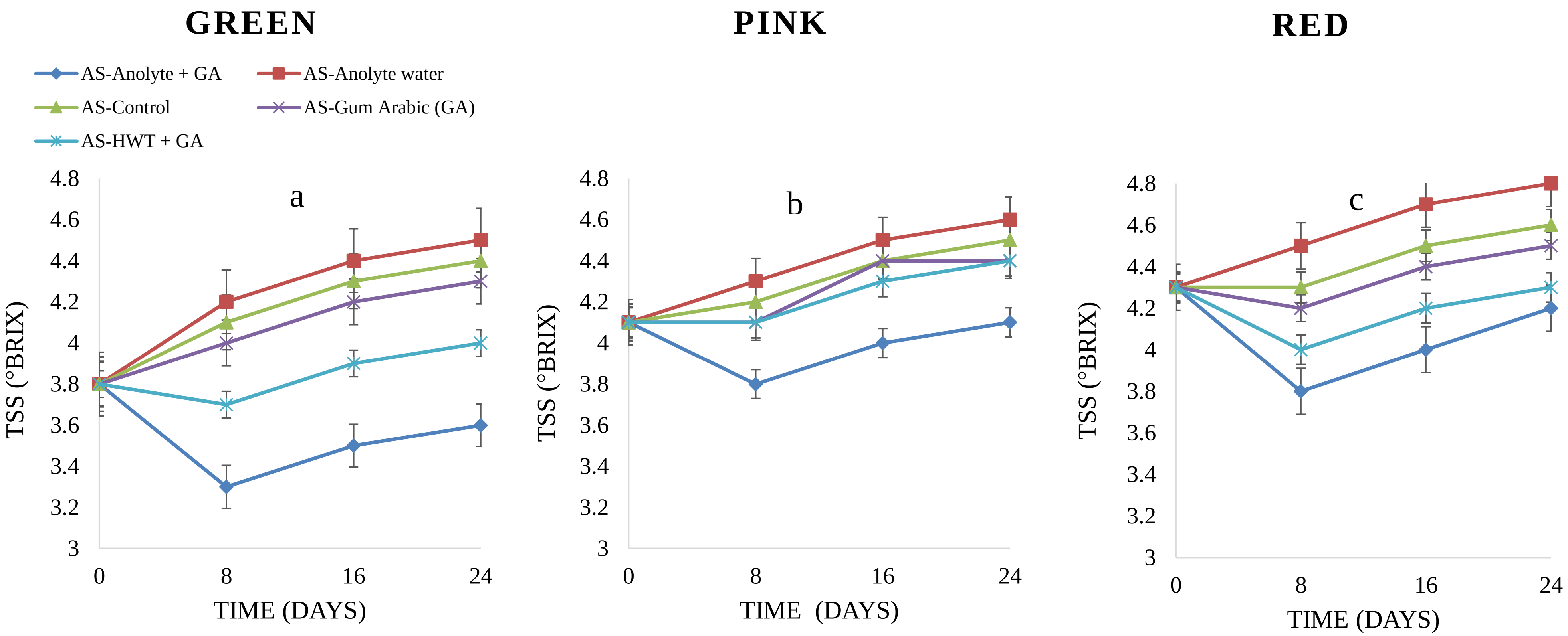

Figure 4.16 The interaction effects of harvesting maaturity stages and pre-storage treatments on TSS under ambient storage conditions for green (a), pink (b) and red ripe (c) tomatoes (LSD ($P < 0.05$) = 0.120, CV% = 0.2)

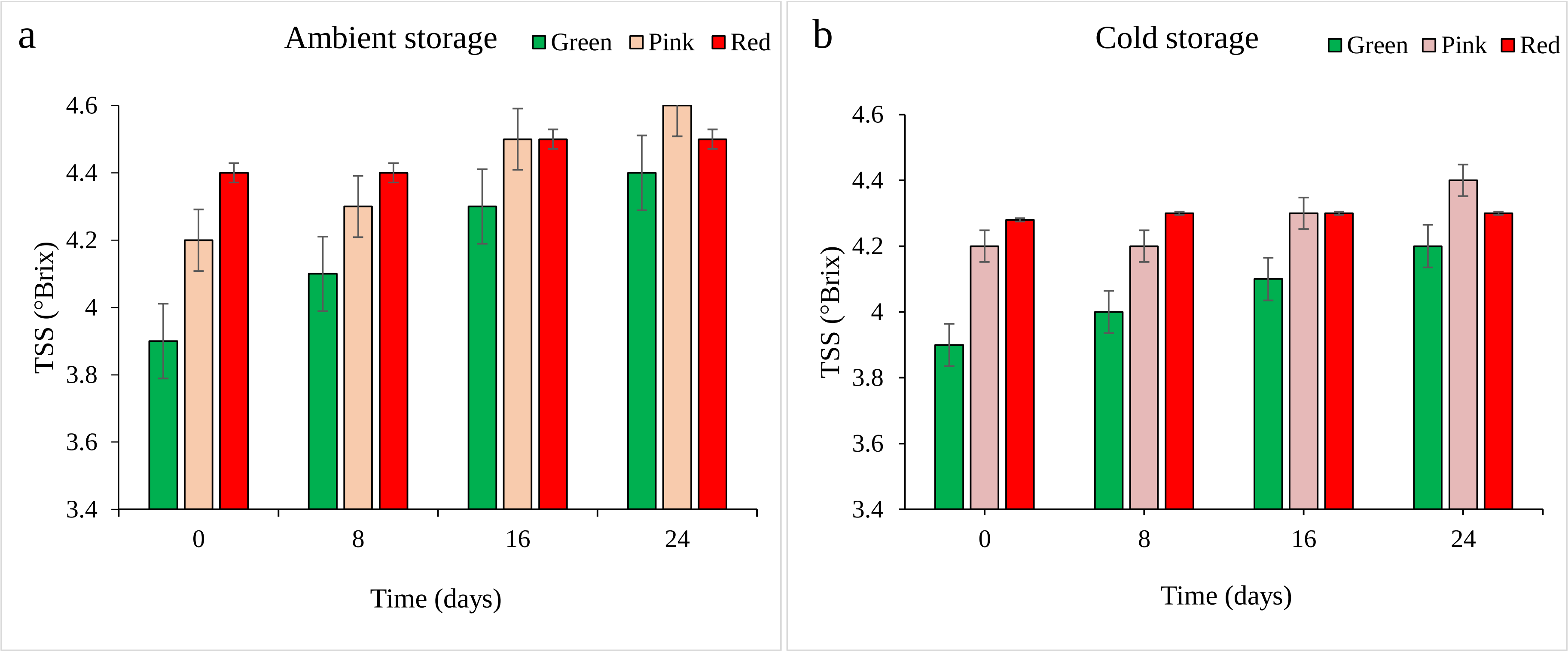

Figure 4.17 The effect of maturity (a and b) and storage conditions on tomato soluble solids (LSD ($P < 0.05$) = 0.120, CV% = 0.2)

4.3.6 Phenolic compounds

The full layout of all treatment combinations as per experimental design is presented in Appendix F and analysis of variance in Appendix I. The total phenolic compounds (TPC) in tomatoes generally varied with the harvesting seasons. They were generally higher in fruit harvested in winter than fruit harvested in summer (data not shown). These results were correlated with the longer shelf life exhibited by tomatoes harvested in winter compared to the ones harvested in summer. TPC also varied significantly ($P < 0.001$) with the different supply routes, where tomatoes from Letaba Municipality had the highest amount of total phenolic compounds (TPC), followed by Pontdrift, then Esmé4. TPC also varied significantly ($P < 0.001$) with harvesting maturity stages, with green-matured tomatoes having the highest phenolic content followed by pink, then red. Similar results were reported by (Helyes *et al.*, 2006) whereby green-matured tomatoes retained more polyphenols than riper maturity stages.

Within the maturity stages, TPC varied significantly ($P < 0.001$) with storage conditions, whereby fruit that were kept at ambient storage condition had lower TPC values than fruit that were kept at cold storage conditions. Similar results were reported by (Parker and Maalekuu, 2013) who reported that tomatoes continuously lose polyphenols as they respire during the ripening process. This can be attributed to some polyphenols becoming oxidised during respiration. Similar results were also reported by (Buta and Spaulding, 1997) who reported a continuous declining of phenolic compounds in tomato pericarp as fruit ripens. Declining of total phenolic compounds in tomato during ripening is associated with a reduction of a 5'-caffeolyquinic acid (CaQ), which is one of the three predominant compounds composing phenolic compounds in tomatoes. This compound is the major determinant of phenolic compounds in the pericarp because it has protective function, thus dominated the pericarp tissue of tomatoes, while others dominated the pulp.

TPC in tomatoes also varied significantly ($P < 0.001$) with the pre-storage treatments used to disinfect or coat tomato fruit prior to storage, whereby anolyte water treatment was superior to other treatments in terms of retaining quality and extending shelf life of tomatoes. On average, anolyte water treatment retained as high as 0.337, 0.329, and 0.234 mg GAE/g FW, in tomatoes from Pontdrift, Letaba and Esme4 regions, respectively, during Day 16 of sampling. Furthermore, the combined effects of most postharvest treatments had highly significant impact

($P < 0.001$) in retaining higher TPC in tomatoes. Among interaction effects, the two-way interaction of supply routes, pre-storage treatments and storage conditions had highly significant effect ($P < 0.001$) in sustaining phenolic compounds across different tomato maturity stages (Figure 4.16). Furthermore, the three-way interaction of supply routes, maturity stages and storages had most superior results in sustaining phenolic compounds in tomatoes of different maturity stages. Other two- and three-way interactions had significant impact ($P < 0.05$) in sustaining the levels of phenolic compounds in tomatoes, with route × treatments interaction effect as an exception. In addition to that, a four-way interaction sustained tomato shelf life in a visual perspective, however, its effect was not significantly different ($P > 0.05$) from the control in terms of retaining higher TPC.

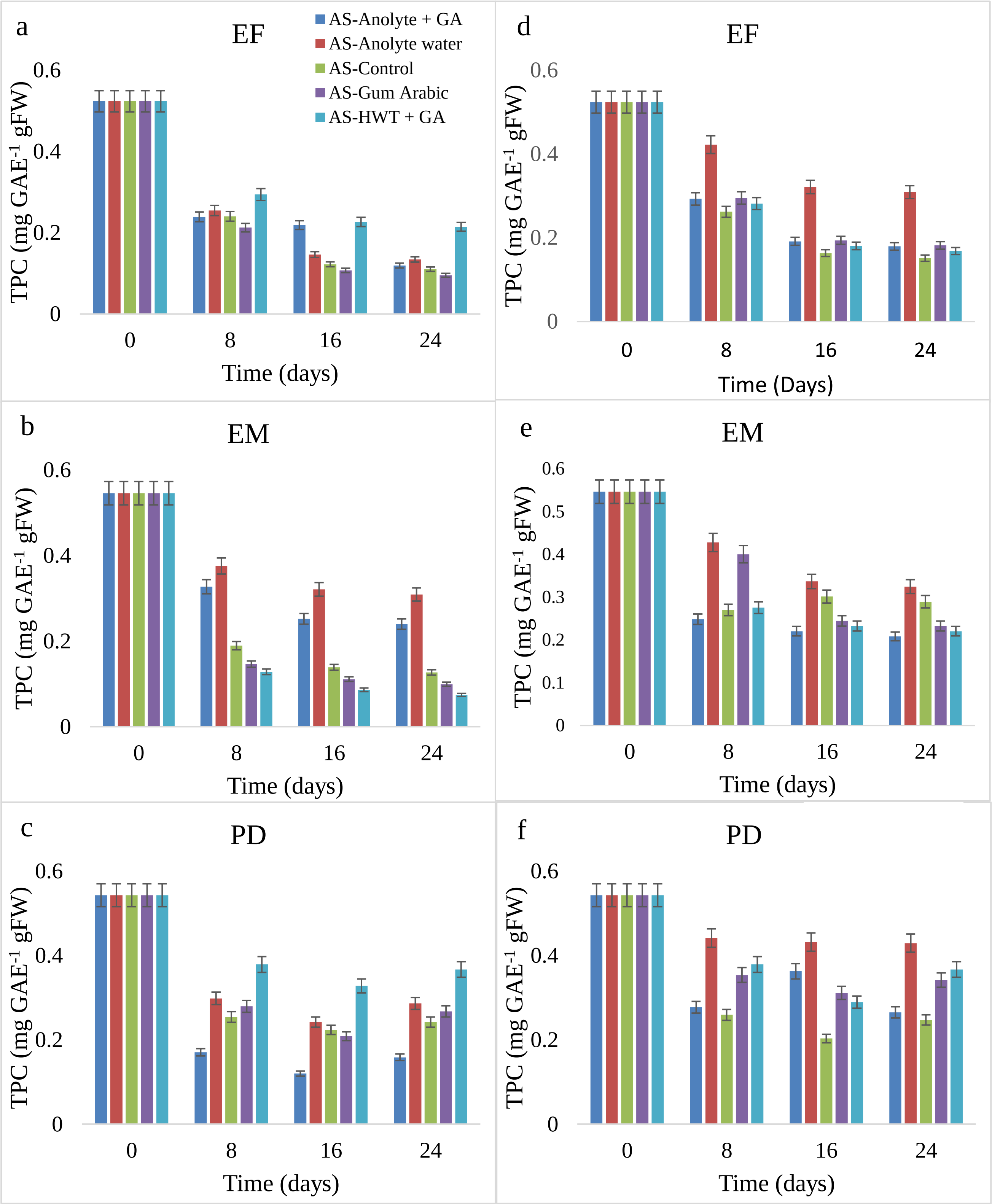

Figure 4.18 The effects of supply routes, pre-storage treatments and storage conditions on the TPC of tomatoes harvested at green maturity. (CS and AS means cold storage and ambient storage, respectively. HWT = Hot water treatment, GA = Gum Arabic coating). (LSD ($P < 0.05$) = 0.081, CV% = 0.1)

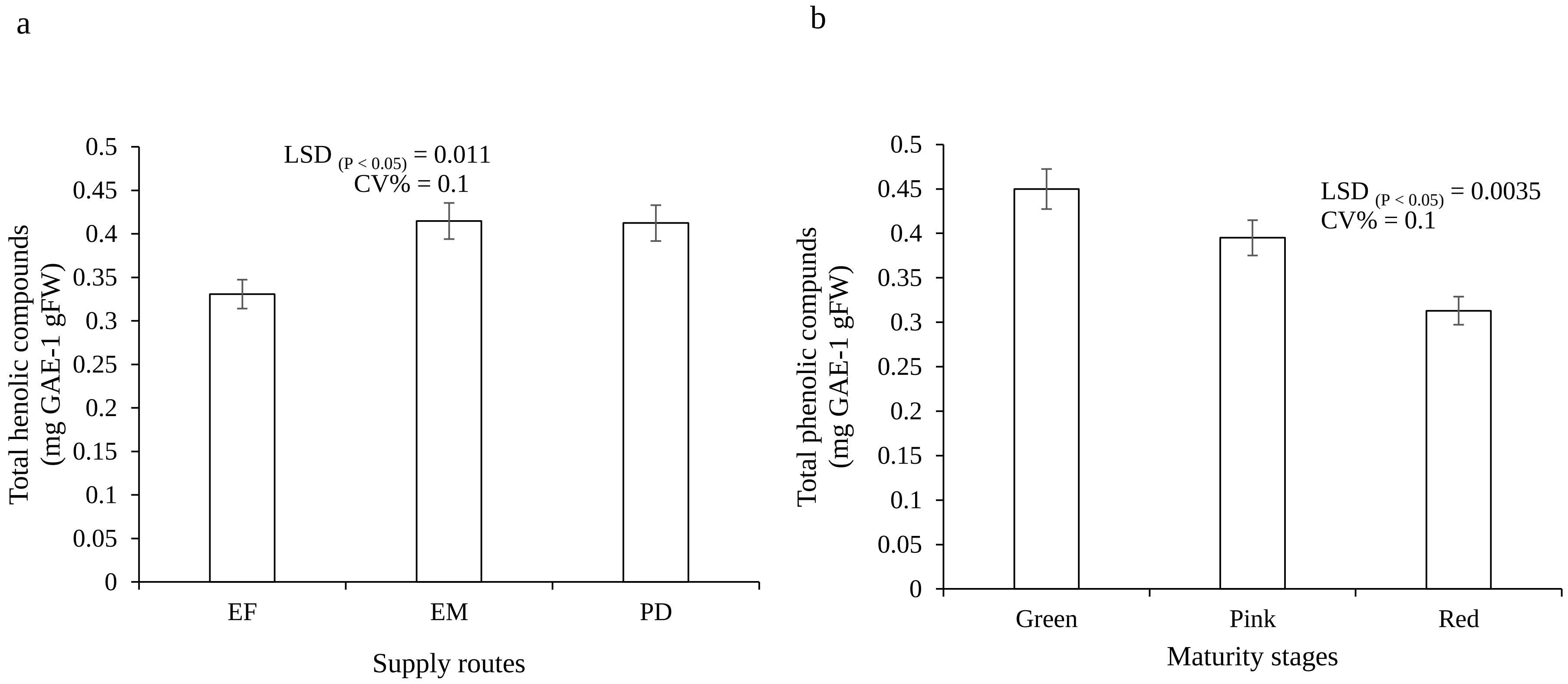

Figure 4.19 The effect of supply routes (a) and harvesting maturity stages (b) in the total phenolic compounds (TPC) in tomatoes

4.3.7 Total antioxidant capacity

The full treatment combinations for the total antioxidant capacity (TAC) as per the experimental design is presented in Appendix G and analysis of variance in Appendix I. The TAC in tomatoes generally varied with the harvesting seasons. The TAC was higher in fruit harvested in winter than the ones harvested in summer, with an average of 47.59% and 37.64% for winter and summer, respectively. These results were correlated with the longer shelf life exhibited by tomatoes harvested in winter compared to the ones harvested in summer. TAC also varied significantly ($P < 0.001$) with the different supply routes, where tomatoes from Letaba Municipality had the highest TAC, followed by Pontdrift, then Esmé4. Similar results were reported by (Verheul *et al.*, 2015b) whereby postharvest quality of cherry tomatoes was significantly ($P < 0.05$) affected by transportation effects which include temperature, relative humidity, light and ethylene concentration within a truck. Effects of supply routes involve crop genome, growing site (i.e. environmental effects and management practices during the growing season, plus handling and transportation effects on fruit quality). However, this study mainly focused on the handling and transportation effects in tomato quality, since growing conditions and management practices were made same.

TAC also varied significantly ($P < 0.001$) with harvesting maturity stages. Green-matured tomatoes had the highest antioxidant capacity which was followed by pink, and then red. Similar results were reported by Getinet *et al*. (2008) whereby green-matured tomatoes maintained the higher chemical quality than tomatoes harvested at pink and red maturity stages. The highest TAC of green matured tomatoes was positively correlated with their percentage marketability which gave them an ability to live longer than riper tomatoes. TAC started higher during Day 0 of sampling and continuously decreased with fruit ripening, and then slightly increased again during ripening. Similar results were reported by Adetuyi *et al*. (2008) in pawpaw, whereby there was continuous reduction in antioxidants with fruit ripening. This could be associated with degradation of certain pigments, carbohydrates, and organic compounds and including the phenolic compounds for the formation of carotenoids, lycopene, sugars and other organic compounds. Ali *et al.* (.2013) described a later increment in the TAC as associated with the accumulation of carotenoids, particularly lycopene. Within the maturity stages, TAC varied significantly ($P < 0.001$) with storage conditions, whereby fruit from ambient conditions had lower TAC than fruit from the cold storage.

TAC in tomatoes also varied significantly (P < 0.001) with the pre-storage treatments used. Anolyte water treatment was superior to other treatments in terms of retaining quality and extending shelf life of tomatoes. Moreover, the combined effects of cold storage with green matured tomatoes harvested from Letaba Municipality gave the most superior results in terms of retaining the highest TAC. There was highly significant (P < 0.001) difference in the TAC of tomatoes subjected to the two-way and three-way interaction effects of supply routes, maturity stage, pre-storage treatments and storage conditions (Figure 4.18). As expected, there was a positive correlation between TAC and TPC, (i.e. where there were high TPC), there was high TAC. This is due to the fact that TPC form the major components of TAC and phenolic compounds are the major active antioxidants in tomatoes (Ali *et al.*, .2013). Shen *et al*. (2013) reported that fruit's antioxidant capacity is influenced by total phenolic compounds and ascorbic acid, therefore individual and combination treatments that preserve phenolic compounds are enhancing the total antioxidant capacity indirectly.

Total antioxidant capacity describes the capacity of antioxidants to be protective in fruit mainly against oxidative stress (Eghdami and Sadeghi, 2010). Oxidative stress in fruit usually caused by high accumulation of reactive oxygen species (ROS), which at higher levels turns to react with membrane lipids, protein and DNA, resulting in cell's death. By so doing they are weakening the fruit membrane, causing number of membrane disorders (e.g. membrane lesions, water leakage, water soaking). Examples of reactive oxygen species are superoxide, hydrogen peroxide, and the hydroxyl radicals. All are highly reactive, therefore they quickly react with biomolecules under stress conditions. Therefore, TAC describes mainly a capacity of antioxidants to scavenge the reactive oxygen species (ROS), or to quench a singlet oxygen species, thus enhance fruit defence system (Eghdami and Sadeghi, 2010, Pinela *et al*., 2012). This basically means having anolyte water as a leading treatment in sustaining TAC of tomatoes implies a high potential of anolyte water treated fruit to withstand adverse conditions such as too high or too low temperatures, when compared to other treatments.

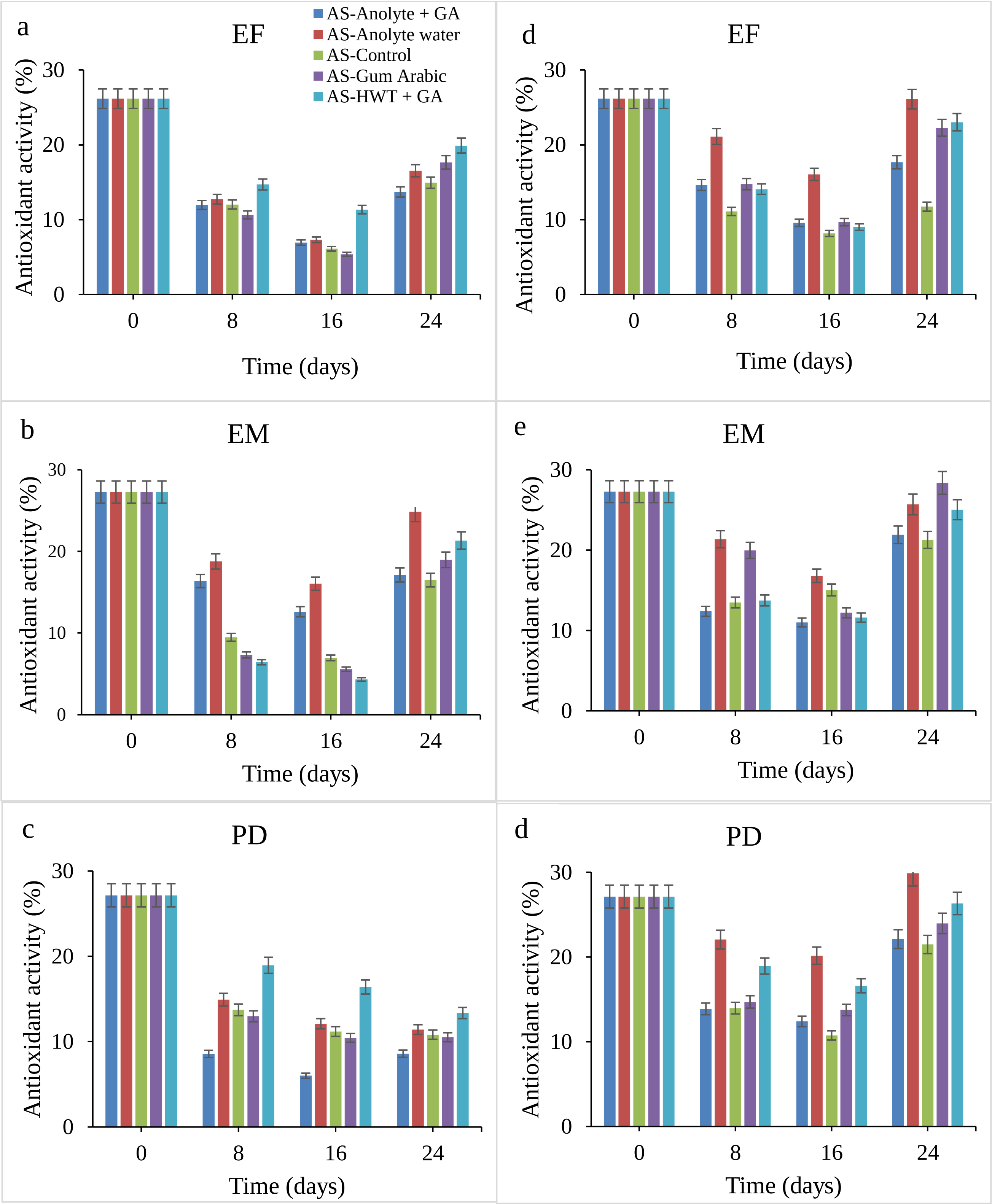

Figure 4.20 The effects of supply routes, pre-storage treatments and storage conditions on antioxidant activity of tomatoes harvested at green maturity stage. (CS and AS means cold storage and ambient storage, respectively). (LSD ($P < 0.05$) = 3.211, CV% = 0.2)

4.3.8 Marketability

The full layout of all treatment combinations for the tomato marketability as per the experimental design is presented in Appendix H and analysis of variance in Appendix I. Tomato fruit marketability varied significantly ($P < 0.001$) with the supply routes. Tomatoes from Letaba municipality had the highest marketability percentage with an average of 73.1% followed by Pontdrift 53.8%, then Esmé4 53.5%. Even though tomatoes from Pontdrift region were more marketable than the ones from Esmé4, statistically, there was no significant ($P > 0.05$) difference between the marketability percentage of tomatoes from Pontdrift and Esmé4 (Figure 4.19a). Tomato fruit marketability also varied with harvesting maturity stages, whereby green, pink and red-matured tomatoes had 65.3%, 59.5% and 55.6 % marketable tomatoes, respectively (Figure 5.19b). There was highly significant difference ($P < 0.05$) in the marketability percentage of tomatoes harvested at different maturity stages. Similar results were reported by Parker and Maalekuu (2013), whereby green-matured tomatoes maintained higher marketability percentage than pink and red ripe tomatoes. These results also agrees with the ones reported by (Moneruzzaman *et al*., 2008). (Moneruzzaman *et al*., 2008) reported that green-matured tomatoes retained a higher quality than half matured and red matured tomatoes stored over time. Green matured tomatoes have the longer shelf life than pink and red tomatoes because they undergo a long chain of metabolic processes before they become red ripe (Parker and Maalekuu, 2013).

Pre-storage treatments also had significant ($P < 0.05$) impact in maintaining shelf life thus marketability of tomatoes of different maturity stages. Generally, anolyte water was the most effective treatment in retaining quality of tomatoes with an average marketability of 70.6%. It was then followed by Gum Arabic, Anolyte + GA, HWT + GA and the control, with an average of 62.1%, 62.0%, 53.8% and 52.2%, respectively (Figure 5.19c). The percentage marketability of tomatoes also varied significantly ($P < 0.05$) with storage conditions. Fruit that were stored under cold conditions retained higher marketability percentage that the ones at ambient storage. This could be associated with the efficiency of the cooling system to reduce the rate of metabolic activities taking place within the fruit, resulting in sustaining fruit quality, thus marketability (Wu, 2010, Tilahun, 2010). Similar results were reported by Workneh and Osthoff (2015), whereby tomatoes stored under cold conditions retained more quality than the ones kept at ambient, thus highly marketable.

The combined effects of supply routes and storage conditions resulted in significant ($P < 0.05$) sustenance of tomato fruit quality across different maturity stages (Figure 5.21d). Furthermore, the combined effects of supply routes, pre-storage treatments and storage conditions, had highly significant ($P < 0.001$) effect in sustaining the quality of tomatoes, hence marketability. Generally, tomatoes that were sourced from Letaba Municipality treated with anolyte water and kept under cold storage conditions, retained high quality than tomatoes from other supply routes, across all maturity stages. This could be associated with the road quality and distance from Letaba Municipality to Pietermaritzburg. Road quality and distance are regarded as the most important factors in this case because, generally fruit quality is affected by temperature and relative humidity within the truck during transportation, and severity of exposure to high temperature or low relative humidity depends on the distance and road quality. Therefore, integration of treatments remained the best technology to be adopted my tomato industry in order sustain tomato quality, thus economic returns.

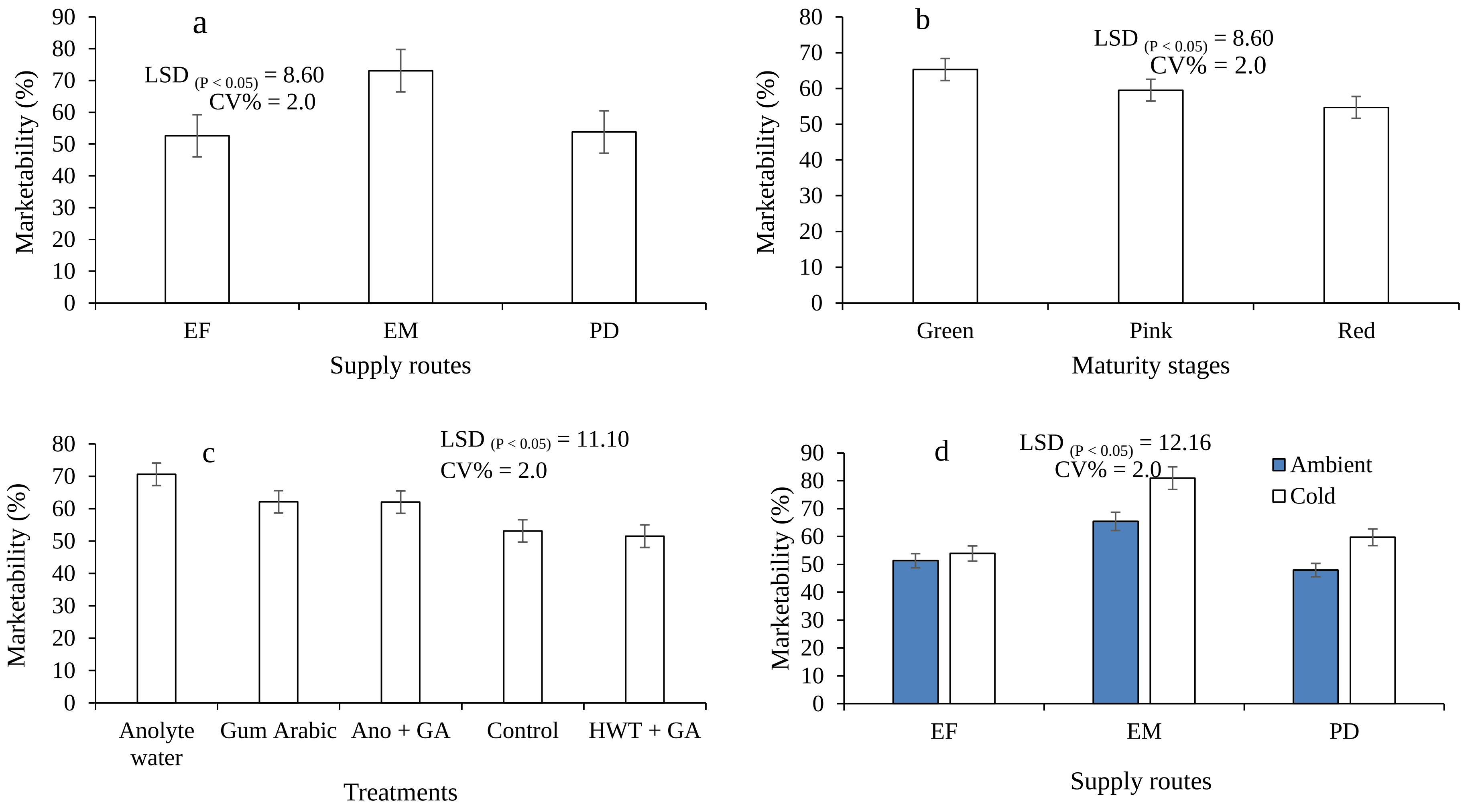

Figure 4.21 The effect of supply routes (a), maturity stages (b) and pre-storage treatments (c), and supply routes + storage conditions (d) in percentage marketability of tomatoes

4.4 CONCLUSIONS

Postharvest losses are a serious concern in the South African tomato industry and other developing countries. In this study the effect of a holistic approach of maintaining quality and extending shelf life of tomatoes was evaluated. This approach involved the effect of harvesting maturity stages, transporting tomatoes through different routes from Limpopo to Pietermaritzburg, the effect of pre-storage treatments and the effect of storage conditions in the market. With regards to harvesting maturity stages, it was deduced from this study that harvesting at green matured stage have a high potential to extend shelf life of tomatoes which is advantageous in South Africa since they are mainly sourced from Limpopo. Green-matured stage is suitable for tomatoes which still need to be transported. A potential for a long shelf life of green-matured harvested tomatoes could be described as a potential to resist physiological, mechanical damages and microbiological infections. This could be associated with the levels of phenolic compounds and antioxidant capacity that green matured tomatoes had higher compared to pink- and red ripe fruit, which made them more resistant physiological disorders and pathological infections which lead that quality loss/ decay.

The long shelf life (of about 4 and 7 additional days at ambient and cold storage, respectively) of green mature harvested tomatoes could also be associated with their ability to interact with other induced postharvest technologies e.g. pre-storage treatments (such as disinfectants, coating), ambient and cold storage temperatures. This conclusion was drawn based on mainly the highest percentage marketability that was achieved by tomatoes that were harvested at green maturity stage across different supply routes. The highest marketability percentage was achieved more in green-matured tomatoes stored under cold conditions than ambient. However, with regard to the accumulation of soluble solids and sugars, TSS of tomatoes harvested at green maturity never reached the level achieved by pink and red-ripe tomatoes. Therefore this suggest that even though green matured tomatoes had a potential and achieved the longest shelf life, but organoleptic quality might have been compromised. Therefore, this can result in sufficient time of selling tomatoes, however, experienced and health or dietary concerned customers cannot appreciate it.

Anolyte water treatment has shown to be an effective disinfectant in maintaining quality and extending shelf life of tomatoes. However, the mode of action has not yet understood because, example, disinfecting green-matured tomatoes with anolyte water resulted in them being completely red within a week of storage, and under both storage conditions. In addition to that, anolyte water treated sample achieved the highest total soluble solids, which indicated an outstanding achievement in terms of organoleptic quality. Furthermore, anolyte water was among the best treatments in sustaining the higher levels of phenolic compounds and the total antioxidant activity.

Integration of anolyte water treatment with other technologies such as cold storage, and optimum harvesting maturity resulted in the more superior results than anolyte water only (Appendix I). This was deduced from the percentage marketability that was achieved which was higher in tomatoes that were harvested at green maturity and stored at cold conditions (11 °C), when compared to the ones stored at ambient conditions. This implies the efficiency of a holistic approach of using number of postharvest technologies in reducing tomato quality losses instead of individual treatments.

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5. CONCLUSIONS AND RECOMMENDATIONS

Tomato is among the most important fruit due to its nutritional value which has made it the most popular and most consumed fruit worldwide (Arthur *et al*., 2015). In addition, tomatoes are a highly recommended crop in South Africa. In South Africa, approximately 95% of the total production of tomato has been contributed by commercial farmers, while small scale farmers were only contributing 5% of the total production (DAFF, 2013). According to Mashau *et al*. (2012) tomato is one of the main crops produced in South Africa by commercial and smallholder farmers. However, postharvest losses become a major challenging limiting smallholder farmers contributions towards the supply of tomatoes in the country. Insufficient research has been conducted in seeking solutions to alleviate postharvest losses in tomatoes.

The literature showed that for efficiency to be ensured, minimizing postharvest losses must begin from harvesting and towards the end user of a fruit. The holistic approach, which included different postharvest treatment of technologies can be advantageous. This study was undertaken to evaluate the effects of harvesting maturity stages, supply chain routes, pre-storage treatments and storage conditions on postharvest quality of 'Nemo-Netta' tomatoes. The first objective was to evaluate the effect of different supply chain routes, pre-storage conditions and storage conditions in microbial quality and marketability of tomatoes harvested at pink maturity stage.

The effect of disinfecting tomatoes with different solutions (anolyte water, chlorinated water and hot water) or coating tomatoes (with Gum Arabic), on the microbiological quality of tomatoes during storage after transportation in non-refrigerated trucks along three different supply chain routes was evaluated. The sample tomatoes harvested at pink maturity stage without blemishes were selected , treated and stored on either ambient (16/ 25 °C) or cold (11 °C). The sampling was performed on Days 0, 16 and 30 for quality assessment during storage. An experiment was laid out as a factorial design, split-plot with supply routes as main plots, storage conditions as subplots and random allocation of treatments with each subplot. An experiment was conducted in two seasons during winter harvest and during summer harvest.

Different supply routes, storage environments and pre-storage treatments had highly significant ($P < 0.001$) influence on the microbiological population (log cfu.cm^{-2}) and marketability (%)

of tomatoes. Anolyte water dipping treatment was the most effective treatment in maintaining microbiological quality of tomatoes. It reduced the initial microbial load significantly ($P < 0.001$) from 4.8 to 3.8 log cfu cm^{-2}. It also limited the microbial growth to 4.0 log cfu cm^{-2} during Day 16. This represented the second highest log reduction of 1.0 log cfu cm^{-2} when compared to the microbiological population associated with untreated control. Chlorinated water dipping treatment was the second most effective pre-storage disinfection treatment in reducing the microbial load and reducing the rate of microbial growth during the storage period. By so doing, it sustained high quality and thus higher percentage marketability of tomatoes harvested at pink maturity stage. However, it induced some surface defects which significantly reduced marketability during Day 30 of sampling.

Furthermore, three-way interaction of supply route, disinfection treatments particularly anolyte water combined with low temperature storage remained the most superior treatment in the microbial quality of tomatoes harvested at pink maturity stage. It reduced the initial microbial load significantly ($P < 0.001$) from 4.3 to 2.8 log cfu cm^{-2}, and it also limited the microbial growth to 3.4 log cfu cm^{-2} during Day 16, which was the highest log reduction. This represented the highest log reduction of 1.5 log cfu cm^{-2}, when compared to the microbiological population associated with the untreated samples. Anolyte water also maintained the highest percentage marketability of tomatoes harvested at pink maturity stage under cold and ambient storage conditions and across all the supply routes. The fruit also maintained a high exterior glossiness. This is of important since consumers base their decision to purchase on the aesthetic appeal of fruit. Furthermore, the three-way interaction between supply routes, disinfection treatments, particularly anolyte water with low temperature storage remained to be the most superior treatment in maintaining percentage marketability of tomatoes across all the supply routes.

The second objective (Chapter 4) was to evaluate the effects of different supply chain routes, harvesting maturity stages, pre-storage disinfection treatments and storage conditions on physiological, chemical and biochemical quality of tomatoes. The effect of disinfecting treatment (anolyte water, and hot water) or coating (with Gum Arabic), and their combinations on the physiological, chemical and biochemical quality of sample tomatoes during storage after transportation in non-refrigerated trucks along three different supply chain routes was evaluated. Sample tomatoes harvested at green, pink and red maturity stages without blemishes were treated, stored on either ambient (16/ 25 °C) or cold (11 °C) and sampled for quality analysis on Days 0, 8, 16, 24 and 30 of storage. An experiment was laid out as a factorial design, split-split plot with supply routes as main plots, maturity stages as subplots, storage conditions as sub-subplots and random allocation of treatments with each subplot. An experiment was conducted in two seasons during winter harvest and during summer harvest.

Gum Arabic coating was found to be the most effective treatment in suppressing the respiration rate of tomatoes harvested at green, pink and red maturity stages, across all the supply routes. This resulted in a substantial reduction in quality losses. However, with regards to sustaining quality, Gum Arabic was found to be the most effective treatment under ambient storage conditions. Under cold storage, GA retained some moisture on the fruit surface, which enhanced the rate of microbial growth.

Letaba Municipality was found to be the best supply route in terms of retaining fruit quality in tomatoes across different maturity stages, which is followed by Pontdrift region, then Esmé4. Low temperature storage was the most effective in maintaining the quality of tomato fruit, regardless of their maturity stage and across all the supply routes. Anolyte water disinfection treatment was the best treatment in maintaining the quality of tomatoes harvested at different maturity stages and across all supply routes. This was the most superior disinfection treatment in maintain most of tested quality parameters including: PWL, TSS, total phenolic compounds, total antioxidant capacity, firmness and marketability. With regard to the PWL, anolyte water was the best in reducing the rate of transpiration which is the most effective process which lead to fruit physiological weight loss. Similarly, for the TSS anolyte water also proved to be the most effective treatment in promoting high levels of TSS. Allowing accumulation of the highest levels of soluble solids and shelf life of tomatoes. Total soluble solids are good indicators of quality in fresh produce such as, fruits and vegetables (Turhan and Şeniz, 2009).

This means anolyte water disinfection treatment hastened the rate of physiological and biochemical changes associated with tomato ripening during storage. Gum Arabic coating was the second best treatment in terms of sustaining tomato quality, while the control was the worst treatment.

These results revealed the high efficiency of anolyte water dipping treatment in maintaining quality of tomatoes harvested at different maturity stages compared to the other treatments. However in all cases, anolyte water and Gum Arabic were most effective in treating tomatoes harvested at green-maturity stage and under cold storage conditions. Furthermore, the efficiency of all treatments was also affected by the supply routes. Integration of technologies was most effective in maintaining the quality of tomatoes of different maturity stages across different supply routes. This study revealed that reducing quality degradation of tomatoes starts at harvesting (maturity stage to harvest). The following recommendations can be made:

- Harvesting tomatoes at the green-maturity stage is good, especially for tomatoes that still need to be transported distances.
- Precooling immediately after harvest to remove the filed heat using the disinfectants particularly anolyte to reduce quality losses.
- Road quality affects the quality of tomatoes. Therefore, it is advisable to use alternative routes which are shortcuts and having better road quality, if possible.
- Transportation using cooling or refrigerated truck is most efficient in maintaining quality of tomatoes.
- Further research on anolyte water disinfecting treatment and Gum Arabic coating as potential alternative pre-storage treatments to be used in maintaining quality of tomatoes
- The integration of different postharvest treatments such as pre-storage treatments, cooling systems and cold storage conditions are most efficient in sustaining quality, thus can be adopted to extend shelf life of tomatoes.

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5.2 APPENDICES

APPENDIX A

Table 5.1 The effects of supply routes, maturity stages, pre-storage treatments and storage conditions in tomato colour change (hue angle)

Route	Maturity	Treatments	Storage	Winter season – Hue angle (h)					Summer season – Hue angle (h)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
PD	Green	Anolyte + GA	Ambient	107.87	55.31	53.65	48.07	40.21	98.67	54.77	53.87	49.00	-
			Cold	107.87	61.95	58.76	49.64	49.94	98.67	90.84	54.70	51.23	48.33
		Anolyte water	Ambient	107.87	48.51	45.08	40.08	38.44	98.67	53.92	44.72	50.01	-
			Cold	107.87	63.93	49.29	56.41	49.11	98.67	78.48	53.91	48.56	44.43
		Control	Ambient	107.87	48.52	46.94	42.09	40.08	98.67	51.59	45.00	0.00	-
			Cold	107.87	57.16	48.26	47.67	45.16	98.67	68.26	50.92	47.43	43.13
		Gum Arabic (GA)	Ambient	107.87	72.70	45.60	41.00	38.79	98.67	55.74	51.42	46.40	-
			Cold	107.87	55.96	53.62	50.25	53.71	98.67	58.68	55.20	50.50	45.66
		HWT + GA	Ambient	107.87	63.84	49.28	45.10	42.67	98.67	69.68	48.23	0.00	-
			Cold	107.87	68.24	53.19	52.06	59.31	98.67	65.69	53.05	49.49	49.06
	Pink	Anolyte + GA	Ambient	74.33	55.32	53.60	45.02	-	65.92	51.71	43.88	45.18	-
			Cold	74.33	54.78	56.33	48.97	50.30	65.92	58.79	45.03	61.32	47.93
		Anolyte water	Ambient	74.33	51.65	45.20	43.48	41.06	65.92	47.82	42.83	43.37	-
			Cold	74.33	56.20	54.35	49.88	49.27	65.92	48.53	46.43	45.07	46.71
		Control	Ambient	74.33	51.81	44.86	40.13	-	65.92	45.90	44.61	43.37	-
			Cold	74.33	56.95	51.92	48.73	44.46	65.92	51.34	42.68	45.84	43.78
		Gum Arabic (GA)	Ambient	74.33	56.06	46.71	42.14	40.08	65.92	46.17	42.84	40.03	-
			Cold	74.33	61.48	51.74	46.91	54.67	65.92	54.81	48.20	43.85	44.41
		HWT + GA	Ambient	74.33	49.97	47.75	43.48	-	65.92	46.46	45.06	43.71	-
			Cold	74.33	62.49	52.63	48.35	50.52	65.92	53.09	47.71	49.85	-
	Red	Anolyte + GA	Ambient	58.77	55.27	47.39	43.17	-	50.34	48.57	42.82	43.07	-
			Cold	58.77	49.22	51.49	50.30	47.52	50.34	48.42	42.64	0.00	-
		Anolyte water	Ambient	58.77	46.48	47.80	43.66	-	50.34	44.43	43.84	43.30	-
			Cold	58.77	53.10	51.52	48.74	47.81	50.34	48.17	44.05	45.94	42.98
		Control	Ambient	58.77	46.03	44.88	40.13	-	50.34	47.02	44.78	41.99	-
			Cold	58.77	52.00	51.07	49.17	41.04	50.34	46.39	44.82	44.36	41.48
		Gum Arabic (GA)	Ambient	58.77	48.55	47.41	43.22	40.01	50.34	49.48	45.74	45.34	-
			Cold	58.77	52.34	48.08	49.50	49.45	50.34	49.55	44.86	46.32	44.36
		HWT + GA	Ambient	58.77	53.13	47.92	44.71	-	50.34	47.09	45.20	43.50	-
			Cold	58.77	65.41	61.37	52.26	57.33	50.34	52.77	47.63	44.76	-

Route	Maturity	Treatments	Storage	Winter season – Hue angle (h)					Summer season – Hue angle (h)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
EM	Green	Anolyte + GA	Ambient	101.57	45.98	41.08	40.71	38.66	107.85	44.790	44.64	42.28	41.02
			Cold	101.57	57.68	51.98	51.87	45.16	107.85	58.420	51.60	51.35	46.99
		Anolyte water	Ambient	101.57	48.54	42.29	39.60	39.01	107.85	47.187	46.86	44.12	41.18
			Cold	101.57	69.11	48.16	49.20	52.52	107.85	56.127	46.53	47.71	45.67
		Control	Ambient	101.57	55.47	47.01	42.51	-	107.85	45.597	45.81	41.33	-
			Cold	101.57	54.99	49.01	44.87	45.89	107.85	55.230	45.73	49.00	46.19
		Gum Arabic (GA)	Ambient	101.57	54.71	45.87	41.33	40.04	107.85	47.870	47.68	43.77	37.05
			Cold	101.57	56.26	50.74	46.69	45.08	107.85	62.617	50.15	47.68	45.94
		HWT + GA	Ambient	101.57	64.60	44.40	40.17	-	107.85	46.917	46.46	44.68	-
			Cold	101.57	81.80	67.35	53.67	45.03	107.85	73.730	82.72	61.65	57.95
	Pink	Anolyte + GA	Ambient	90.02	45.24	41.77	38.66	-	58.49	47.473	45.75	-	42.72
			Cold	90.02	53.35	51.09	47.07	50.76	58.49	49.917	50.23	50.44	51.39
		Anolyte water	Ambient	90.02	43.49	43.65	40.07	-	58.49	47.457	42.47	43.20	-
			Cold	90.02	55.35	44.83	45.16	46.59	58.49	50.437	48.07	46.96	47.81
		Control	Ambient	90.02	45.32	45.62	41.33	-	58.49	47.083	45.25	43.79	-
			Cold	90.02	56.32	51.81	50.92	47.82	58.49	49.203	46.91	49.64	47.73
		Gum Arabic (GA)	Ambient	90.02	48.91	43.37	40.21	-	58.49	47.183	44.46	42.31	40.72
			Cold	90.02	64.88	54.25	48.15	48.53	58.49	49.333	47.57	46.64	46.11
		HWT + GA	Ambient	90.02	48.89	44.66	40.33	-	58.49	52.283	48.06	-	-
			Cold	90.02	61.40	49.99	54.55	49.21	58.49	56.597	50.76	47.49	49.08
	Red	Anolyte + GA	Ambient	53.86	45.98	44.31	46.14	-	51.53	44.333	43.41	-	-
			Cold	53.86	53.75	44.88	47.99	41.88	51.53	50.423	46.17	48.15	45.19
		Anolyte water	Ambient	53.86	41.63	42.73	37.41	-	51.53	42.957	43.22	43.92	-
			Cold	53.86	48.86	45.20	40.97	42.74	51.53	47.297	45.77	46.50	44.79
		Control	Ambient	53.86	43.96	41.04	38.22	-	51.53	45.310	43.46	44.16	-
			Cold	53.86	43.17	41.65	41.27	43.09	51.53	48.157	43.08	44.93	42.53
		Gum Arabic (GA)	Ambient	53.86	43.72	42.26	38.17	-	51.53	46.750	43.94	43.44	-
			Cold	53.86	53.02	48.74	44.82	46.16	51.53	52.727	49.50	48.00	48.55
		HWT + GA	Ambient	53.86	47.04	42.45	39.88	-	51.53	44.720	42.26	-	-
			Cold	53.86	52.10	51.99	46.71	45.40	51.53	43.513	48.26	49.00	43.10

Route	Maturity	Treatments	Storage	Winter season – Hue angle (h)					Summer season – Hue angle (h)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
EF	Green	Anolyte + GA	Ambient	110.44	65.16	47.503	44.31	-	111.64	53.28	47.79	44.11	-
			Cold	110.44	71.18	59.683	53.23	52.74	111.64	64.13	51.90	56.00	-
		Anolyte water	Ambient	110.44	46.50	45.570	41.75	-	111.64	48.58	44.52	42.23	40.81
			Cold	110.44	59.59	53.340	50.38	49.79	111.64	55.29	64.37	51.49	-
		Control	Ambient	110.44	54.77	53.087	49.71	-	111.64	47.12	46.86	-	-
			Cold	110.44	69.71	68.403	50.11	-	111.64	53.49	57.78	48.31	-
		Gum Arabic (GA)	Ambient	110.44	61.70	44.733	41.22	-	111.64	56.98	48.94	46.44	-
			Cold	110.44	68.92	53.217	48.90	49.56	111.64	54.60	47.04	54.42	-
		HWT + GA	Ambient	110.44	63.28	58.293	54.26	-	111.64	54.36	47.34	-	-
			Cold	110.44	86.37	71.467	68.89	62.06	111.64	62.13	71.39	59.73	-
	Pink	Anolyte + GA	Ambient	64.55	50.92	43.607	40.12	-	62.99	63.84	60.29	-	-
			Cold	64.55	58.65	46.433	47.95	46.63	62.99	59.58	53.09	48.24	-
		Anolyte water	Ambient	64.55	49.52	44.513	41.32	-	62.99	46.57	45.48	-	-
			Cold	64.55	58.17	51.260	52.31	48.32	62.99	51.52	48.84	47.93	45.47
		Control	Ambient	64.55	45.39	43.550	40.05	-	62.99	46.78	44.40	-	-
			Cold	64.55	54.48	51.657	51.06	49.62	62.99	50.96	48.41	47.30	-
		Gum Arabic (GA)	Ambient	64.55	50.54	46.947	42.62	-	62.99	46.11	44.34	-	-
			Cold	64.55	53.04	50.443	53.37	47.84	62.99	52.83	51.04	55.97	-
		HWT + GA	Ambient	64.55	70.23	44.080	41.78	-	62.99	47.66	46.30	-	-
			Cold	64.55	61.05	51.687	54.91	-	62.99	53.99	47.53	50.64	-
	Red	Anolyte + GA	Ambient	51.36	54.63	40.020	38.49	-	54.48	51.00	47.78	-	-
			Cold	51.36	49.12	47.027	44.45	47.74	54.48	47.93	50.00	53.60	-
		Anolyte water	Ambient	51.36	44.02	41.410	38.11	-	54.48	46.32	44.45	41.38	-
			Cold	51.36	45.94	45.610	47.80	47.90	54.48	48.93	47.60	46.36	-
		Control	Ambient	51.36	44.12	43.503	41.33	-	54.48	46.86	45.72	-	-
			Cold	51.36	43.93	45.817	46.44	47.56	54.48	47.12	46.53	44.22	-
		Gum Arabic (GA)	Ambient	51.36	45.71	41.483	37.09	-	54.48	46.76	47.70	45.22	-
			Cold	51.36	51.54	50.323	48.69	49.69	54.48	47.97	47.35	49.37	-
		HWT + GA	Ambient	51.36	48.89	41.460	38.71	-	54.48	52.02	45.65	-	-
			Cold	51.36	56.98	55.427	57.24	-	54.48	48.29	51.03	46.09	-

APPENDIX B

Table 5.2 The effects of supply routes, maturity stages, pre-storage treatments and storage conditions on tomato texture (N)

Route	Maturity	Treatments	Storage	Winter season - Texture (N)					Summer season - Texture (N)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
PD	Green	Anolyte + GA	Ambient	27.12	22.42	18.09	15.55	-	27.67	22.76	19.43	17.90	-
			Cold	27.12	23.17	19.97	19.50	-	27.67	23.61	20.28	21.03	-
		Anolyte water	Ambient	27.12	21.31	16.65	15.71	-	27.67	21.24	15.58	14.89	-
			Cold	27.12	22.77	18.77	19.26	-	27.67	22.57	17.90	18.30	-
		Control	Ambient	27.12	21.44	16.44	15.34	-	27.67	21.49	15.16	14.62	-
			Cold	27.12	23.20	19.53	21.35	-	27.67	23.41	20.08	24.42	-
		Gum Arabic (GA)	Ambient	27.12	19.05	12.38	11.68	-	27.67	21.61	16.28	15.11	-
			Cold	27.12	23.40	20.40	19.79	-	27.67	24.63	21.96	21.56	-
		HWT + GA	Ambient	27.12	22.22	18.22	15.76	-	27.67	22.08	18.08	17.15	-
			Cold	27.12	27.10	27.09	21.45	-	27.67	27.76	27.79	22.07	-
	Pink	Anolyte + GA	Ambient	21.60	18.36	16.36	15.12	-	20.45	18.65	16.99	16.45	-
			Cold	21.60	22.16	22.29	17.75	-	20.45	21.33	22.03	19.83	-
		Anolyte water	Ambient	21.60	18.40	16.40	13.44	-	20.45	17.96	15.92	13.69	-
			Cold	21.60	20.91	20.44	12.82	-	20.45	21.07	21.67	18.59	-
		Control	Ambient	21.60	18.57	15.91	13.61	-	20.45	18.70	17.37	14.97	-
			Cold	21.60	19.90	18.57	16.85	-	20.45	18.48	16.81	16.96	-
		Gum Arabic (GA)	Ambient	21.60	18.28	15.28	14.55	-	20.45	15.19	14.53	14.03	-
			Cold	21.60	20.85	20.18	19.56	-	20.45	20.89	21.26	16.73	-
		HWT + GA	Ambient	21.60	17.69	14.69	14.28	-	20.45	19.66	18.66	18.16	-
			Cold	21.60	19.35	15.69	12.82	-	20.45	18.35	16.35	14.26	-
	Red	Anolyte + GA	Ambient	16.14	16.14	15.14	13.07	-	16.82	15.35	14.35	12.25	-
			Cold	16.14	18.31	20.11	19.94	-	16.82	19.36	20.69	21.02	-
		Anolyte water	Ambient	16.14	16.62	16.45	15.45	-	16.82	17.90	17.13	16.53	-
			Cold	16.14	16.19	16.43	18.97	-	16.82	17.54	18.07	19.57	-
		Control	Ambient	16.14	15.83	15.70	14.95	-	16.82	16.82	16.36	16.22	-
			Cold	16.14	13.98	12.62	15.13	-	16.82	17.63	14.30	14.42	-
		Gum Arabic (GA)	Ambient	16.14	14.44	14.07	13.44	-	16.82	15.73	15.40	14.13	-
			Cold	16.14	16.61	16.57	17.82	-	16.82	17.63	18.13	20.02	-
		HWT + GA	Ambient	16.14	12.77	12.53	11.63	-	16.82	13.45	10.78	9.45	-
			Cold	16.14	15.60	15.10	14.67	-	16.82	16.08	15.28	12.62	-

Route	Maturity	Treatments	Storage	Winter season - Texture (N)					Summer - Texture (N)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
EM	Green	Anolyte + GA	Ambient	33.47	28.78	17.85	15.72	-	32.33	27.42	19.81	18.28	-
			Cold	33.47	29.53	25.95	22.36	-	32.33	28.27	26.67	25.07	-
		Anolyte water	Ambient	33.47	27.67	17.91	17.11	-	32.33	25.90	16.67	16.32	-
			Cold	33.47	29.13	23.27	17.41	-	32.33	27.23	25.43	23.64	-
		Control	Ambient	33.47	27.80	20.28	19.65	-	32.33	26.15	19.42	18.88	-
			Cold	33.47	29.55	28.61	27.66	-	32.33	28.07	26.48	24.89	-
		Gum Arabic (GA)	Ambient	33.47	25.41	17.42	16.72	-	32.33	26.27	18.02	16.85	-
			Cold	33.47	29.76	28.89	28.02	-	32.33	29.29	28.59	27.89	-
		HWT + GA	Ambient	33.47	28.58	31.35	33.82	-	32.33	26.74	26.60	27.53	-
			Cold	33.47	33.46	26.77	20.08	-	32.33	32.42	25.28	18.14	-
	Pink	Anolyte + GA	Ambient	22.32	19.08	24.74	23.51	-	22.29	20.50	24.39	23.86	-
			Cold	22.32	22.88	22.02	21.15	-	22.29	23.17	20.14	17.10	-
		Anolyte water	Ambient	22.32	19.12	20.50	17.53	-	22.29	19.80	21.47	20.17	-
			Cold	22.32	21.63	22.24	22.85	-	22.29	22.91	22.74	22.56	-
		Control	Ambient	22.32	19.29	17.63	15.33	-	22.29	20.55	16.95	14.55	-
			Cold	22.32	20.62	21.09	21.55	-	22.29	20.32	21.06	21.80	-
		Gum Arabic (GA)	Ambient	22.32	19.00	20.48	19.75	-	22.29	17.03	20.28	20.12	-
			Cold	22.32	21.57	18.33	15.08	-	22.29	22.73	18.88	15.03	-
		HWT + GA	Ambient	22.32	18.41	17.37	16.96	-	22.29	21.51	24.22	23.82	-
			Cold	22.32	20.07	13.32	11.61	-	22.29	20.19	13.15	12.74	-
	Red	Anolyte + GA	Ambient	21.47	21.47	17.22	15.15	-	21.62	20.15	21.35	19.25	-
			Cold	21.47	23.64	17.61	11.58	-	21.62	24.16	18.55	12.93	-
		Anolyte water	Ambient	21.47	21.95	20.61	0.00	-	21.62	22.70	21.36	0.00	-
			Cold	21.47	21.52	18.85	16.17	-	21.62	22.34	18.12	13.91	-
		Control	Ambient	21.47	21.16	10.07	0.00	-	21.62	21.62	11.09	0.00	-
			Cold	21.47	19.31	17.61	15.91	-	21.62	22.43	19.87	17.30	-
		Gum Arabic (GA)	Ambient	21.47	19.77	20.29	20.25	-	21.62	20.53	19.60	20.20	-
			Cold	21.47	21.94	17.86	13.79	-	21.62	22.43	19.36	16.28	-
		HWT + GA	Ambient	21.47	18.10	14.71	14.15	-	21.62	18.25	17.15	15.82	-
			Cold	21.47	20.93	18.95	16.97	-	21.62	20.88	19.00	17.11	-

Route	Maturity	Treatments	Storage	Winter season - Texture (N)					Summer - Texture (N)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
EF	Green	Anolyte + GA	Ambient	43.57	28.93	14.28	0.00	-	36.62	26.08	15.53	0.00	-
			Cold	43.57	32.32	21.07	23.67	-	36.62	32.25	27.87	25.87	-
		Anolyte water	Ambient	43.57	29.40	15.22	12.68	-	36.62	26.97	17.31	10.99	-
			Cold	43.57	33.27	22.97	17.96	-	36.62	32.04	27.45	21.37	-
		Control	Ambient	43.57	32.13	20.70	9.26	-	36.62	27.49	18.35	9.22	-
			Cold	43.57	32.09	20.62	21.55	-	36.62	29.03	21.43	24.70	-
		Gum Arabic (GA)	Ambient	43.57	30.55	17.53	4.52	-	36.62	26.99	17.37	7.74	-
			Cold	43.57	30.72	17.88	21.34	-	36.62	27.58	18.54	19.62	-
		HWT + GA	Ambient	43.57	32.99	22.40	11.82	-	36.62	29.76	22.89	16.03	-
			Cold	43.57	37.19	30.80	19.55	-	36.62	33.15	29.69	20.19	-
	Pink	Anolyte + GA	Ambient	18.81	17.55	16.29	15.03	-	20.01	19.61	19.21	18.82	-
			Cold	18.81	19.62	20.43	15.43	-	20.01	20.90	21.78	17.87	-
		Anolyte water	Ambient	18.81	19.24	19.67	20.10	-	20.01	18.84	17.67	16.50	-
			Cold	18.81	17.74	16.67	18.22	-	20.01	18.62	17.22	15.50	-
		Control	Ambient	18.81	0.00	0.00	0.00	-	20.01	0.00	0.00	0.00	-
			Cold	18.81	17.21	15.60	15.68	-	20.01	17.91	15.81	14.36	-
		Gum Arabic (GA)	Ambient	18.81	18.56	18.31	18.05	-	20.01	19.11	18.21	17.31	-
			Cold	18.81	18.70	18.58	24.37	-	20.01	19.67	19.33	23.44	-
		HWT + GA	Ambient	18.81	17.08	15.35	13.62	-	20.01	17.14	14.26	11.39	-
			Cold	18.81	23.13	27.44	13.39	-	20.01	21.10	22.18	14.08	-
	Red	Anolyte + GA	Ambient	16.04	0.00	0.00	0.00	-	16.91	0.00	0.00	0.00	-
			Cold	16.04	0.00	16.02	14.69	-	16.91	0.00	14.64	13.31	-
		Anolyte water	Ambient	16.04	17.01	17.97	18.94	-	16.91	17.19	17.46	17.73	-
			Cold	16.04	0.00	15.31	13.31	-	16.91	0.00	14.63	13.30	-
		Control	Ambient	16.04	16.25	16.47	16.68	-	16.91	16.58	16.25	15.92	-
			Cold	16.04	16.36	8.22	6.88	-	16.91	15.64	8.11	6.11	-
		Gum Arabic (GA)	Ambient	16.04	14.84	13.65	12.45	-	16.91	14.93	12.95	10.97	-
			Cold	16.04	15.65	16.43	15.76	-	16.91	15.63	17.07	16.07	-
		HWT + GA	Ambient	16.04	17.93	19.82	21.71	-	16.91	17.69	18.47	19.25	-
			Cold	16.04	17.66	19.28	10.37	-	16.91	19.54	22.16	9.50	-

APPENDIX C

Table 5.3 The effects of supply route, maturity stages, pre-storage treatments and storage conditions on tomato physiological weight loss (PWL)

Route	Maturity	Treatments	Storage	Winter season – PWL (%)					Summer – PWL (%)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
PD	Green	Anolyte + GA	Ambient	0.00	1.77	13.12	18.13	22.14	0.00	5.77	17.13	23.13	27.18
			Cold	0.00	1.74	3.16	3.47	4.64	0.00	3.74	6.64	6.97	9.14
		Anolyte water	Ambient	0.00	1.76	9.93	14.90	18.91	0.00	5.76	13.90	19.92	23.90
			Cold	0.00	2.00	2.88	4.05	4.19	0.00	4.03	6.38	7.55	8.69
		Control	Ambient	0.00	1.96	12.56	17.52	21.51	0.00	5.97	16.52	22.58	26.52
			Cold	0.00	1.40	3.06	4.42	5.30	0.00	3.43	6.56	7.92	9.82
		Gum Arabic (GA)	Ambient	0.00	1.76	16.71	21.72	25.71	0.00	5.77	20.71	26.74	30.70
			Cold	0.00	2.24	3.53	3.97	4.61	0.00	4.24	7.03	7.47	9.13
		HWT + GA	Ambient	0.00	1.86	10.17	15.17	19.17	0.00	5.86	14.17	20.17	24.17
			Cold	0.00	1.95	3.25	4.23	4.39	0.00	3.95	6.77	7.71	8.89
	Pink	Anolyte + GA	Ambient	0.00	1.93	11.56	16.54	20.51	0.00	5.93	15.59	21.57	26.04
			Cold	0.00	1.53	2.92	3.31	3.59	0.00	3.53	6.42	6.81	8.08
		Anolyte water	Ambient	0.00	1.51	9.25	14.25	18.25	0.00	5.51	13.25	19.25	23.25
			Cold	0.00	1.84	2.67	3.74	4.50	0.00	3.84	6.17	7.24	9.00
		Control	Ambient	0.00	1.75	5.61	10.61	14.61	0.00	5.95	9.81	15.81	8.90
			Cold	0.00	1.67	4.58	6.43	7.89	0.00	3.87	8.48	10.33	12.79
		Gum Arabic (GA)	Ambient	0.00	1.55	9.59	14.59	18.59	0.00	5.55	13.59	19.59	23.59
			Cold	0.00	2.13	3.39	3.75	3.92	0.00	4.13	6.89	7.25	8.42
		HWT + GA	Ambient	0.00	1.68	8.65	13.61	17.68	0.00	5.67	12.68	18.64	9.33
			Cold	0.00	1.64	3.30	5.17	6.19	0.00	3.65	6.87	8.67	10.68
	Red	Anolyte + GA	Ambient	0.00	1.92	10.02	15.06	19.04	0.00	5.92	14.05	20.04	12.23
			Cold	0.00	2.19	3.83	4.55	6.97	0.00	4.16	7.33	8.08	11.47
		Anolyte water	Ambient	0.00	1.78	13.48	18.48	22.48	0.00	5.71	17.48	23.48	27.48
			Cold	0.00	1.56	2.20	2.68	3.17	0.00	3.56	5.70	6.18	7.67
		Control	Ambient	0.00	1.80	7.09	12.09	16.09	0.00	6.20	11.49	17.49	9.05
			Cold	0.00	2.25	5.79	7.85	9.09	0.00	4.65	10.09	12.15	14.39
		Gum Arabic (GA)	Ambient	0.00	1.96	9.58	14.55	18.57	0.00	5.96	13.52	19.59	23.58
			Cold	0.00	1.95	2.66	3.56	3.62	0.00	3.95	6.16	7.04	8.11
		HWT + GA	Ambient	0.00	2.19	9.35	14.39	18.38	0.00	6.19	13.36	19.34	8.99
			Cold	0.00	1.70	3.64	5.04	6.70	0.00	3.70	7.16	8.56	11.27

Route	Maturity	Treatments	Storage	Winter season – PWL (%)					Summer – PWL (%)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
EM	Green	Anolyte + GA	Ambient	0.00	2.04	7.59	11.51	14.56	0.00	5.02	12.54	16.56	18.57
			Cold	0.00	2.03	2.92	3.43	4.14	0.00	3.00	4.92	5.45	6.11
		Anolyte water	Ambient	0.00	1.93	9.05	13.02	16.07	0.00	4.96	14.07	18.02	20.04
			Cold	0.00	2.15	2.91	3.14	3.34	0.00	3.15	4.90	5.15	5.33
		Control	Ambient	0.00	2.16	5.34	9.39	12.38	0.00	5.16	10.37	14.39	16.36
			Cold	0.00	1.72	2.93	3.63	4.26	0.00	2.71	4.95	5.66	6.28
		Gum Arabic (GA)	Ambient	0.00	1.98	6.46	10.45	13.49	0.00	4.98	11.90	15.45	17.46
			Cold	0.00	1.79	2.75	3.47	4.08	0.00	2.79	4.78	5.47	6.06
		HWT + GA	Ambient	0.00	1.79	7.76	11.74	14.73	0.00	4.77	12.79	16.76	18.77
			Cold	0.00	1.63	2.60	3.96	4.68	0.00	2.64	4.61	5.95	6.69
	Pink	Anolyte + GA	Ambient	0.00	1.93	10.97	11.99	13.94	0.00	4.91	12.94	15.90	17.97
			Cold	0.00	1.89	6.95	10.75	12.14	0.00	2.88	11.95	13.77	14.18
		Anolyte water	Ambient	0.00	1.73	5.97	9.96	12.99	0.00	4.73	10.96	14.95	16.93
			Cold	0.00	1.90	2.54	3.32	4.16	0.00	2.90	4.57	5.32	6.18
		Control	Ambient	0.00	2.14	6.01	10.06	13.05	0.00	5.34	11.43	15.41	17.47
			Cold	0.00	2.11	5.98	7.18	8.33	0.00	3.31	8.18	9.38	10.50
		Gum Arabic (GA)	Ambient	0.00	1.70	6.18	10.16	13.18	0.00	4.70	11.14	15.18	17.15
			Cold	0.00	2.03	2.75	4.61	5.08	0.00	3.03	4.75	6.61	7.09
		HWT + GA	Ambient	0.00	2.13	9.37	13.30	16.35	0.00	5.13	14.30	18.30	20.30
			Cold	0.00	1.83	3.56	3.91	4.41	0.00	2.83	5.51	5.94	6.37
	Red	Anolyte + GA	Ambient	0.00	1.70	5.92	9.91	12.97	0.00	4.70	10.93	14.92	16.99
			Cold	0.00	1.92	7.51	8.36	9.20	0.00	2.94	9.53	10.38	11.25
		Anolyte water	Ambient	0.00	2.08	6.15	10.13	13.16	0.00	5.08	11.16	15.14	17.13
			Cold	0.00	2.04	2.54	4.62	5.53	0.00	3.04	4.56	6.61	7.52
		Control	Ambient	0.00	1.93	5.71	9.70	12.70	0.00	5.33	11.50	15.57	17.53
			Cold	0.00	1.72	24.25	25.33	26.44	0.00	2.82	26.55	27.63	28.74
		Gum Arabic (GA)	Ambient	0.00	1.68	7.76	11.78	14.76	0.00	4.68	12.76	16.74	18.79
			Cold	0.00	2.05	3.64	4.25	4.46	0.00	3.03	5.63	6.25	6.48
		HWT + GA	Ambient	0.00	1.63	14.90	18.93	21.90	0.00	4.61	19.90	23.94	25.96
			Cold	0.00	1.95	3.05	3.58	3.96	0.00	2.96	5.08	5.55	5.94

Route	Maturity	Treatments	Storage	Winter season – PWL (%)					Summer – PWL (%)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
EF	Green	Anolyte + GA	Ambient	0.00	2.17	10.55	16.56	20.55	0.00	7.15	17.53	22.58	18.27
			Cold	0.00	2.35	4.23	4.45	4.63	0.00	5.35	7.73	8.35	8.53
		Anolyte water	Ambient	0.00	1.93	7.67	13.64	17.69	0.00	6.93	14.69	19.67	16.54
			Cold	0.00	2.06	3.38	3.86	4.43	0.00	5.03	6.85	7.74	8.38
		Control	Ambient	0.00	2.53	11.15	17.19	21.15	0.00	7.50	18.17	23.18	18.62
			Cold	0.00	1.89	4.91	6.96	8.65	0.00	4.86	8.42	10.84	12.58
		Gum Arabic (GA)	Ambient	0.00	2.44	13.86	19.83	23.85	0.00	7.46	20.84	25.83	20.18
			Cold	0.00	2.27	3.34	4.47	5.49	0.00	5.28	6.84	8.39	9.39
		HWT + GA	Ambient	0.00	2.18	7.81	13.83	17.82	0.00	7.18	14.86	19.81	16.67
			Cold	0.00	2.31	3.22	4.25	5.08	0.00	5.33	6.72	8.17	8.98
	Pink	Anolyte + GA	Ambient	0.00	2.66	11.96	17.97	21.96	0.00	7.69	18.93	23.96	18.97
			Cold	0.00	2.07	3.42	4.09	4.91	0.00	5.07	6.92	7.99	8.81
		Anolyte water	Ambient	0.00	1.64	8.03	14.03	18.03	0.00	6.64	15.03	20.03	16.80
			Cold	0.00	2.15	2.85	3.63	5.82	0.00	5.15	6.35	7.53	9.72
		Control	Ambient	0.00	2.29	9.58	15.58	19.58	0.00	7.29	16.58	21.58	14.24
			Cold	0.00	2.06	9.19	11.52	13.20	0.00	5.11	12.74	15.47	17.15
		Gum Arabic (GA)	Ambient	0.00	2.05	8.45	14.45	18.45	0.00	7.05	15.45	20.45	17.04
			Cold	0.00	2.25	4.43	6.02	7.28	0.00	5.25	7.93	9.92	11.18
		HWT + GA	Ambient	0.00	2.27	9.78	15.78	19.78	0.00	7.27	16.78	21.78	13.56
			Cold	0.00	2.06	4.68	5.89	7.35	0.00	5.06	8.18	9.79	11.25
	Red	Anolyte + GA	Ambient	0.00	2.08	7.14	13.13	10.25	0.00	7.08	14.13	19.15	6.73
			Cold	0.00	2.42	4.12	4.94	5.85	0.00	5.42	7.61	8.84	9.74
		Anolyte water	Ambient	0.00	2.48	8.07	14.07	18.07	0.00	7.48	15.05	20.07	16.82
			Cold	0.00	2.39	3.22	3.35	3.51	0.00	5.37	6.73	7.25	7.40
		Control	Ambient	0.00	1.99	7.48	13.49	6.11	0.00	6.97	14.69	19.66	11.93
			Cold	0.00	2.17	4.53	6.53	8.72	0.00	5.27	8.13	10.53	12.72
		Gum Arabic (GA)	Ambient	0.00	2.63	10.64	16.63	20.67	0.00	7.60	17.65	22.66	18.32
			Cold	0.00	2.11	4.23	10.67	12.36	0.00	5.17	7.73	14.54	16.26
		HWT + GA	Ambient	0.00	2.59	12.45	18.46	14.69	0.00	7.38	19.46	24.44	12.82
			Cold	0.00	2.30	4.77	7.60	8.97	0.00	5.53	8.27	11.50	12.09

APPENDIX D

Table 5.4 The effects of supply route, maturity stages, pre-storage treatments and storage conditions on tomato respiration rate

Route	Maturity	Treatments	Storage	Winter season – respiration rate (ml CO_2 /kg.hr)					Summer season – respiration rate (ml CO_2 /kg.hr)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
PD	Green	Anolyte + GA	Ambient	17.04	17.54	13.93	12.16	-	23.69	15.33	23.21	16.11	-
			Cold	17.04	18.15	5.56	4.83	-	23.69	12.84	17.66	9.23	-
		Anolyte water	Ambient	17.04	15.73	17.19	14.40	-	23.69	16.29	13.60	14.64	-
			Cold	17.04	14.22	4.70	1.80	-	23.69	9.61	8.75	14.74	-
		Control	Ambient	17.04	23.80	19.92	2.96	-	23.69	13.94	17.24	14.77	-
			Cold	17.04	15.89	9.54	6.59	-	23.69	9.27	11.40	19.72	-
		Gum Arabic (GA)	Ambient	17.04	17.35	11.58	9.68	-	23.69	13.95	14.79	19.85	-
			Cold	17.04	20.66	3.78	3.43	-	23.69	11.27	12.84	16.72	-
		HWT + GA	Ambient	17.04	15.18	13.45	4.44	-	23.69	13.50	20.89	3.02	-
			Cold	17.04	27.44	5.82	3.33	-	23.69	10.40	12.29	17.76	-
	Pink	Anolyte + GA	Ambient	14.19	13.81	7.44	9.31	-	22.67	9.89	23.71	19.51	-
			Cold	14.19	15.82	6.28	6.09	-	22.67	9.61	12.62	6.61	-
		Anolyte water	Ambient	14.19	14.24	11.31	13.12	-	22.67	11.62	14.59	22.11	-
			Cold	14.19	14.22	4.86	7.78	-	22.67	11.94	11.80	12.59	-
		Control	Ambient	14.19	14.61	12.19	8.91	-	22.67	10.49	16.71	28.17	-
			Cold	14.19	20.27	5.74	7.02	-	22.67	8.83	12.47	12.74	-
		Gum Arabic (GA)	Ambient	14.19	13.35	0.00	8.94	-	22.67	12.00	22.22	3.02	-
			Cold	14.19	7.57	3.22	8.53	-	22.67	11.47	9.99	13.55	-
		HWT + GA	Ambient	14.19	15.53	12.32	14.93	-	22.67	10.55	15.85	30.52	-
			Cold	14.19	26.00	8.22	12.16	-	22.67	10.33	13.29	14.35	-
	Red	Anolyte + GA	Ambient	9.44	19.11	12.41	20.37	-	18.73	13.93	26.63	13.02	-
			Cold	9.44	14.08	5.12	8.10	-	18.73	11.87	18.77	9.24	-
		Anolyte water	Ambient	9.44	11.24	11.35	12.69	-	18.73	12.15	26.73	19.44	-
			Cold	9.44	11.44	6.32	9.01	-	18.73	10.77	18.74	13.86	-
		Control	Ambient	9.44	14.05	15.22	12.54	-	18.73	12.91	20.32	25.35	-
			Cold	9.44	20.30	8.46	10.88	-	18.73	11.04	7.86	12.70	-
		Gum Arabic (GA)	Ambient	9.44	14.45	10.88	13.94	-	18.73	12.07	26.65	19.05	-
			Cold	9.44	18.70	8.38	13.67	-	18.73	8.37	18.50	13.91	-
		HWT + GA	Ambient	9.44	12.97	10.33	13.94	-	18.73	13.08	21.40	22.78	-
			Cold	9.44	17.21	6.87	14.23	-	18.73	10.30	13.72	13.08	-

Route	Maturity	Treatments	Storage	Winter season – respiration rate (ml CO_2 /kg.hr)					Summer season – respiration rate (ml CO_2 /kg.hr)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
EM	Green	Anolyte + GA	Ambient	10.92	11.32	12.30	10.60	-	13.94	14.33	15.31	13.62	-
			Cold	10.92	4.06	13.46	1.36	-	13.94	6.08	16.47	4.38	-
		Anolyte water	Ambient	10.92	9.28	14.44	27.23	-	13.94	12.29	17.45	30.25	-
			Cold	10.92	3.60	7.64	3.91	-	13.94	6.61	10.66	6.93	-
		Control	Ambient	10.92	11.87	17.71	16.32	-	13.94	14.89	20.72	19.34	-
			Cold	10.92	3.74	7.94	12.22	-	13.94	5.55	10.96	15.24	-
		Gum Arabic (GA)	Ambient	10.92	9.72	9.74	15.15	-	13.94	12.73	12.76	18.17	-
			Cold	10.92	6.36	3.34	3.00	-	13.94	8.65	4.35	2.44	-
		HWT + GA	Ambient	10.92	10.43	14.36	15.05	-	13.94	13.44	17.37	18.07	-
			Cold	10.92	7.91	28.87	23.42	-	13.94	3.61	31.88	6.44	-
	Pink	Anolyte + GA	Ambient	7.52	8.58	33.77	16.04	-	10.52	11.59	36.78	19.06	-
			Cold	7.52	2.47	11.31	5.67	-	10.52	5.48	4.32	8.69	-
		Anolyte water	Ambient	7.52	6.17	19.08	8.45	-	10.52	9.19	22.09	11.47	-
			Cold	7.52	3.01	5.45	4.28	-	10.52	6.02	8.46	7.30	-
		Control	Ambient	7.52	9.24	13.74	9.19	-	10.52	12.25	16.75	12.21	-
			Cold	7.52	1.47	4.73	14.30	-	10.52	4.48	7.74	17.32	-
		Gum Arabic (GA)	Ambient	7.52	5.21	10.45	10.65	-	10.52	8.22	13.46	13.67	-
			Cold	7.52	3.48	6.73	5.09	-	10.52	4.49	9.75	8.11	-
		HWT + GA	Ambient	7.52	7.44	9.82	10.30	-	10.52	10.46	3.01	3.02	-
			Cold	7.52	4.70	2.66	10.05	-	10.52	2.32	5.67	13.07	-
	Red	Anolyte + GA	Ambient	7.86	11.14	14.68	13.72	-	10.85	10.15	13.70	3.02	-
			Cold	7.86	7.28	10.90	8.16	-	10.85	14.50	23.92	11.18	-
		Anolyte water	Ambient	7.86	5.17	10.94	9.19	-	10.85	8.18	13.26	12.21	-
			Cold	7.86	3.45	9.28	6.35	-	10.85	6.46	13.79	9.37	-
		Control	Ambient	7.86	7.81	11.92	9.00	-	10.85	10.82	14.93	12.02	-
			Cold	7.86	4.18	10.72	11.57	-	10.85	7.19	13.74	14.59	-
		Gum Arabic (GA)	Ambient	7.86	6.57	8.96	8.77	-	10.85	9.58	11.97	11.79	-
			Cold	7.86	5.31	13.75	5.22	-	10.85	6.32	16.76	8.24	-
		HWT + GA	Ambient	7.86	7.95	11.42	9.67	-	10.85	10.97	14.43	10.02	-
			Cold	7.86	3.71	10.07	13.57	-	10.85	5.73	13.08	16.60	-

Route	Maturity	Treatments	Storage	Winter season – respiration rate (ml CO_2 /kg.hr)					Summer season – respiration rate (ml CO_2 /kg.hr)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
EF	Green	Anolyte + GA	Ambient	17.04	17.54	13.93	12.16	-	20.17	20.55	16.94	15.14	-
			Cold	17.04	18.15	5.56	4.83	-	20.17	21.16	8.58	7.85	-
		Anolyte water	Ambient	17.04	15.73	17.19	14.40	-	20.17	18.74	20.20	17.38	-
			Cold	17.04	14.22	4.70	1.80	-	20.17	17.23	7.71	4.82	-
		Control	Ambient	17.04	15.80	19.92	2.96	-	20.17	18.81	22.93	5.93	-
			Cold	17.04	23.89	9.54	6.59	-	20.17	26.90	12.55	9.61	-
		Gum Arabic (GA)	Ambient	17.04	17.35	11.58	9.68	-	20.17	20.36	14.60	13.33	-
			Cold	17.04	20.66	3.78	3.43	-	20.17	23.67	6.80	6.45	-
		HWT + GA	Ambient	17.04	15.18	13.45	4.44	-	20.17	18.19	16.46	3.68	-
			Cold	17.04	27.44	5.82	3.33	-	20.17	30.45	8.83	6.35	-
	Pink	Anolyte + GA	Ambient	14.19	13.81	7.44	9.31	-	17.12	16.82	10.45	12.29	-
			Cold	14.19	15.82	6.28	6.09	-	17.12	18.83	9.29	9.11	-
		Anolyte water	Ambient	14.19	14.24	11.31	13.12	-	17.12	17.25	14.33	16.09	-
			Cold	14.19	14.22	4.86	7.78	-	17.12	17.23	7.87	10.80	-
		Control	Ambient	14.19	14.61	12.19	8.91	-	17.12	17.62	15.21	11.88	-
			Cold	14.19	20.27	5.74	7.02	-	17.12	23.29	8.76	10.04	-
		Gum Arabic (GA)	Ambient	14.19	13.35	3.44	8.94	-	17.12	16.37	5.01	7.36	-
			Cold	14.19	7.57	3.22	8.53	-	17.12	10.58	6.23	11.55	-
		HWT + GA	Ambient	14.19	15.53	12.32	14.93	-	17.12	28.54	15.33	14.51	-
			Cold	14.19	26.00	8.22	12.16	-	17.12	19.01	11.23	14.18	-
	Red	Anolyte + GA	Ambient	9.44	19.11	12.41	20.37	-	12.49	22.12	15.43	11.18	-
			Cold	9.44	14.08	5.12	8.10	-	12.49	17.10	8.13	11.12	-
		Anolyte water	Ambient	9.44	11.24	11.35	12.69	-	12.49	14.25	14.37	15.66	-
			Cold	9.44	11.44	6.32	9.01	-	12.49	14.45	9.33	12.03	-
		Control	Ambient	9.44	14.05	15.22	12.54	-	12.49	23.07	18.23	15.51	-
			Cold	9.44	20.30	8.46	10.88	-	12.49	17.31	11.47	13.90	-
		Gum Arabic (GA)	Ambient	9.44	14.45	10.88	13.94	-	12.49	17.46	13.89	16.85	-
			Cold	9.44	18.70	8.38	13.67	-	12.49	21.71	11.40	16.70	-
		HWT + GA	Ambient	9.44	12.97	10.33	13.94	-	12.49	20.99	13.35	17.06	-
			Cold	9.44	17.21	6.87	14.23	-	12.49	15.22	9.88	12.25	-

APPENDIX E

Table 5.5 The effects of supply route, maturity stages, pre-storage treatments and storage conditions on tomato soluble solids

Route	Maturity	Treatments	Storage	Winter season – TSS (°Brix)					Summer season – TSS (°Brix)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
PD	Green	Anolyte + GA	Ambient	4.0	4.3	4.4	4.2	4.1	4.2	4.5	4.6	4.4	4.3
			Cold	4.0	4.0	4.1	3.9	3.8	4.1	4.1	4.2	4.0	3.9
		Anolyte water	Ambient	4.0	4.3	4.5	4.1	4.2	4.2	4.5	4.7	4.3	4.4
			Cold	4.0	4.1	4.2	3.8	3.5	4.1	4.2	4.3	4.0	4.0
		Control	Ambient	4.0	4.2	4.2	4.3	4.3	4.2	4.4	4.4	4.5	4.5
			Cold	4.0	4.4	4.5	4.6	4.6	4.1	4.5	4.6	4.7	4.7
		Gum Arabic (GA)	Ambient	4.0	4.2	4.3	4.3	4.4	4.2	4.4	4.5	4.5	4.6
			Cold	4.0	4.1	4.2	3.8	4.1	4.1	4.2	4.3	3.9	4.2
		HWT + GA	Ambient	4.0	4.5	4.5	4.2	4.1	4.2	4.7	4.7	4.4	4.3
			Cold	4.0	4.2	4.3	4.0	3.8	4.1	4.3	4.4	4.1	3.9
	Pink	Anolyte + GA	Ambient	4.2	4.6	4.7	4.3	4.6	4.6	5.0	5.1	4.7	5.0
			Cold	4.2	4.3	4.4	4.0	4.3	4.4	4.5	4.6	4.2	4.5
		Anolyte water	Ambient	4.2	4.5	4.6	4.3	4.4	4.6	4.9	5.0	4.7	4.8
			Cold	4.2	4.2	4.3	4.0	3.6	4.4	4.4	4.5	4.2	3.8
		Control	Ambient	4.2	4.4	4.4	4.5	4.6	4.6	4.8	4.8	4.9	5.0
			Cold	4.2	4.6	4.7	4.7	4.7	4.4	4.8	4.9	4.9	4.9
		Gum Arabic (GA)	Ambient	4.2	4.5	4.5	4.3	3.9	4.6	4.9	4.9	4.7	4.3
			Cold	4.2	4.2	4.2	3.9	4.3	4.4	4.4	4.4	4.1	4.5
		HWT + GA	Ambient	4.2	4.6	4.6	4.5	4.1	4.6	5.0	5.0	4.9	4.5
			Cold	4.2	4.3	4.3	4.3	3.8	4.4	4.5	4.5	4.5	4.0
	Red	Anolyte + GA	Ambient	4.4	4.8	4.9	4.6	3.9	5.0	5.4	5.5	5.2	4.5
			Cold	4.4	4.4	4.5	4.3	3.6	4.8	4.8	4.9	4.7	4.0
		Anolyte water	Ambient	4.4	4.6	4.7	4.6	4.5	5.0	5.2	5.3	5.2	5.1
			Cold	4.4	4.5	4.5	4.3	4.2	4.8	4.9	4.9	4.7	4.6
		Control	Ambient	4.4	4.6	4.7	4.7	4.7	5.0	5.2	5.3	5.3	5.3
			Cold	4.4	4.6	4.7	4.7	4.7	4.8	5.0	5.1	5.1	5.1
		Gum Arabic (GA)	Ambient	4.4	4.5	4.6	4.5	3.7	5.0	5.1	5.2	5.1	4.3
			Cold	4.4	4.3	4.3	4.1	4.5	4.8	4.7	4.7	4.5	4.9
		HWT + GA	Ambient	4.4	4.6	4.7	4.7	4.9	5.0	5.2	5.3	5.3	5.5
			Cold	4.4	4.4	4.4	4.3	4.5	4.8	4.8	4.8	4.7	4.9

Route	Maturity	Treatments	Storage	Winter season – TSS (°Brix)					Summer season – TSS (°Brix)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
EM	Green	Anolyte + GA	Ambient	3.9	4.0	4.4	4.2	4.3	4.1	4.2	4.6	4.4	4.5
			Cold	3.9	3.8	3.8	3.9	4.0	4.0	3.9	3.9	4.0	4.1
		Anolyte water	Ambient	3.9	4.4	4.7	4.7	3.7	4.1	4.6	4.9	4.9	3.9
			Cold	3.9	4.3	4.2	4.6	3.4	4.0	4.4	4.3	4.7	3.5
		Control	Ambient	3.9	4.4	4.6	4.6	4.7	4.1	4.6	4.8	4.8	4.9
			Cold	3.9	4.2	4.2	4.3	4.4	4.0	4.3	4.3	4.4	4.5
		Gum Arabic (GA)	Ambient	3.9	4.0	4.2	4.2	3.7	4.1	4.2	4.4	4.4	3.9
			Cold	3.9	3.8	3.8	3.9	3.5	4.0	3.9	3.9	4.0	3.6
		HWT + GA	Ambient	3.9	3.6	3.8	3.7	3.6	4.1	3.8	4.0	3.9	3.8
			Cold	3.9	3.4	3.4	3.4	3.3	4.0	3.5	3.5	3.5	3.4
	Pink	Anolyte + GA	Ambient	4.2	4.8	5.0	4.9	4.1	4.6	5.2	5.4	5.3	4.5
			Cold	4.2	4.6	4.6	4.6	3.8	4.4	4.8	4.8	4.8	4.0
		Anolyte water	Ambient	4.2	4.5	4.7	4.8	4.6	4.6	4.9	5.1	5.2	5.0
			Cold	4.2	4.3	4.3	4.5	4.3	4.4	4.5	4.5	4.7	4.5
		Control	Ambient	4.2	4.5	4.7	4.7	4.8	4.6	4.9	5.1	5.1	5.2
			Cold	4.2	4.3	4.3	4.4	4.5	4.4	4.5	4.5	4.6	4.7
		Gum Arabic (GA)	Ambient	4.2	4.2	4.4	4.4	4.6	4.6	4.6	4.8	4.8	5.0
			Cold	4.2	4.0	4.0	4.1	4.3	4.4	4.2	4.2	4.3	4.5
		HWT + GA	Ambient	4.2	4.0	4.0	4.1	4.5	4.6	4.4	4.4	4.5	4.9
			Cold	4.2	3.8	3.8	3.6	4.2	4.4	4.0	4.0	3.8	4.4
	Red	Anolyte + GA	Ambient	4.4	4.1	4.3	4.3	4.3	5.0	4.7	4.9	4.9	4.9
			Cold	4.4	3.9	3.9	4.0	4.0	4.8	4.3	4.3	4.4	4.4
		Anolyte water	Ambient	4.4	4.8	5.0	5.0	4.3	5.0	5.4	5.6	5.6	4.9
			Cold	4.4	4.6	4.6	4.7	4.0	4.8	5.0	5.0	5.1	4.4
		Control	Ambient	4.4	4.7	4.9	4.9	5.0	5.0	5.3	5.5	5.5	5.6
			Cold	4.4	4.5	4.5	4.6	4.7	4.8	4.9	4.9	5.0	5.1
		Gum Arabic (GA)	Ambient	4.4	4.4	4.5	4.3	4.2	5.0	5.0	5.1	4.9	4.8
			Cold	4.4	4.2	4.2	3.7	3.9	4.8	4.6	4.6	4.1	4.3
		HWT + GA	Ambient	4.4	4.1	4.1	4.1	3.7	5.0	4.7	4.7	4.5	4.3
			Cold	4.4	3.5	3.5	3.6	3.4	4.8	3.9	3.9	4.0	3.8

Route	Maturity	Treatments	Storage	Winter season – TSS (°Brix)					Summer season – TSS (°Brix)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
EF	Green	Anolyte + GA	Ambient	3.8	3.3	3.5	3.6	3.7	4.0	3.5	3.7	3.8	3.9
			Cold	3.8	3.8	4.0	4.7	4.5	3.9	3.9	4.1	4.8	4.6
		Anolyte water	Ambient	3.8	4.2	4.4	4.5	4.6	4.0	4.4	4.6	4.7	4.8
			Cold	3.8	3.8	4.0	4.8	3.6	3.9	3.9	4.1	4.9	3.7
		Control	Ambient	3.8	4.1	4.3	4.4	4.4	4.0	4.3	4.5	4.6	4.6
			Cold	3.8	3.8	4.0	4.1	4.1	3.9	3.9	4.1	4.2	4.2
		Gum Arabic (GA)	Ambient	3.8	4.0	4.2	4.3	4.3	4.0	4.2	4.4	4.5	4.5
			Cold	3.8	4.0	4.2	4.6	3.5	3.9	4.1	4.3	4.7	3.6
		HWT + GA	Ambient	3.8	3.7	3.9	4.0	4.1	4.0	3.9	4.1	4.2	4.3
			Cold	3.8	4.3	4.5	4.3	3.6	3.9	4.4	4.6	4.4	3.7
	Pink	Anolyte + GA	Ambient	4.1	3.8	4.0	4.1	3.5	4.5	4.2	4.4	4.5	3.6
			Cold	4.1	4.0	4.2	5.0	3.1	4.3	4.2	4.4	5.2	3.3
		Anolyte water	Ambient	4.1	4.3	4.5	4.6	4.6	4.5	4.7	4.9	5.0	4.7
			Cold	4.1	4.1	4.3	4.2	3.6	4.3	4.3	4.5	4.4	3.8
		Control	Ambient	4.1	4.2	4.4	4.5	4.5	4.5	4.6	4.8	4.9	4.7
			Cold	4.1	4.1	4.3	4.3	4.4	4.3	4.3	4.5	4.5	4.6
		Gum Arabic (GA)	Ambient	4.1	4.1	4.3	4.4	4.5	4.5	4.5	4.7	4.8	4.5
			Cold	4.1	4.1	4.2	4.3	3.6	4.3	4.3	4.4	4.5	3.8
		HWT + GA	Ambient	4.1	4.1	4.3	4.4	4.4	4.5	4.5	4.7	4.8	4.5
			Cold	4.1	3.8	4.0	4.8	4.0	4.3	4.0	4.2	5.0	4.0
	Red	Anolyte + GA	Ambient	4.3	3.8	4.0	4.2	4.0	4.9	4.4	4.6	4.8	4.1
			Cold	4.3	3.9	4.1	3.6	3.5	4.7	4.3	4.5	4.0	3.7
		Anolyte water	Ambient	4.3	4.5	4.7	4.8	4.2	4.9	5.1	5.3	5.4	4.5
			Cold	4.3	4.6	4.8	3.6	3.4	4.7	5.0	5.2	4.0	3.8
		Control	Ambient	4.3	4.3	4.5	4.6	4.6	4.9	4.9	5.1	5.2	4.8
			Cold	4.3	4.5	4.7	4.7	4.7	4.7	4.9	5.1	5.1	4.9
		Gum Arabic (GA)	Ambient	4.3	4.2	4.4	4.5	4.2	4.9	4.8	5.0	5.1	4.4
			Cold	4.3	4.6	4.8	5.8	4.0	4.7	5.0	5.2	6.2	4.4
		HWT + GA	Ambient	4.3	4.0	4.2	4.3	4.4	4.9	4.6	4.8	4.9	4.6
			Cold	4.3	3.4	3.6	4.0	3.8	4.7	3.8	4.0	4.4	3.9

APPENDIX F

Table 5.6 The effects of supply route, maturity stages, pre-storage treatments and storage conditions on tomato total phenolic compounds (TPC)

Route	Maturity	Treatments	Storage	Winter season – TPC (mg GAE^{-1} g FW)					Summer season – TPC (mg GAE^{-1} g FW)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
PD	Green	Anolyte + GA	Ambient	0.659	0.394	0.312	0.259	-	0.543	0.277	0.255	0.242	-
			Cold	0.659	0.558	0.531	0.598	-	0.543	0.371	0.320	0.271	-
		Anolyte water	Ambient	0.659	0.558	0.560	0.614	-	0.543	0.441	0.743	0.698	-
			Cold	0.659	0.413	0.383	0.429	-	0.543	0.298	0.242	0.328	-
		Control	Ambient	0.659	0.478	0.230	0.648	-	0.543	0.359	0.111	0.530	-
			Cold	0.659	0.402	0.375	0.424	-	0.543	0.274	0.224	0.316	-
		Gum Arabic (GA)	Ambient	0.659	0.370	0.731	0.696	-	0.543	0.254	0.615	0.579	-
			Cold	0.659	0.393	0.366	0.420	-	0.543	0.259	0.209	0.310	-
		HWT + GA	Ambient	0.659	0.495	0.437	0.743	-	0.543	0.379	0.321	0.627	-
			Cold	0.659	0.441	0.414	0.443	-	0.543	0.379	0.328	0.367	-
	Pink	Anolyte + GA	Ambient	0.644	0.228	0.228	0.228	-	0.527	0.341	0.307	0.302	-
			Cold	0.644	0.228	0.228	0.228	-	0.527	0.370	0.320	0.306	-
		Anolyte water	Ambient	0.644	0.558	0.500	0.370	-	0.527	0.421	0.283	0.253	-
			Cold	0.644	0.558	0.518	0.391	-	0.527	0.441	0.342	0.274	-
		Control	Ambient	0.644	0.476	0.346	0.205	-	0.527	0.359	0.329	0.188	-
			Cold	0.644	0.509	0.440	0.493	-	0.527	0.393	0.324	0.277	-
		Gum Arabic (GA)	Ambient	0.644	0.370	0.333	0.217	-	0.527	0.254	0.217	0.201	-
			Cold	0.644	0.486	0.425	0.348	-	0.527	0.370	0.309	0.231	-
		HWT + GA	Ambient	0.644	0.328	0.246	0.229	-	0.527	0.276	0.276	0.272	-
			Cold	0.644	0.403	0.381	0.286	-	0.527	0.332	0.333	0.302	-
	Red	Anolyte + GA	Ambient	0.642	0.284	0.304	0.244	-	0.526	0.267	0.287	0.208	-
			Cold	0.642	0.361	0.396	0.375	-	0.526	0.291	0.328	0.328	-
		Anolyte water	Ambient	0.642	0.426	0.375	0.324	-	0.526	0.309	0.259	0.208	-
			Cold	0.642	0.534	0.483	0.432	-	0.526	0.417	0.366	0.316	-
		Control	Ambient	0.642	0.337	0.287	0.236	-	0.526	0.221	0.170	0.120	-
			Cold	0.642	0.445	0.395	0.344	-	0.526	0.329	0.278	0.228	-
		Gum Arabic (GA)	Ambient	0.642	0.391	0.341	0.290	-	0.526	0.275	0.224	0.173	-
			Cold	0.642	0.499	0.448	0.398	-	0.526	0.383	0.332	0.281	-
		HWT + GA	Ambient	0.642	0.299	0.263	0.251	-	0.526	0.285	0.250	0.242	-
			Cold	0.642	0.379	0.415	0.371	-	0.526	0.412	0.449	0.380	-

Route	Maturity	Treatments	Storage	Winter season – TPC (mg GAE^{-1} g FW)					Summer season – TPC (mg GAE^{-1} g FW)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
EM	Green	Anolyte + GA	Ambient	0.677	0.459	0.384	0.674	-	0.546	0.327	0.252	0.342	-
			Cold	0.677	0.408	0.388	0.522	-	0.546	0.248	0.220	0.438	-
		Anolyte water	Ambient	0.677	0.507	0.271	0.429	-	0.546	0.376	0.139	0.698	-
			Cold	0.677	0.490	0.442	0.643	-	0.546	0.427	0.322	0.214	-
		Control	Ambient	0.677	0.317	0.267	0.658	-	0.546	0.490	0.339	0.330	-
			Cold	0.677	0.404	0.421	0.594	-	0.546	0.270	0.201	0.226	-
		Gum Arabic (GA)	Ambient	0.677	0.278	0.243	0.211	-	0.546	0.346	0.311	0.379	-
			Cold	0.677	0.476	0.393	0.371	-	0.546	0.400	0.244	0.267	-
		HWT + GA	Ambient	0.677	0.260	0.218	0.258	-	0.546	0.228	0.286	0.327	-
			Cold	0.677	0.416	0.391	0.334	-	0.546	0.275	0.232	0.701	-
	Pink	Anolyte + GA	Ambient	0.710	0.464	0.344	0.305	-	0.578	0.349	0.349	0.224	-
			Cold	0.710	0.519	0.472	0.401	-	0.578	0.333	0.348	0.289	-
		Anolyte water	Ambient	0.710	0.407	0.420	0.431	-	0.578	0.376	0.389	0.299	-
			Cold	0.710	0.583	0.568	0.492	-	0.578	0.451	0.336	0.360	-
		Control	Ambient	0.710	0.321	0.472	0.356	-	0.578	0.190	0.340	0.224	-
			Cold	0.710	0.522	0.433	0.411	-	0.578	0.391	0.301	0.279	-
		Gum Arabic (GA)	Ambient	0.710	0.278	0.518	0.440	-	0.578	0.403	0.287	0.308	-
			Cold	0.710	0.573	0.376	0.473	-	0.578	0.441	0.344	0.341	-
		HWT + GA	Ambient	0.710	0.404	0.347	0.234	-	0.578	0.276	0.276	0.244	-
			Cold	0.710	0.508	0.477	0.305	-	0.578	0.254	0.262	0.278	-
	Red	Anolyte + GA	Ambient	0.818	0.365	0.305	0.221	-	0.687	0.311	0.251	0.056	-
			Cold	0.818	0.307	0.363	0.228	-	0.687	0.202	0.278	0.150	-
		Anolyte water	Ambient	0.818	0.356	0.377	0.276	-	0.687	0.224	0.246	0.144	-
			Cold	0.818	0.464	0.485	0.384	-	0.687	0.332	0.353	0.252	-
		Control	Ambient	0.818	0.582	0.380	0.278	-	0.687	0.450	0.248	0.147	-
			Cold	0.818	0.690	0.488	0.386	-	0.687	0.558	0.356	0.254	-
		Gum Arabic (GA)	Ambient	0.818	0.236	0.378	0.277	-	0.687	0.104	0.246	0.145	-
			Cold	0.818	0.344	0.486	0.384	-	0.687	0.212	0.354	0.253	-
		HWT + GA	Ambient	0.818	0.283	0.238	0.219	-	0.687	0.259	0.214	0.208	-
			Cold	0.818	0.331	0.385	0.289	-	0.687	0.260	0.326	0.255	-

Route	Maturity	Treatments	Storage	Winter season – TPC (mg GAE^{-1} g FW)					Summer season – TPC (mg GAE^{-1} g FW)				
				0	8	16	24	30	0	8	16	24	30
EF	Green	Anolyte + GA	Ambient	0.620	0.389	0.288	0.208	-	0.524	0.293	0.191	0.201	-
			Cold	0.620	0.428	0.266	0.120	-	0.524	0.339	0.219	0.202	-
		Anolyte water	Ambient	0.620	0.518	0.417	0.208	-	0.524	0.422	0.321	0.275	-
			Cold	0.620	0.379	0.322	0.236	-	0.524	0.255	0.146	0.271	-
		Control	Ambient	0.622	0.034	0.067	0.208	-	0.524	0.062	0.163	0.276	-
			Cold	0.620	0.372	0.309	0.376	-	0.524	0.241	0.122	0.413	-
		Gum Arabic (GA)	Ambient	0.620	0.391	0.290	0.208	-	0.524	0.295	0.194	0.273	-
			Cold	0.620	0.357	0.301	0.320	-	0.524	0.213	0.107	0.356	-
		HWT + GA	Ambient	0.620	0.378	0.276	0.208	-	0.524	0.282	0.180	0.263	-
			Cold	0.620	0.391	0.349	0.119	-	0.524	0.294	0.227	0.226	-
	Pink	Anolyte + GA	Ambient	0.573	0.408	0.371	0.279	-	0.477	0.367	0.367	0.346	-
			Cold	0.573	0.433	0.404	0.308	-	0.477	0.345	0.336	0.332	-
		Anolyte water	Ambient	0.573	0.518	0.568	0.366	-	0.477	0.422	0.472	0.358	-
			Cold	0.573	0.522	0.243	0.581	-	0.477	0.426	0.446	0.484	-
		Control	Ambient	0.575	0.037	0.600	0.442	-	0.477	0.462	0.402	0.388	-
			Cold	0.575	0.484	0.221	0.599	-	0.477	0.485	0.422	0.400	-
		Gum Arabic (GA)	Ambient	0.573	0.391	0.553	0.432	-	0.477	0.295	0.457	0.425	-
			Cold	0.573	0.420	0.204	0.560	-	0.477	0.324	0.107	0.464	-
		HWT + GA	Ambient	0.573	0.401	0.345	0.211	-	0.477	0.273	0.273	0.287	-
			Cold	0.573	0.445	0.432	0.208	-	0.477	0.309	0.329	0.302	-
	Red	Anolyte + GA	Ambient	0.412	0.302	0.132	0.234	-	0.450	0.302	0.232	0.302	-
			Cold	0.397	0.261	0.329	0.321	-	0.450	0.314	0.277	0.362	-
		Anolyte water	Ambient	0.546	0.304	0.253	0.208	-	0.450	0.208	0.157	0.285	-
			Cold	0.546	0.412	0.361	0.543	-	0.450	0.316	0.265	0.497	-
		Control	Ambient	0.549	0.218	0.167	0.210	-	0.450	0.120	0.069	0.289	-
			Cold	0.549	0.326	0.275	0.462	-	0.450	0.228	0.177	0.416	-
		Gum Arabic (GA)	Ambient	0.546	0.270	0.219	0.208	-	0.450	0.173	0.123	0.282	-
			Cold	0.546	0.378	0.327	0.537	-	0.450	0.281	0.231	0.488	-
		HWT + GA	Ambient	0.380	0.265	0.295	0.173	-	0.450	0.268	0.298	0.212	-
			Cold	0.374	0.369	0.347	0.286	-	0.450	0.299	0.397	0.320	-

APPENDIX G

Table 5.7 The effects of supply route, maturity stages, pre-storage treatments and storage conditions on tomato total antioxidant capacity (TAC)

Route	Maturity	Treatments	Storage	Winter season - TAC (%)					Summer season - TAC (%)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
PD	Green	Anolyte + GA	Ambient	68.93	42.38	40.16	48.89	-	57.28	30.73	58.51	57.24	-
			Cold	67.40	42.69	37.66	41.39	-	57.28	31.90	26.83	30.14	-
		Anolyte water	Ambient	68.93	58.80	88.96	84.40	-	57.28	37.14	27.31	32.75	-
			Cold	68.35	44.46	38.94	47.38	-	57.28	42.84	37.20	35.83	-
		Control	Ambient	68.93	50.75	25.96	67.80	-	57.28	38.93	14.14	55.98	-
			Cold	68.35	42.26	37.31	46.38	-	57.28	30.43	25.36	34.64	-
		Gum Arabic (GA)	Ambient	68.93	40.03	76.15	72.60	-	57.28	28.37	24.49	24.95	-
			Cold	68.35	40.65	35.69	45.60	-	57.28	29.95	23.88	24.02	-
		HWT + GA	Ambient	68.93	52.53	46.74	77.31	-	57.28	40.88	35.09	35.66	-
			Cold	68.24	47.37	42.34	48.16	-	57.28	40.87	35.81	39.70	-
	Pink	Anolyte + GA	Ambient	67.38	45.66	36.83	27.81	-	55.73	27.95	27.05	19.59	-
			Cold	67.38	49.82	43.84	38.44	-	55.73	28.91	29.00	20.06	-
		Anolyte water	Ambient	67.38	58.80	52.99	39.99	-	55.73	47.14	41.34	28.34	-
			Cold	67.38	58.77	38.85	42.05	-	55.73	47.12	27.20	30.40	-
		Control	Ambient	67.38	50.58	47.58	43.46	-	55.73	38.93	35.93	31.81	-
			Cold	67.38	53.91	37.01	32.33	-	55.73	42.26	25.36	20.68	-
		Gum Arabic (GA)	Ambient	67.38	40.03	46.34	34.74	-	55.73	28.37	34.69	23.09	-
			Cold	67.38	51.63	35.53	27.76	-	55.73	39.98	23.88	16.11	-
		HWT + GA	Ambient	67.38	45.63	34.81	25.87	-	55.73	18.93	18.93	16.83	-
			Cold	67.38	50.82	46.90	39.84	-	55.73	24.13	24.21	20.02	-
	Red	Anolyte + GA	Ambient	67.20	21.21	23.53	17.00	-	55.55	15.78	18.10	7.22	-
			Cold	67.20	33.45	37.25	31.04	-	55.55	28.89	32.78	21.62	-
		Anolyte water	Ambient	67.20	45.57	40.51	35.44	-	55.55	33.92	28.86	23.79	-
			Cold	67.20	56.36	51.30	46.23	-	55.55	44.71	39.65	34.58	-
		Control	Ambient	67.20	36.75	31.68	26.62	-	55.55	25.10	20.03	14.97	-
			Cold	67.20	47.54	42.47	37.41	-	55.55	35.89	30.82	25.76	-
		Gum Arabic (GA)	Ambient	67.20	42.12	37.05	31.99	-	55.55	30.47	25.40	20.34	-
			Cold	67.20	52.91	47.84	42.78	-	55.55	41.26	36.19	31.13	-
		HWT + GA	Ambient	67.20	29.77	15.32	24.70	-	36.07	20.53	16.07	14.39	-
			Cold	67.20	39.23	43.04	37.87	-	36.16	35.15	39.04	30.69	-

Route	Maturity	Treatments	Storage	Winter season - TAC (%)					Summer season - TAC (%)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
EM	Green	Anolyte + GA	Ambient	70.74	48.91	41.37	70.41	-	57.57	35.74	28.20	57.24	-
			Cold	70.74	44.71	40.03	68.02	-	57.57	27.80	25.01	66.83	-
		Anolyte water	Ambient	70.74	53.73	30.08	85.93	-	57.57	40.56	16.90	72.76	-
			Cold	70.74	58.56	49.65	86.58	-	57.57	45.75	36.63	74.40	-
		Control	Ambient	70.74	34.74	29.68	68.75	-	57.57	21.97	16.90	55.98	-
			Cold	70.74	42.76	45.81	77.57	-	57.57	29.98	33.10	65.58	-
		Gum Arabic (GA)	Ambient	70.74	30.82	27.31	74.12	-	57.57	17.65	14.14	60.95	-
			Cold	70.74	55.87	40.65	91.78	-	57.57	42.99	27.42	79.72	-
		HWT + GA	Ambient	70.74	29.01	24.79	78.83	-	57.57	15.84	11.61	65.66	-
			Cold	70.74	47.10	41.77	83.10	-	57.57	30.50	26.21	73.08	-
	Pink	Anolyte + GA	Ambient	73.97	27.37	27.37	38.57	-	60.80	25.70	25.33	25.39	-
			Cold	73.97	27.37	27.37	27.37	-	60.80	21.87	23.92	25.42	-
		Anolyte water	Ambient	73.97	53.73	55.02	46.11	-	60.80	40.56	41.85	32.94	-
			Cold	73.97	61.31	49.80	52.19	-	60.80	48.13	36.63	39.02	-
		Control	Ambient	73.97	35.14	50.22	38.57	-	60.80	21.97	37.05	25.39	-
			Cold	73.97	55.23	46.27	44.08	-	60.80	42.05	33.10	30.91	-
		Gum Arabic (GA)	Ambient	73.97	30.82	54.83	47.01	-	60.80	17.65	41.66	33.84	-
			Cold	73.97	60.29	40.60	50.27	-	60.80	47.12	27.42	37.10	-
		HWT + GA	Ambient	73.97	47.33	27.37	20.11	-	60.80	48.26	18.26	14.65	-
			Cold	73.97	67.09	40.22	27.30	-	60.80	54.67	25.86	16.92	-
	Red	Anolyte + GA	Ambient	64.84	35.65	29.22	20.32	-	71.67	27.16	20.73	5.51	-
			Cold	64.84	48.59	35.16	17.44	-	71.67	16.16	24.78	13.69	-
		Anolyte water	Ambient	64.84	38.56	40.73	30.59	-	71.67	25.39	27.56	17.42	-
			Cold	64.84	49.35	51.52	41.39	-	71.67	36.18	38.35	28.21	-
		Control	Ambient	64.84	61.20	40.96	30.83	-	71.67	48.03	27.79	17.66	-
			Cold	64.84	61.99	53.75	41.62	-	71.67	58.82	38.58	28.45	-
		Gum Arabic (GA)	Ambient	64.84	26.59	40.78	30.65	-	71.67	13.42	27.61	17.48	-
			Cold	64.84	37.38	51.57	41.44	-	71.67	24.21	38.40	28.27	-
		HWT + GA	Ambient	64.84	29.34	24.57	22.57	-	71.67	38.07	13.30	9.23	-
			Cold	64.84	33.37	39.62	28.55	-	71.67	48.48	25.92	17.42	-

Route	Maturity	Treatments	Storage	Winter season - TAC (%)					Summer season - TAC (%)				
				Day 0	Day 8	Day 16	Day 24	Day 30	Day 0	Day 8	Day 16	Day 24	Day 30
EF	Green	Anolyte + GA	Ambient	64.98	41.89	31.76	23.82	-	55.36	32.26	22.13	16.92	-
			Cold	63.58	37.46	25.83	13.95	-	55.36	28.98	16.70	13.31	-
		Anolyte water	Ambient	64.98	54.85	44.72	23.82	-	55.36	45.22	35.09	16.81	-
			Cold	64.49	38.20	27.61	28.21	-	55.36	28.47	17.64	20.34	-
		Control	Ambient	65.21	26.43	13.70	23.82	-	55.36	53.19	43.32	26.88	-
			Cold	64.71	42.87	25.26	20.55	-	55.36	27.06	15.23	20.90	-
		Gum Arabic (GA)	Ambient	64.98	42.12	31.99	23.82	-	55.36	32.50	22.37	16.70	-
			Cold	64.49	34.09	23.81	40.39	-	55.36	24.26	13.75	32.45	-
		HWT + GA	Ambient	64.98	40.78	30.65	23.82	-	55.36	31.15	21.02	11.96	-
			Cold	64.41	39.77	30.51	22.68	-	55.36	32.43	25.67	16.60	-
	Pink	Anolyte + GA	Ambient	23.82	23.82	23.82	27.34	-	27.86	31.71	27.79	24.33	-
			Cold	23.82	23.82	23.82	23.82	-	28.87	31.00	28.78	26.28	-
		Anolyte water	Ambient	60.29	54.85	59.78	38.58	-	50.67	45.22	50.16	30.06	-
			Cold	60.29	55.23	27.27	61.05	-	50.67	45.60	17.64	51.43	-
		Control	Ambient	60.52	66.66	63.02	49.15	-	50.67	9.19	53.17	44.35	-
			Cold	60.52	51.40	25.08	62.86	-	50.67	41.55	15.23	53.01	-
		Gum Arabic (GA)	Ambient	60.29	42.12	58.33	47.78	-	50.67	32.50	48.70	39.29	-
			Cold	60.29	45.04	23.37	58.98	-	50.67	35.42	13.75	49.35	-
		HWT + GA	Ambient	23.82	23.82	23.82	18.03	-	18.84	22.69	18.77	12.73	-
			Cold	23.82	23.82	23.82	23.82	-	18.96	23.05	23.99	21.42	-
	Red	Anolyte + GA	Ambient	57.63	23.19	15.21	10.45	-	48.01	19.48	11.65	8.41	-
			Cold	57.63	21.88	30.06	21.86	-	48.01	21.49	27.41	22.55	-
		Anolyte water	Ambient	57.63	33.41	28.35	23.82	-	48.01	23.79	18.72	16.84	-
			Cold	57.63	44.21	39.14	61.73	-	48.01	34.58	29.51	53.64	-
		Control	Ambient	57.86	24.82	19.75	24.05	-	48.01	14.97	9.90	16.94	-
			Cold	57.86	35.61	30.54	50.53	-	48.01	25.76	20.69	42.51	-
		Gum Arabic (GA)	Ambient	57.63	29.96	24.90	23.82	-	48.01	20.34	15.27	16.72	-
			Cold	57.63	40.75	35.69	60.96	-	48.01	31.13	26.06	52.73	-
		HWT + GA	Ambient	57.63	26.13	8.14	9.28	-	48.01	18.61	12.78	8.18	-
			Cold	57.63	26.48	35.85	24.68	-	48.01	23.41	33.67	22.70	-

APPENDIX H

Table 5.8 The effects of supply route, maturity stages, pre-storage treatments and storage conditions on tomato marketability (%)

Route	Maturity	Treatments	Storage	Winter					Summer				
				0	8	16	24	30	0	8	16	24	30
PD	Green	Anolyte + GA	Ambient	100.00	100.00	37.50	0.00	7.50	100.00	93.33	53.33	20.00	-
			Cold	100.00	100.00	97.50	95.00	35.00	100.00	68.89	40.33	23.67	11.51
		Anolyte water	Ambient	100.00	100.00	32.50	19.50	0.00	100.00	95.56	60.00	28.89	71.87
			Cold	100.00	100.00	95.00	90.50	37.50	100.00	44.44	44.31	73.33	64.44
		Control	Ambient	100.00	70.00	32.50	20.00	0.00	100.00	88.89	55.55	31.35	0.00
			Cold	100.00	100.00	92.50	40.00	20.00	100.00	88.89	55.55	31.35	6.04
		Gum Arabic (GA)	Ambient	100.00	100.00	30.00	22.50	7.50	100.00	82.22	26.67	8.89	43.13
			Cold	100.00	100.00	97.50	87.50	22.50	100.00	62.22	46.67	51.11	35.56
		HWT + GA	Ambient	100.00	100.00	40.00	7.50	0.00	100.00	71.11	46.67	17.78	3.47
			Cold	100.00	100.00	95.00	57.50	17.50	100.00	80.00	44.23	22.22	8.89
	Pink	Anolyte + GA	Ambient	100.00	100.00	32.50	13.50	0.00	100.00	100.00	33.33	16.67	6.33
			Cold	100.00	100.00	100.00	75.00	12.50	100.00	68.89	68.89	35.67	14.44
		Anolyte water	Ambient	100.00	100.00	72.50	57.00	31.50	100.00	97.78	45.09	24.44	13.09
			Cold	100.00	100.00	100.00	85.00	22.50	100.00	44.44	44.44	42.22	28.89
		Control	Ambient	100.00	60.00	27.50	27.50	2.50	100.00	77.78	51.52	23.41	5.24
			Cold	100.00	100.00	90.00	51.50	5.00	100.00	88.00	73..20	27.00	11.00
		Gum Arabic (GA)	Ambient	100.00	100.00	60.00	62.50	2.50	100.00	86.67	16.74	0.00	40.80
			Cold	100.00	100.00	97.50	67.50	10.00	100.00	51.11	46.67	48.89	33.33
		HWT + GA	Ambient	100.00	90.00	42.44	14.00	7.42	100.00	86.67	22.22	9.11	0.00
			Cold	100.00	100.00	90.00	27.50	5.00	100.00	75.56	20.00	11.22	3.02
	Red	Anolyte + GA	Ambient	100.00	100.00	15.00	10.00	0.00	100.00	62.22	17.78	4.44	0.00
			Cold	100.00	100.00	95.00	60.00	12.50	100.00	55.56	8.89	0.00	0.00
		Anolyte water	Ambient	100.00	100.00	32.50	17.50	10.00	100.00	84.44	46.67	20.00	12.29
			Cold	100.00	100.00	100.00	72.50	30.00	100.00	86.67	71.11	53.33	26.67
		Control	Ambient	100.00	55.00	30.00	7.50	0.00	100.00	80.00	46.67	15.56	0.00
			Cold	100.00	97.50	85.00	62.50	17.50	100.00	53.33	44.44	16.67	0.00
		Gum Arabic (GA)	Ambient	100.00	100.00	52.50	2.50	10.00	100.00	71.11	22.22	14.44	3.11
			Cold	100.00	100.00	97.50	87.50	37.50	100.00	77.78	40.00	22.22	6.67
		HWT + GA	Ambient	100.00	87.50	15.00	0.00	0.00	100.00	63.05	23.51	6.67	0.00
			Cold	100.00	100.00	87.50	52.50	2.50	100.00	80.00	24.44	8.89	0.00

Route	Maturity	Treatments	Storage	Winter					Summer				
				0	8	16	24	30	0	8	16	24	30
EM	Green	Anolyte + GA	Ambient	100.00	100.00	60.00	57.50	40.00	100.00	100.00	71.11	51.11	28.75
			Cold	100.00	100.00	100.00	50.00	47.50	100.00	100.00	84.44	77.78	70.12
		Anolyte water	Ambient	100.00	100.00	92.50	51.00	37.50	100.00	97.78	73.33	57.78	32.36
			Cold	100.00	100.00	100.00	57.50	45.00	100.00	100.00	77.78	62.22	40.14
		Control	Ambient	100.00	100.00	85.00	52.50	52.50	100.00	95.56	68.89	40.00	22.52
			Cold	100.00	100.00	100.00	37.50	10.00	100.00	100.00	84.44	70.00	54.97
		Gum Arabic (GA)	Ambient	100.00	100.00	97.50	55.00	42.50	100.00	100.00	77.78	32.22	13.68
			Cold	100.00	100.00	100.00	65.00	50.03	100.00	100.00	86.67	43.33	38.06
		HWT + GA	Ambient	100.00	100.00	12.50	10.00	10.00	100.00	68.89	20.00	8.89	0.00
			Cold	100.00	100.00	97.50	47.50	30.00	100.00	97.78	73.33	42.22	19.54
	Pink	Anolyte + GA	Ambient	100.00	100.00	25.00	16.14	5.00	100.00	97.78	35.56	15.56	8.56
			Cold	100.00	100.00	90.00	37.50	17.50	100.00	100.00	80.00	62.22	40.76
		Anolyte water	Ambient	100.00	100.00	55.00	7.50	2.50	100.00	97.78	84.44	47.78	36.78
			Cold	100.00	100.00	97.50	40.00	22.50	100.00	100.00	88.89	64.44	51.32
		Control	Ambient	100.00	100.00	80.00	47.50	47.50	100.00	95.56	73.33	20.00	4.80
			Cold	100.00	100.00	90.00	40.00	7.50	100.00	93.33	75.56	24.44	12.21
		Gum Arabic (GA)	Ambient	100.00	95.00	30.00	0.00	5.00	100.00	93.33	40.00	34.44	12.00
			Cold	100.00	100.00	97.50	37.50	17.50	100.00	100.00	77.78	68.89	73.33
		HWT + GA	Ambient	100.00	100.00	37.50	5.50	2.50	100.00	82.22	31.30	11.17	0.00
			Cold	100.00	100.00	95.00	72.50	45.00	100.00	90.00	41.04	31.11	5.56
	Red	Anolyte + GA	Ambient	100.00	90.00	47.50	7.50	2.50	100.00	66.67	11.11	0.00	-
			Cold	100.00	100.00	95.00	42.50	12.50	100.00	93.33	40.00	14.44	7.71
		Anolyte water	Ambient	100.00	92.50	92.50	7.50	2.50	100.00	91.11	77.78	41.77	23.61
			Cold	100.00	100.00	95.00	40.30	17.51	100.00	100.00	82.22	60.03	31.32
		Control	Ambient	100.00	95.00	67.50	25.33	30.09	100.00	86.67	35.56	20.04	44.17
			Cold	97.50	100.00	75.00	30.17	20.00	100.00	91.11	0.00	46.67	29.33
		Gum Arabic (GA)	Ambient	100.00	100.00	0.00	7.50	7.50	100.00	84.44	57.78	0.00	21.60
			Cold	100.00	100.00	95.00	37.50	7.50	100.00	100.00	93.33	51.11	15.90
		HWT + GA	Ambient	100.00	82.50	12.50	0.00	0.00	100.00	51.11	8.89	0.00	-
			Cold	100.00	100.00	92.50	37.50	17.50	100.00	93.33	80.00	24.44	8.66

Route	Maturity	Treatments	Storage	Winter					Summer				
				0	8	16	24	30	0	8	16	24	30
EF	Green	Anolyte + GA	Ambient	100.00	100.00	62.50	15.00	10.00	100.00	91.11	22.22	26.67	18.19
			Cold	100.00	100.00	100.00	52.50	35.00	100.00	82.22	55.56	53.33	37.22
		Anolyte water	Ambient	100.00	100.00	67.50	17.50	15.00	100.00	100.00	57.78	35.56	16.60
			Cold	100.00	100.00	100.00	37.50	20.00	100.00	84.44	57.78	57.78	30.14
		Control	Ambient	100.00	65.00	45.00	12.50	2.50	100.00	97.78	55.56	6.67	50.16
			Cold	100.00	100.00	77.50	70.00	37.50	100.00	8.89	4.44	0.00	-
		Gum Arabic (GA)	Ambient	100.00	100.00	67.50	35.00	17.50	100.00	86.67	33.33	35.56	50.07
			Cold	100.00	100.00	100.00	60.00	40.00	100.00	75.56	48.89	44.44	31.53
		HWT + GA	Ambient	100.00	100.00	42.50	5.00	7.50	100.00	95.56	24.44	0.00	-
			Cold	100.00	100.00	92.50	35.00	17.50	100.00	66.67	40.00	35.56	12.64
	Pink	Anolyte + GA	Ambient	100.00	100.00	32.50	17.33	12.50	100.00	68.89	15.56	6.67	0.00
			Cold	100.00	100.00	100.00	47.50	27.50	100.00	64.44	37.78	24.44	13.88
		Anolyte water	Ambient	100.00	97.50	42.50	14.50	12.50	100.00	71.11	41.87	22.22	15.11
			Cold	100.00	100.00	100.00	57.50	40.08	100.00	82.22	55.56	48.89	27.15
		Control	Ambient	100.00	62.50	50.00	32.50	10.00	100.00	95.56	8.89	4.44	0.00
			Cold	100.00	95.00	87.50	52.50	25.00	100.00	62.22	26.67	16.33	12.01
		Gum Arabic (GA)	Ambient	100.00	100.00	40.00	62.44	32.50	100.00	97.78	2.22	2.22	45.39
			Cold	100.00	100.00	100.00	40.00	20.00	100.00	51.11	24.44	11.11	34.58
		HWT + GA	Ambient	100.00	97.50	67.09	2.50	0.00	100.00	46.67	11.11	0.00	-
			Cold	100.00	100.00	77.50	5.00	0.00	100.00	60.00	18.89	8.22	0.00
	Red	Anolyte + GA	Ambient	100.00	95.00	61.44	0.00	-	100.00	84.44	11.11	0.00	-
			Cold	100.00	100.00	82.50	17.50	2.50	100.00	42.22	17.78	2.22	3.19
		Anolyte water	Ambient	100.00	97.50	97.50	0.00	0.00	100.00	73.33	8.89	22.22	10.62
			Cold	100.00	100.00	92.50	35.00	15.00	100.00	68.89	46.67	26.67	15.69
		Control	Ambient	100.00	35.00	25.00	17.50	0.00	100.00	51.11	38.72	22.22	19.45
			Cold	100.00	60.00	60.00	30.00	17.50	100.00	15.56	44.44	38.87	30.29
		Gum Arabic (GA)	Ambient	100.00	100.00	25.00	0.00	0.00	100.00	60.00	35.56	0.00	-
			Cold	100.00	100.00	95.00	37.50	12.50	100.00	20.00	12.67	6.22	-
		HWT + GA	Ambient	100.00	100.00	15.00	0.00	0.00	100.00	28.89	15.56	7.44	0.00
			Cold	100.00	90.00	40.00	2.50	0.00	100.00	33.33	28.89	21.91	8.15

APPENDIX I

Table 5.9 Analysis of variance of tomato quality in response to different supply routes, harvesting maturity stages, pre-storage treatments and storage conditions

Parameters	Season	Route (A)	Maturity (B)	Treatment (C)	Storage (D)	AB	AC	BC	ABC	AD	BD	CD	ABD	ACD	BCD	ABCD
PWL	***	***	***	***	***	***	***	***	***	***	***	***	**	***	***	***
Respiration	***	***	***	***	***	**	**	**	***	***	***	***	***	**	***	***
Texture	ns	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Colour	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TSS	***	***	***	***	*	***	***	***	ns	***	***	***	***	***	***	***
TPC	***	***	***	***	***	***	ns	***	***	***	***	***	***	***	***	***
TAC	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Marketability	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***

ns, *, **, ***, means: not significant, significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively.