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

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PREFACE

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ABSTRACT

South Africa is one of the developing countries that is trying to improve tomato production to meet the demands of human beings and conquer food insecurity issues. In addition to food security reasons, tomato is a unique crop, popular for being nutritious. Furthermore, tomatoes have been recognized as very important potential sources of antioxidants, mainly lycopene and β-carotene that are very important for fighting cancer and heart diseases. Some criteria that are used by South Africa to improve tomato production involves small scale farmers being part of production sectors, in addition to the well-known commercial farmers who contribute significantly in the national tomato production. Commercial farmers contribute 95% to tomato production, nationally, while small scale farmers only contribute 5%. Postharvest losses have been pronounced to be the most restrictive of constraints in tomato production sector. These losses were reviewed and found to occur at every point in the tomato supply chain. Tomato is one of the most perishable fresh produce, thus highly susceptible to postharvest losses. This is due to being a climacteric fruit, which consists of a ripening pattern that is characterised by a burst in ethylene production accompanied by a rise in the rate of respiration. Pre-harvest factors (such as mineral nutrition, irrigation, training and pruning), environmental factors (such as temperature, relative humidity, and atmospheric composition), and technical factors (such as mechanical injuries, bruising) were found to be the most problematic factors in jeopardising tomato fruit quality. These factors jeopardize fruit quality by stimulating fruit physiological processes such as respiration, ethylene production and transpiration and biochemical processes (such as enzyme activities and microbial growth). Maturity stage at harvest, time of harvesting and harvesting methods were found to be among the factors affecting postharvest life of tomatoes. Furthermore, supply chain routes were also found to hasten tomato quality losses, mainly due to road quality and distance between production and marketing sites. Pre-storage treatments for maintaining tomato quality have included use of different chemicals such as disinfectants, blanching treatments, coating, packaging and low temperature storage. All of them had positive effects in maintaining tomato quality, however, their efficiency varied with maturity stages. Integrating pre-storage treatments optimise fruit quality, however supply chain routes also need to be considered. Therefore, the research proposal presented in this document aims to evaluate the effect of supply chain routes and pre-storage treatments in quality of stored tomatoes.

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1. INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) belonging to the family *Solanaceae* (Tigist *et al.,* 2012), is the second most important and widely consumed fruit crop in the world (Wilcox *et al*., 2003). It is also the second most widespread fruit 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 the morphological diversity of tomatoes combined with the soil and climatic conditions of South Africa which allows production in summer and winter (in frost free areas) (DAFF, 2013). The importance of tomatoes is due to their nutritional value (Wilcox *et al*., 2003). They are 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). 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.

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. Fresh fruits postharvest losses are approximated at 20-50% in developing countries (Kader, 1992; Kader, 2005). 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 to be rectified 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. 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 have 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 in 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).

All the mentioned postharvest technologies (pre-storage, packaging and cooling treatments) are compatible with each other, thus can be combined to optimize fruit quality. Most of the time, integration of different postharvest technologies is recommended to optimize fruit postharvest quality (Beckles, 2012). 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 efficiently reduced losses and extended shelf life of tomatoes.

2. LITERATURE REVIEW

Introduction

Tomato production and efficient postharvest handling is very essential as it is very important in human diet, however postharvest losses are still problematic especially in developing countries. Therefore, an overview of tomato production and postharvest losses in South Africa, mitigating tomato quality losses, factors influencing deterioration of tomato quality, effect of: harvesting, supply chain routes and pre-storage treatments will be discussed in this section. Furthermore, important quality attributes for testing tomato quality will be discussed.

2.1 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 (Wilcox, 2003; Directorate Marketing, 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 the 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). 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). These losses are more pronounced in the 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). Fresh fruit postharvest losses are estimated between 20-50% in developing countries like South Africa (Kader, 1992; Kader, 2005). 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).

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). 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 used. High temperatures of non-refrigerated trucks, which affect poor storage conditions, are used.

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 showed potential to reduce postharvest losses. As reported by Melkamu et al. (2008), as much as these treatments have 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 (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.

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). Therefore, low temperature might also reduce microbial load in stored tomatoes. Biochemically, higher storage temperatures in tomatoes enhance development of polygalacturonase (PG) 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, reducing temperature could slow down all these biochemical processes and maintain quality of tomatoes.

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*., 2013).

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 (Wu, 2010). 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 (Wu, 2010). The condition whereby the new atmospheric composition has been created around the fruit by addition or removal of certain gases is termed controlled atmosphere (CA) or modified atmosphere (MA) (Wu, 2010). The gas composition within the modified atmosphere and controlled 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).

2.4 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).

2.4.1 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). Generally, large scale 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.

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.

2.4.2 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 by an author concerning harvesting at the end of the day, on tomato shelf life.

2.4.3 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 fruits 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.

2.5 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 have 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 generally 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).

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 (Workneh and Osthoff, 2015). 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.

2.6.1 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 100µg 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.

2.6.2 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.

2.6.3 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).

2.6.4 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). Figure 2.1 shows GA exudates and granules.

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.

2.7 Storage conditions

Storage conditions of fresh horticultural products like tomatoes are fully dependent on temperature (Wu, 2010). Temperature is the major environmental factor that controls the postharvest life of fruits and vegetables by manipulating metabolic processes within a fruit (Workneh and Osthoff, 2015; Wu, 2010; Aung and Chang, 2014). Tomato, a climacteric fruit, has a shorter shelf life of about 10 to 12 days when stored at ambient temperature (Shahnawaz *et al.*, 2012). However, this is not a sufficient period for marketing the high production volumes of tomatoes, thus tons of tomatoes become vulnerable to postharvest losses, which occur between harvesting, and marketing (Shahnawaz *et al.*, 2012). Ambient temperature stimulates the rate of metabolic and enzymatic activities taking place within the fruit thus reduce fruit quality (Wu, 2010; Workneh and Osthoff, 2015; Nunes et al., 2014).

Low storage temperatures (<12 °C) are suitable for tomato storage in order to slow down the fruit metabolic activities, maintain fruit quality and extend shelf-life (Pinheiro et al., 2013a), however, tomato is a tropical fruit, and develops physiological disorders such as chilling injury under low storage temperatures (Gómez et al., 2009). The optimum ripening storage temperature for tomato ranges between 18 and 21 °C. Exposure of unripe tomatoes to temperatures below 10°C for two weeks or below 5 °C for one-week result in uneven ripening, poor colour and flavour development (Gómez *et al.,* 2009). Tomatoes stored at chilling temperatures lose ability to develop into full colour (Ding *et al*., 2002). The development of colour in tomato during ripening is fully dependent on storage temperature, therefore it is important to optimize temperature for better tomato quality to be retained (Verheul *et al*., 2015). The fruit colour, flavour and firmness are the major quality parameters that attract a consumer to buy tomato, thus need to be sustained (Verheul *et al*., 2015). The best storage temperature for optimizing quality and shelf life of green matured tomatoes is above 13 °C (Palenta *et al*., 2006). Pinheiro *et al.* (2012) reported that the optimum storage temperature of green mature tomatoes is 10°C, for tomatoes at breaker maturity stage is 10 -13 °C

(Verheul *et al*., 2015). The best storage temperature which is intermediate to all different maturity stages is 12 °C (Verheul *et al*., 2015). Workneh (2010) reported that the optimum storage temperature for tomatoes ranges between 5 and 12 °C.

The findings from several studies mentioned above reveal that, storage conditions with reduced temperature are essential to sustain tomato quality and extend its shelf life. There are many ways at which cold storage temperatures may be achieved, but they are expensive, and not suitable for accommodating both emerging and commercial farmers. Evaporative cooling, less expensive, has low maintenance costs and it is energy efficient thus can be used by small scale farmers (Workneh, 2010).

2.8 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).

2.8.1 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 1.46N/mm.

2.8.2 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 a gas analyser (Singh *et al.*, 2013).

Mass loss

Most fresh fruits are harvested while they contain approximately 70-95% of water thus have maximum fresh mass (Pinheiro *et al.,* 2013b). The fresh mass of tomato fruit is dominated by water. Approximately 94-95% of tomato fruit is water and 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).

2.8.3 Chemical properties

Chemical composition of tomato fruit is the major determinant of fruit maturity and quality (Suárez *et al.,* 2008). 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 (Suárez *et al.,* 2008). 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 the 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 and relatively high acids content, because too high acid contents results in sour tomatoes (Turhan and Serniz, 2009). High sugars are practically denoted by high TSS value, therefore, 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.,* 2014). 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).

2.8.4 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.

2.8.5 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).

3. 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) physiological, biochemical properties; (2) microbiological properties of tomatoes, and (3) to evaluate the most suitable harvesting maturity stage that will minimize postharvest losses.

4. PROJECT PROPOSAL

4.1 Introduction

This project proposal consists of the problem statement, rationale, research questions, aim, objectives, methodology, intellectual considerations and project impact assessment.

4.2 Problem statement

Tomatoes are one of the most valuable crops, nutritionally, and their 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 of 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. The literature provides some information regarding reduction of tomato postharvest losses. However, attention has mostly been paid to fruit in the market and does not consider factors upstream in the supply chain (Kalantari *et al*., 2015). This effectively results in knowledge gaps and leads to the research question: what is the effect of different supply chain routes in the quality of tomato fruits? To maintain postharvest quality of tomato, different pre-storage treatments have been used, disinfectants, blanching, coating, packaging and low temperature storage (Tigist *et al*., 2013, Ali *et al*., 2013). All of them had some positive effects in maintaining tomato quality, however, their efficiency varied with maturity stages (Getinet *et al*., 2008; Teka, 2013). Moreover, there is little research and information on which pre-storage treatment or treatment combination is most effective and at which maturity stage under South African conditions? Currently, the 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 or combination of treatments for use by fresh produce industry (Romanazzi *et al*., 2016).

4.3 Rationale

Different postharvest technologies do exist in South Africa; including blanching, low temperature storage, coating, and disinfectants, however, most of them are too complex and expensive to be used by both large and small-scale farmers. Furthermore, most tested pre-storage treatments caused substantial human health concerns (Ölmez, and Kretzschmar, 2009). Therefore, simple, environmentally friendly and affordable pre-storage treatments are still desired.

4.4 Research questions

- What is the effect of supply chain routes and pre-storage treatments (anolyte water, Gum Arabic (GA) coating, anolyte water + GA, and hot water + GA treatments) on the physical, physiological, and biochemical quality of stored tomatoes?
- What is the effect of the combination of supply chain routes, pre-storage treatments (anolyte water, chlorinated water, hot water and Gum Arabic coating) and storage temperature in microbial load of pink-matured tomatoes?
- What is the most suitable maturity stage that will retain optimum physical, physiological, and biochemical quality, hence extend tomato fruit shelf life during handling and storage?

4.5 Aim and objectives

This study aims to develop integrated postharvest treatments and handling methods that will sustain fruit quality and extend shelf life of tomatoes.

The specific objectives are:

- To evaluate the effect of supply chain routes, pre-storage treatments (anolyte water, Gum Arabic (GA (10%)) coating, anolyte water + GA, and hot water + GA) and storage temperature on the physiological and biochemical quality of tomatoes

- To evaluate the combined effects of supply chain routes, pre-storage treatments (anolyte water, chlorinated water, hot water and Gum Arabic coating) and storage temperature in reducing microbial load of pink-matured tomatoes

- To determine the most suitable maturity stage that will retain optimum physical, physiological, and biochemical quality, hence extend tomato fruit shelf life during handling and storage.

4.6 Methodology

4.6.1 Experimental site

The experiment will take place at the Bioresources Engineering Laboratory of the University of KwaZulu-Natal; Pietermaritzburg Campus, Pietermaritzburg, KwaZulu-Natal, South Africa.

4.6.2 Experimental design

Experiment I

A factorial experiment with three supply chain routes (harvesting locations), three maturity stages, five pre-storage treatments, two storage conditions (temperatures) and three replications will be used in this study. The experimental design will be a randomized complete split-plot with supply chain routes and maturity stages being main and sub-plots, respectively. The design will take place in a factorial arrangement with three replicates of three fruit samples per each treatment. Three tomato samples will be taken randomly from each treatment group on each sampling day and analysed for different quality parameters. The number of tomato fruit samples to be used in this experiment will be 4050 (3 Supply chain routes × 3 Maturity stages × 2 Storage temperatures × 5 Treatments × 5 dates × 3 Replications × 3 Samples). The layout is tabulated below (Figure 4.1).

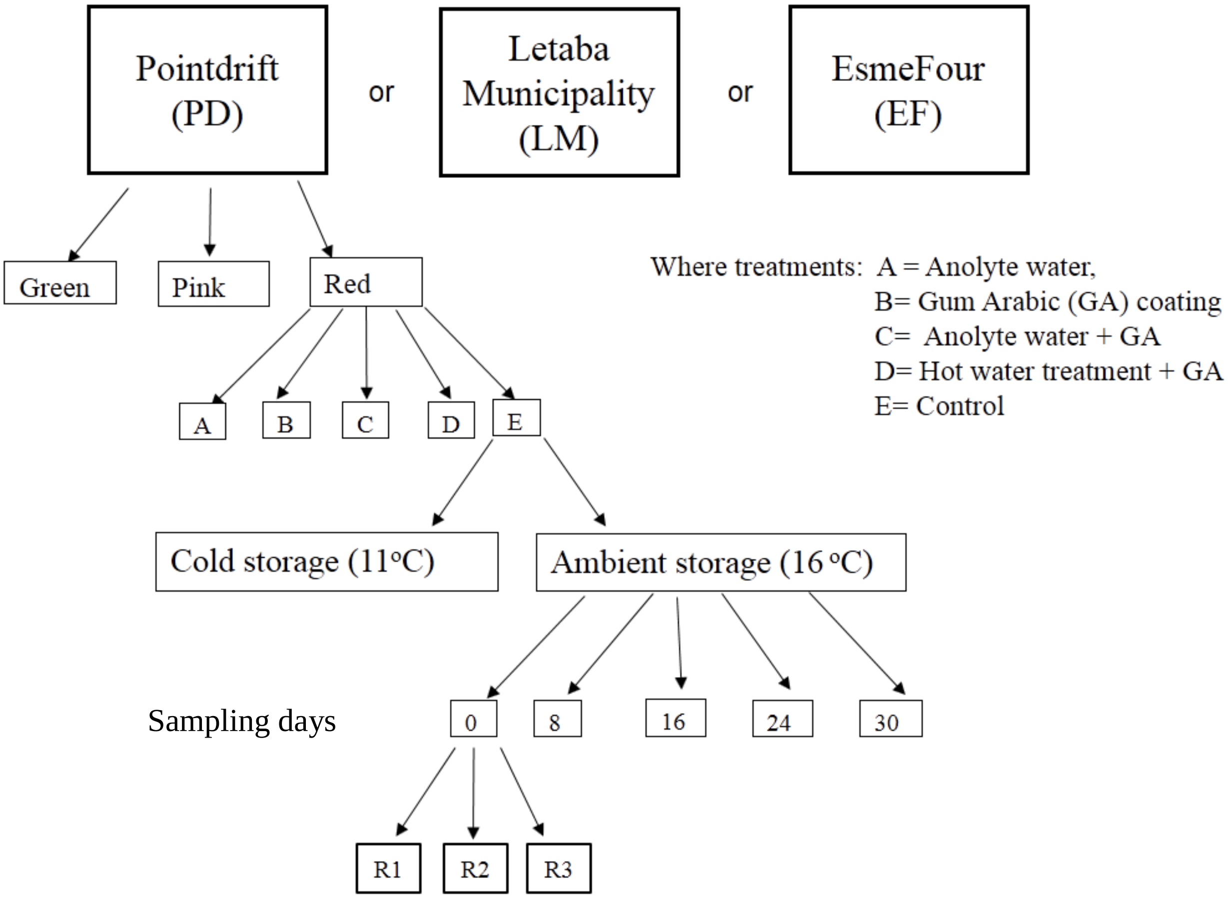

Figure 4.1 The effect of supply chain routes and pre-storage treatments in the physical, physiological and biochemical properties of stored tomatoes (Experiment I).

Experiment II

A factorial experiment with three harvesting locations, one maturity stage, five pre-storage treatments, two storage conditions (temperatures) and three replications will be used in this study. The experimental design will be a randomized complete block design (with supply chain routes as blocking factor) in a factorial arrangement with two fruit samples from each treatment. Three tomato samples will be taken randomly from each treatment on each sampling day and an assessment of microbial surface burden will be performed. The total of 180 fruit (2 fruits × 5 treatments × 3 Routes × 3 sampling days × 2 storage temperatures = 180 fruit) will be used for this experiment (Table 4.2). The findings will be determined by counting the number of colony forming units (CFU), where the most effective treatments will be noted by having reduced (low) number of colony forming units (CFU).

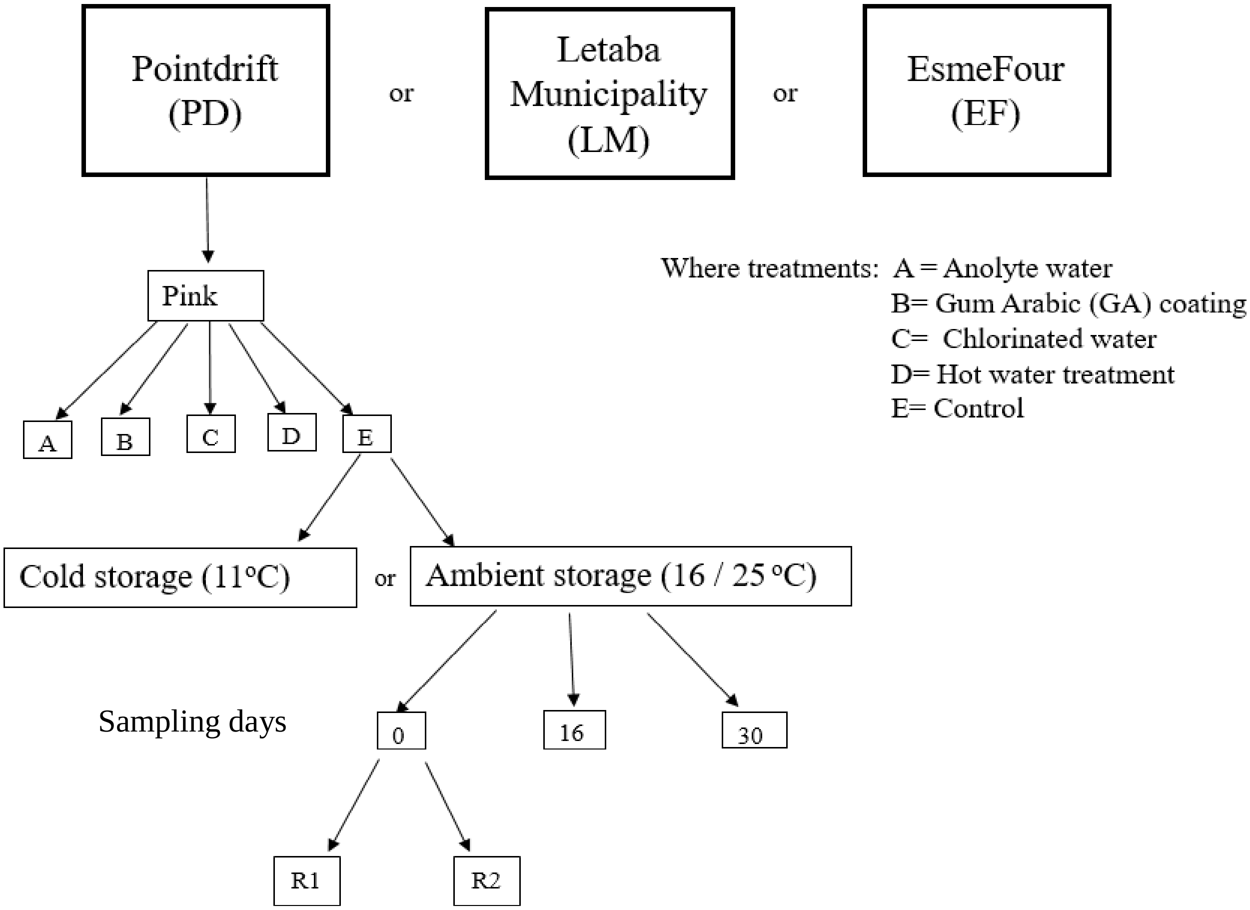

Figure 4.2 The effect of supply chain routes and pre-storage treatments in the microbiological quality of tomatoes (Experiment II).

4.6.3 Materials and methods

Experiment I

Tomatoes (cv. ‘Nemo-netta’ and ‘Topacio’) of three different maturity stages: green, pink and red will be harvested manually to reduce mechanical damage. Uniformity in colour and size will be ensured within each of the maturity stages to reduce experimental bias. Only fruits with freedom from blemishes will be selected to be used for experimentation, and fruits with any sort of mechanical injuries, defects, or bruises will be discarded. The selected fruits will be wiped thoroughly with a damp cloth to remove dust and surface dirt. They will then be divided according to treatments, weighed and treated as per the experimental design. The total of five treatments namely; anolyte water treatment, Gum Arabic (GA) (10% w/v) coating, the anolyte water and Gum Arabic, the combination of hot water treatment (HWT) (42 °C) and Gum Arabic and lastly, the control (untreated) will be used. The number of tomato fruit samples that will be used in this experiment will be 4050 (3 Harvesting sites × 3 Maturity stages × 2 Storage temperatures × 5 Treatments × 5 sampling dates × 3 Replications × 3 Samples). They will then be divided into two, half will be stored at ambient temperature (16°C) and another half will be stored at (11°C). Hobos will be kept on these storage conditions to monitor the temperature and relative humidity. Three tomato samples will be taken randomly from each treatment group on each sampling day and used for the different quality analyses. Quality analysis will start from non-destructive parameters including marketability percentage (%), colour, mass loss, respiration (CO_2 evolution) and then destructive parameters including; firmness, total soluble solids (TSS) and pH.

Experiment II

Tomatoes of pink maturity will be harvested manually to reduce mechanical injury. Only pink matured fruit will be selected for this study, and fruit from all the locations (supply chain routes), because this is the maturity stage that is preferable by the producers as in high demand (ZZ2, 2015). Uniformity in colour and size will be ensured to reduce experimental bias. Only fruits free from blemishes will be selected to be used for experimentation, and fruits with any sort of mechanical injuries, defects, or bruises will be discarded. The selected fruit will then be divided according to treatments, weighed and treated as per the experimental design. The total of five treatments will be used for this experiment namely; anolyte water treatment, chlorinated water (500 ppm) treatment, hot water treatment (42°C for 30 min), Gum Arabic (10% w/v) coating, and the control (untreated). They will then be divided, half will be stored at ambient temperature (16°C) and another half will be stored at (11°C). Temperature data loggers (hobos) will be kept on these storage conditions to monitor the temperature and relative humidity. The microbial analysis will be done during the first day of sampling (day 0) immediately after complete surface drying the treated fruits, during day 16 and during day 30 of sampling. Only two fruits will be used per treatment from ambient and cold rooms. The total of 180 fruit (2 fruits × 5 treatments × 3 Routes × 3 sampling days × 2 storage temperatures = 180 fruits) will be used for this experiment. Briefly, each pink-mature tomato sample will be weighed and washed with 30ml peptone water for 5mins. One millilitre of peptone water will then be pipetted into a test tube. Then decimal dilutions will be done up to the sixth test tube (consist of 0,-1,-2,-3,-4 and -5 dilutions). Plating will be done by pipetting 100µl of sample from each test tube, and plating will be duplicated, which will lead to 12 petri-dishes per fruit. Plating will be done and petri-dishes will be incubated at 28°C for 48 hours to allow colony formation. The findings will be determined by counting the number of colony forming units (CFU), where the most effective treatments will be noted by having reduced (low) numbers of colony forming units (CFU).

4.6.4 Data Collection

Assessment of tomato quality parameters will be done according to Table 4.1 below.

Table 4.1: Parameters for tomato quality assessment

Fruit properties	**Quality parameters**	**References**
Physical properties	Colour Firmness	-Dominguez *et al*., 2012 -Dominguez *et al*., 2012
Physiological properties	Respiration % Mass loss	-Dominguez *et al*., 2012 -Ali *et al*., 2010
Chemical properties	Total soluble acids pH Total phenolic content Antioxidant activity (FRAP & DPPH)	-Ali *et al*., 2010 -Nunes and Emond, 1999 -Singleton and Rossi, 1965 -Ali *et al*., 2013
Microbiological properties	Total microbial population (Colony forming units)	-Brackett, 1990

Physical properties

Colour

The colour of tomato fruits will be assessed in each fruit sample of each replicate. Colour of each individual fruit on the surface around the equatorial region (Arias *et al.* 2000) will be assessed. Tomato surface colour will be analysed by measuring a Hue angle (h°) with a Minolta Chroma meter (Minolta CR-300, Ramsey, NJ, USA) at two different points located in the equatorial area (Dominguez *et al*., 2012).

Firmness

Tomato firmness will be measured using a texture analyser (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 10N force at speed of 25 mm/min will be recorded.

Physiological properties

Respiration

The fruit respiration rate (CO_2 production per hour) will be measured during the storage period using the infrared gas analyser respirometer (EGM-4 Environmental Gas analyser, PP Systems, Massachusetts, USA as done by Dominguez *et al.,* (2012). Briefly, each fruit in four fruit per treatment will be weighed, volume measured (using displacement) and incubated for 15min, in a 1L jar. Then carbon dioxide (CO_2) emission will be measured using infrared gas analyser. Respiration rate will then be calculated by taking into consideration mass and volume of fruit, volume of the container, of CO_2 empty container and CO_2 after fruit incubation.

Weight loss percentage

Tomato samples will be 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 will be considered as the total weight loss during each storage interval. The weight loss percentage is then calculated on the initial weight (wet basis) using the method applied by AOAC (1984).

The weight loss percentage will be determined by using the following formula:

$$Weight\ loss(\%) = \frac{Initial\ weight - Final\ weight}{Initial\ weight} \times 100 \tag{4.1}$$

Chemical properties

Total soluble solids (TSS)

Total soluble solids will be determined by using the method used by Ali *et al.* (2010). Briefly, fruit juice will be extracted and filtered with the muslin cloth as per (Subramanian *et al.*, 2006). TSS of each fruit will then be measured by adding about three juice drops on the lens of a digital refractometer (Atago Palette- PR32, Tokyo, Japan) as determined by Ali *et al.* (2010).

Total phenolic content

The amount of total phenolic contents in tomato fruit will be determined by the Folin-Ciocalteau (FC) reagent procedure as determined by Singleton and Rossi (1965) with few modifications. Briefly, 0.1 ml of fruit sample in three fruits from each treatment will be mixed with 0.5 ml FC reagent long with 1.5 mL of 7% sodium carbonate solution. Distilled water is added to the solution to make the volume up to 10 mL. The mixture is then incubated at 40°C for 2 h, 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 are expressed in mg of Gallic acid equivalent to 100 g of fresh weight of fruit sample.

Antioxidant activity

There are many possible methods that may be used when measuring antioxidant activity of tomatoes, and they can be divided into two important groups. For efficient measurement of an antioxidant activity in tomatoes a method involving organic radical producers (such as ABTS, DPPH, DMPD or PLC) must be used. In addition to either of these named methods, the method using metal ions for oxidation must also be used (i.e. FRAP). Several authors do not confer reliability in only one method, and both groups should be considered for attaining the most precise results (Gómez-Romero *et al*., 2007). Therefore, in this study, DPPH and FRAP methods will be used as they have been shown to be reliable and efficient in measuring antioxidant activity of tomatoes (Ali *et al*., 2013).

FRAP assay

Ferric capacity in tomato fruit. Briefly, 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 a pH of 3.6 (Benzie and Strain, 1996). The reaction mixture consists of 40µL of fruit extract from each of 3 fruit per treatment mixed with 3 mL of FRAP reagent followed by incubation at 37 °C for 4 min. Absorbance will then be recorded at 593 nm using UV-VIS Spectrophotometer (Varioskan Flash Multimode Reader, Thermo Fisher Scientific, USA) and the results will be expressed as the concentration of antioxidant having a ferric reducing activity equivalent to 1 mg^{-1} g ferrous sulfate ($FeSO_4$) of fresh weight of fruit sample.

DPPH Assay

Total antioxidant capacity will also be 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^{-1} L of DPPH solution will be freshly prepared by dissolving in 100% (v/v) methanol. Cuvette will then be filled with 3mL of DPPH solution. Then 5µL of sample from each of 3 fruit in each treatment will be added into the cuvette and mixed well by using the pipette tip. The mixture will be left allowed to react for 15 min. The absorbance will then be 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 will be expressed as a percentage decrease with respect to the absorption value of reference DPPH solution. Reducing Antioxidant Power (FRAP) assay was used to measure the total antioxidant

4.6.5 Data analysis

Accumulated data will be analysed using Genstat® version 17. Statistically significant differences between the treatments will be determined by analysis of variance (ANOVA) with a Genstat® 14th Edition (VSN International), under 5% levels of significance. The Duncan's multiple range tests will be used to present significant difference between treatment means.

4.6.6 Resources

Table 4.2: Resources and equipment required for furthering this research

Resources and Equipment(s)	Application	Availability
Tomato samples	Experiment samples	Available commercially
Anolyte water	Pre-storage treatment	Available commercially
Gum Arabic (AEB AFRICA (PTY) LTD)	Pre-storage treatment	Available commercially
Colour analyser	Quality analysis	Available at UKZN and commercially
Firmness analyser	Quality analysis	Available at UKZN and commercially
Digital refractometer	Quality analysis	Available at UKZN and commercially
pH meter	Quality analysis	Available commercially
Cold storage unit	Postharvest treatment	Available at UKZN
Weighing scale	Quality analysis	Available at UKZN and commercially
Spectrophotometer	Quality analysis	Available at UKZN

4.6.7 Project Impact Assessment

Environmental considerations: the findings from this research will reduce the risk of food spoilage, since produce quality and shelf life will be extended. Integration of the pre-storage treatments and the well-known technologies such as low temperature storage will result in new economic, socio- and environmental friendly postharvest technology.

Economic considerations: findings from this study will present the efficiency of less expensive pre-storage treatments such as disinfectants and coating in maintaining quality and extending shelf life of tomatoes. Postharvest losses will be minimized through this research.

Health and safety considerations: the output of this study will describe the efficiency of pre-storage treatments which are non-toxic to human health, in maintaining fruit quality and extending shelf life. These include anolyte water, hot water (blanching), Gum Arabic (GA) coating, and their combinations. This research will provide a solution that will extend the shelf life of fresh produce beyond cooling and without interfering with human health.

Table 4.3: The proposed project plan

	2015									2016											
	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Literature review	■	■																			
Project proposal		■																			
Harvest one			■	■																	
Laboratory analysis				■	■																
Data capturing					■																
Data analysis																■					
Harvest two						■	■														
Laboratory analysis								■	■												
Data capturing									■												
Data analysis																■					
Thesis write up			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Submission 1st draft of full Review											■										
Submission 2nd draft of full Review													■								
Laboratory analysis													■	■	■						
Data capturing																■					
Data analysis																■	■				
Submission 1st draft																		■			
Corrections of 1st draft																			■		
Submission of final draft																				■	

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