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Mini Review

A review of the role of transportation on the quality changes of fresh tomatoes and their management in South Africa and other emerging markets

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Abstract

This review is a summary of emerging approaches in maintenance of tomato quality from a supply chain planning perspective in South Africa and other emerging markets. The review systematically covered all literature related to postharvest management of fresh tomato fruit quality in South Africa and selected African nations. It hinges discussions on the increasingly important part transportation conditions play in postharvest quality management of fresh tomato fruit in the current global environment, where fresh food supply chains are ever more vertically integrated and coordinated. The review established transportation as one of the important operations accounting for up to 20% of postharvest quality loss that occur in fresh tomato supply chains in Africa and other emerging economies. There is also limited literature on the mechanics and the driving factors of postharvest quality losses during long distance transportation of tomato fruits. The use of old approaches in logistical and supply chain planning where the experience of manages is relied upon increases uncertainty in the performance of these supply chains. The study recommends further research on the impact transportation conditions play in the loss of nutritive elements from fresh tomatoes. Multiple nutrient deterioration kinetics of tomato fruit can be integrated into robust planning models that can aid the supply of quality fresh tomatoes at competitive prices.

Introduction

Tomato *(Solanum Lycopersicum)* is the second most important vegetable globally after potato that is produced for its edible fruit (Mujtaba and Masud, 2014). In fresh forms, it is eaten as fruit salads, sandwiches and salsa, or processed into pastes, preserves, juices and soups (Mujtaba and Masud, 2014; Pinheiro *et al*., 2014). Many dishes are also prepared using tomato and therefore, its consumption in this way is interwoven into the culture of different communities, hence explaining its global appeal to meal preparation (Beckles, 2012). When ripe, it is rich in health promoting compounds that are thought to help prevent the occurrence of degenerative health conditions (Canene-Adams *et al*., 2005).

In south Africa, the tomato industry is one of the important components of the agricultural sector and a valuable contributor to the national gross domestic product (GDP) growth. In 2014, it contributed 24% of the national gross vegetable production and has experienced steady growth in terms of production throughout the last decade (NDA, 2015). It was projected that by the end of 2015, the industry was valued to be in excess of 160 million USD (NDA, 2015).

The growing urban population globally has necessitated the restructuring of food systems with localization of agricultural zones in areas that are far from markets (Louw *et al*., 2008). By the year 2050, it is projected that most of the world's population will reside in urban areas (Madlener and Sunak, 2011). Coupled with the underlying economies of scale in agricultural production, these factors have necessitated transportation of fresh produce over long distances to their markets (Ellis and Sumberg, 1998). This phenomenon will continue put pressure on existing food systems including supply chains and will necessitate efficient management of supply chains especially those of fresh foods including tomatoes.

The physiological nature of tomato fruit lends itself susceptible to a myriad of factors that could lead to appreciable loss in market value and quality during freight (Mujtaba and Masud, 2014). The level of postharvest losses of tomato in sub-Saharan Africa has been reported to be relatively higher than those recorded in developed economies (Sibomana *et al*., 2016). Although concrete data is unavailable, estimates peg postharvest tomato losses to be 10.1 and 10.2% in Kenya and South Africa respectively, and as high as 13.4% in Nigeria (Sibomana *et al.*,

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2016). In contrast, these losses have been reported by FAOSTAT (2015) to be 5, 4 and 5.5%, in Spain, Italy and USA, respectively. Poor infrastructure and lack of adequate investment in research has contributed to these losses. It has been particularly reported that a majority of tomato fruit losses occur during storage and transportation (Idah *et al*., 2007b). Environmental control during transport has been the key approach in maintaining fresh fruits and vegetables' (FFV) quality during their supply (Shewfelt and Prussia, 2009; Kubo, 2015). Temperature and humidity control for instance, has been used to develop standards necessary for tomato and other FFV for certain markets (Kader and Rolle, 2004). In this way, the product time and temperature history is a prerequisite for FFV products to be sold in these markets. Handling conditions during the transport of FFV, including product packaging are critical in management of their quality (Kader, 1984). The road quality during inland transport is also an important factor that can be targeted as a loss mitigating avenue for tomato fruit (Idah *et al*., 2007a).

The need to ensure sustainable food production necessitates the evaluation and implementation of possible strategies that can eliminate or minimize postharvest losses of tomato (Kader, 2004). This review is motivated by the increasingly interconnected agri-food supply networks within the commercial FFVs' global environment, with transportation playing a dominant role in the movement of tomato products and other fresh foods. Unlike other processing operations such as precooling or storage, transportation is one of the delicate operations in tomato supply chains. It contributes to relatively higher economic losses if postharvest losses occur, as it is the last mile to the market. A multi-pronged understanding of this critical operation from fruit physiology, rheological, logistical and supply chain planning perspective will give new insight into new areas of research that need to be explored to further improve efficiency of tomato supply chain networks in South Africa and other emerging markets. The study systematically reviewed all literature related to postharvest management of tomato quality in South Africa and selected African nations, with an emphasis on how transportation conditions leads to losses in quality. Logistical planning and distribution approaches were also reviewed as a means through which knowledge gained from research in quality changes of tomatoes can be integrated in supply chain planning models.

The structure of tomato supply chains in South Africa

Production

Tomato is cultivated in South Africa by both commercial and emerging farmers and is the second most important vegetable in terms of economic importance, just second after potato (Louw *et al.*, 2007; Munyeka, 2014). The South African tomato industry has shown steady growth over the last two decades, and by the end of 2014, the gross production stood at 566,180 million tons (DAFF, 2015).

Table 1. The contribution of South African provinces to national tomato production (Michael and Gundidza, 2012)

Province	Area planted as a % of the national
Limpopo	55
Mpumalanga	14
Eastern Cape	12
KwaZulu-Natal	10
North West	5
Western Cape	3
North West/Free state	1

The production of tomato in South Africa is done in almost all provinces, but Limpopo province (3,590 ha) is the major producer contributing approximately 75% of the total area covered by the crop (DAFF, 2013). Due to its relatively warm climate, it is estimated that Limpopo province contributes 60% of the total fresh tomato fruit grown in South Africa and about 45% of the annual turnover of Johannesburg's fresh produce market (FPM) (Munyeka, 2014). Table 1 shows a summary of the contribution of each province to the national tomato production as a percentage of the total cultivated area.

Commercial tomato production is carried out in all provinces except Gauteng (Michael and Gundidza, 2012), with the commercial sector contributing 95% of the total production and emerging growers contributing the remaining 5% (DAFF, 2013). The tomato industry in South Africa is characterized by concentrated supply chains that are dominated by large companies that organize and coordinate marketing and support services for the industry (Swinnen *et al*., 2013).

Market Size

South Africa is not a major tomato exporter, and therefore, nearly most of the national production goes to the domestic market while a small percentage goes to processing and export (DAFF, 2013). The South African national fresh produce market is the dominant sales outlet, and is generally considered as the preferred marketing avenue for fresh tomatoes and other FFV (DAFF, 2015). In South Africa, the main players in tomato supply chain and distribution are; producers, wholesalers, wholesale-retail, retailers and consumers (DAFF, 2015). In general, the distribution network flows from the producers to the consumers via a range of intermediaries. A detailed description of the South African tomato supply and distribution channels is given by Sibomana *et al.* (2016) and DAFF (2013).

The Limpopo province is clearly the most important producer of fresh tomato in South Africa. There is also evidence of a latent capacity for the expansion of production to target regional and international markets. Exploration of these markets would effectively imply the expansion of the market size of South African tomato industry hence bringing with it the benefits of increased jobs and improvement of rural incomes (Swinnen *et al.*, 2013). Exporting to regional and international markets would have transport as the dominant activity. An in-depth understanding of the effect of long distance transportation on the quality and shelf-life of tomato under South African conditions is, therefore, required in order to effectively export to these markets without incurring appreciable loss in quality. An emerging trend of higher profitability of exported fresh tomato products than products sold in domestic markets (DAFF, 2015) further makes this markets appealing to commercial producers.

Marketing and procurement structure

The South African tomato industry has a well-structured marketing system, the national FPMs being the dominant marketing outlet that producers and individual farmers use to sell their produce (DAFF, 2013). The FPMs have a brokers who sell volumes on a commission basis (DAFF, 2015). Sales also occur through retail chains such as supermarkets as well as informal markets (Sibomana *et al.*, 2016). Unlike other markets in the region such as Mozambique and Malawi, the South African fresh tomato marketing structure allows shorter marketing linkages with none or a minimal number of middlemen in the value chain (Mango *et al*., 2015). This helps deliver value to producers and consumers and avoid excessive price distortions. Although the average tomato prices/ton have been reported to be generally stable in South African domestic market (DAFF, 2015), fluctuation of prices have been reported across various sales outlets with time (Munyeka, 2014) due to variation in the marketing margins by various players in the value chain. Farm gate prices have been shown to the influence the retail prices far more than wholesale prices, hence their predictive power on retail prices (Munyeka, 2014). Although retailers have diverse fresh tomato procurement structures (Louw *et al.*, 2007), supermarkets and other large retail outlets mainly source their tomatoes from a small number of approved suppliers who have the required capital and procurement capacity necessary to meet all year round supply of the products, as well as capacity to comply with the stringent quality requirements (Louw *et al*., 2008). These suppliers enter into sourcing contracts with these retail brands (Louw *et al.,* 2008).

Logistical planning

Transport of tomato is typically from the growers through pack-houses by road using trucks to feed local retail outlets, processing plants or export points (DAFF, 2015). Fresh tomatoes have a short shelf-life and naturally, their quality starts declining immediately after harvest (Moneruzzaman *et al.*, 2009). It has been suggested that the perishability of fresh produce, including tomatoes are risk-loading factors that render these supply chains sensitive to logistical delays and general supply chain disruptions (Zuurbier, 1999). This therefore implies tight margins during their transportation and distribution necessitating good planning and coordination (Zuurbier, 1999). Market information, as well as production and logistical activities have to be well planned and coordinated. Although limited studies have been carried out on how tomato supply chains in South Africa and are managed from a planning and logistical perspective, it has been, however, reported that the tomato industry in South Africa is highly consolidated comparable to emerging markets in central Europe and Latin America (Louw *et al*., 2007). There is a high degree of concentration in processing, distribution and retailing activities compared to other markets in the region and the African continent (Greenberg, 2013). The supply chain activities are also vertically coordinated and integrated due to the increased presence of dominant growers and large retail and supermarket brands (Louw *et al.*, 2008). Vertical coordination is defined as the process of organizing a subsequent set of activities between one or more consumers, while vertical integration is the organization of one or more a stages under the management of a single company (Zuurbier, 1999). Vertical integration and coordination enables information relating to product quality, market dynamics and consumer feedback to flow seamlessly from one end of the supply chain to the other. This reduces risks and improves the efficiency of tomato supply chains. There are efforts by commercial growers to integrate emerging farmers into their supply chains by providing technical support systems and information sharing. Although product traceability is not well developed, after harvest, commercial growers are able to track products from the pack house to the market. The modes of transport by different actors have been discussed in detail by Sibomana *et al.* (2016). Commercial growers, marketing agents and retailers have information sharing tools that enable product tracking and traceability, availability of pricing and inventory information. Generic fresh fruit and vegetable supply chain models have also been developed by Ortmann (2005) that identifies and optimizes utilization of fresh fruit export transport, storage and cooling capacities in South Africa.

Important quality changes that occur during handling and transportation of tomatoes

Tomato is a climacteric fruit that gradually ripens even after harvest, when it has reached a certain maturity point (Rančić *et al.*, 2010). Ripening therefore, is the primary physiological process of importance during handling and transportation of tomato fruit. A ripe tomato fruit contains 93-95% water and 5-7.5% dry matter (Pangaribuan, 2005). Fructose and glucose are the main reducing sugars in tomato with concentrations ranging from 1-1.4%, and 0.93-1.2% of its fresh weight, respectively (Suárez *et al.*, 2008). The compositional nature of tomato makes it susceptible to water loss, decay, microbial attack and damage during transportation and storage. At the end of ripening, tomatoes reach their end of their physiological life and undergo senescence where the product becomes unmarketable. The short post-harvest life of tomato makes it highly perishable necessitating proper handling, coordinating and scheduling of transport activities.

The quality of fresh tomato fruit encompasses physical, nutritive, chemical and safety attributes (Tigist *et al.*, 2013). Some of the attributes that are related to consumer acceptance include texture, flavour, taste (sourness, sweetness) and juiciness, all of which are sensory aspects (Kader, 2002). The physical quality attributes of fresh tomato include firmness, colour, size, shape, and the fresh weight (Gierson and Kader, 1986). Some of the chemical characteristics include the sugar and acid content, while the nutritive parameters that are of importance in fresh tomatoes include vitamin and mineral content (Nasrin *et al.*, 2008). Bioactive compounds comprise of antioxidants (lycopene, β- and α-carotene), phenolic compounds and oxidized metabolites (Gil *et al.*, 2002; Moneruzzaman *et al.*, 2009). These attributes holistically influence the postharvest quality attributes and shelf-life of fresh tomatoes.

Physical quality changes

Colour is an important quality attribute that is used to assess the ripeness of tomato fruit and is an important parameter that influences the buying decisions of consumers (Francis, 1995). There are six maturity indices related to the external colour and the ripening stage of fresh tomatoes according to USDA classification (Choi *et al.*, 1995). These are the green, breaker, turning, pink, light-red and red maturity stages. In general, as the ripening process in tomato progresses, the colour changes from green to red. In the $L^*a^*b^*$ colour space, a^* values gradually increase from negative values with time when tomato reaches the breaker stage and gradually increases to positive values (turning stage) and stabilizes when they reach the light red stage signifying changes in colour from green to red (López Camelo and Gómez, 2004). The L^* (indicative of lightness) and b^* values decrease slightly as ripening approaches the terminal stages (Shewfelt *et al.,* 1988). The $(a^*/b^*)^2$ of tomato is used as an objective index of assessing its ripeness (Pathare *et al.*, 2013).

Light and temperature may influence the ripening index of tomato (Dumas *et al.*, 2003), whereby, screening light inhibits β-carotene synthesis while increased exposure to light increases β-carotene synthesis. Temperature influences colour development by stimulating plastid development at temperatures above 12°C and below 30°C (López Camelo and Gómez, 2004).

The size, shape and weight of tomato at harvest are attributes that are primarily related to the genetic traits of a particular cultivar, and in some instances pre-harvest conditions (Díez and Nuez, 2008). For instance, there are cherry type cultivars, round shaped, pear shaped, plump type, pear oval, pear-elongated, small or large sized tomatoes.

During ripening and maturation, fresh tomato is characterized by changes in its shape and size albeit modest. Shrivelling of tomato fruit occurs as it approaches senescence, and is accompanied by loss of weight due to respiration and water loss (Guo *et al.*, 2014). Changes in shape and size are also accompanied by loss of fruit firmness due to the breakdown of cellulose, pectin and lignin by pectinesterases (PE), polygalacturonase (PG) and β-galacturose (β-gal) in the cell wall (Tigist *et al.*, 2013).The action of these enzymes has significant ramifications on the product's texture, and generally results in mealiness, an attribute that is undesirable to consumers (Tigist *et al.*, 2013). Shrivelled and mealy products loose their market value and consumer appeal. Excessive water loss, respiration and loss of firmness should be managed using appropriate postharvest handling practices to maintain the product quality during transportation, distribution and storage of tomatoes.

Chemical quality changes

Organic acids and soluble sugars are the major components of soluble solids in fresh tomato, and their relative amounts vary depending on the tomato cultivar (Tigist *et al*., 2013). The balance of sugars and acids influences the flavour of fresh tomato fruit. In general, the acid content of tomatoes under normal storage conditions decreases with storage time. Tigist *et al.* (2013) reported that the average acid content of 8 tomato varieties during storage to range from 0.25% at the end of storage, to 0.89% at harvest. Sugars have been reported by Betancourt *et al*. (1977) to initially increase under normal storage conditions and are later used up for growth and terminal metabolic processes (Beckles, 2012). The storage temperature is a significant factor affecting the accumulation of sugars in tomato, with low temperature favouring the accumulation of soluble sugars than higher temperatures (Beckles, 2012). Maul *et al.* (2000) reported glucose levels to be significantly higher in tomato samples stored at 5°C compared to those stored at 12°C and 20°C, while fructose levels and sucrose equivalents were considerably higher in tomato samples stored at 5°C and 10°C compared to those stored at higher temperatures (Beckles, 2012).

Nutritive quality changes

Ascorbic acid (AA) is one of the most important quality attributes in fresh fruits and vegetables. AA content of fresh tomato has been reported to range from 14.6 to 21.7 mg per 100g (Tigist *et al*., 2013). Toor and Savage (2006) also reported AA content of 9.29 to 15.08 per 100 g, and observed a slight increase in AA mid-storage time, followed by a decrease as the fruit approached senescence. In general, minerals and vitamins (apart from vitamin C) are relatively trace and are not aspects that are often assessed as significant contributors to the nutritional quality of fresh market tomatoes (Heuvelink, 2005).

Changes in bioactive compounds

Tomato fruit is rich in lycopene, a bioactive compound that is known to have numerous disease prevention and immune boosting benefits on human health (Brandt *et al*., 2006). Lycopene biosynthesis and accumulation is a genetically controlled process that causes its accumulation to increase under normal storage conditions with storage time, and peaks before senescence. Lycopene is produced through genetically controlled biosynthetic pathways and accumulates following increased expression of hp and ogc genes (Brandt *et al*., 2006). It is synthesized from phytoene, and through the central isoprenoid pathway, four desaturation steps generate lycopene (Liu *et al.,* 2012). Lycopene accumulation in tomato fruit is primarily dependent on prevailing light intensity and temperature conditions (Toor and Savage, 2006), with higher temperatures favouring its accumulation than lower temperatures. Heat treatments on tomato also affect lycopene accumulation. Soto-Zamora *et al.* (2005) and Tucker *et al*. (2007) discussed some of the approaches through which lycopene can be enhanced in fresh tomato. Phenolic content, just like lycopene, has important antioxidant properties in tomato. The accumulation of phenolics in tomato is commonly induced as a response to wounding and serves as a defence mechanism that brings about the accumulation of secondary metabolites (Antunes *et al.*, 2013). Phenolics also have a protective effect on AA content of tomato during storage. Flavonoids are some of the other important phenolics in tomato and are also affected by storage temperature. The factors that control the accumulation of phenolics and other antioxidants in fresh tomato have been discussed in detail by Antunes *et al.* (2013).

Changes in sensory quality

The flavour and aroma of tomato fruit are important customer acceptability traits (Shewfelt, 1999). Amino acids, soluble sugars, pigments and over 400 aroma compounds produce the characteristic tomato flavour (Yilmaz, 2001; Díaz de León-Sánchez *et al.*, 2009). Commercial harvesting conditions as well as postharvest handling practices have a significant effect on the taste of fresh market tomatoes (Maul *et al*., 2000), since these conditions often cause injuries that induce early ripening resulting in qualitative and quantitative changes that alter the product's aroma profile and flavour (Moretti *et al*., 2002). Maul *et al*. (2000) reported that tomato aroma and flavour is significantly affected by low temperatures and long storage durations, with such products exhibiting low tomato flavour and ripe aroma. Poor tomato flavour has been one of the prevalent consumer complaints that is especially commonly encountered in tomato sourced through commercial supply chains (Díaz de León-Sánchez *et al*., 2009).

The postharvest quality of fresh produce is essential to both distributors and consumers as it determines its freshness, shelf-life and the keeping quality. The postharvest quality indicators of fresh tomato are strongly linked to its ripening, a dominant process that occurs during transportation and storage. Due to the perishable nature of tomato fruit, postharvest handling practices and transportation conditions have to be cognizant of these changes to ensure that products are transported to distant market without appreciable loss in quality.

Contribution of transportation to postharvest quality losses of fresh tomato

The composition and structural configuration of tomatoes make them susceptible to mechanical damage and injuries that trigger physiological, chemical and microbial changes that lead to loss in quality. Although it is difficult to quantify the magnitude of losses during transportation of tomatoes, developing countries have generally recorded higher transportation losses than developed nations (Arah *et al*., 2015). Some countries in Africa have reported tomato transportation losses that are as high as 20% (Aba *et al.*, 2012).

The primary factors that contribute to changes in tomato fruit quality during transportation relate to the environmental conditions surrounding the product during transport, physiological and mechanical properties of the fruit, the degree of roughness of the road surface, the vehicle characteristics, characteristics of the packaging units, transit time and distance (Vursavuş and Ozgüven, 2004; Aba *et al*., 2012).

During transportation, tomatoes are often subjected to rough handling and transported over rough roads leading to mechanical injuries and damage hence loss of value as the products move through the supply chains (Idah *et al.*, 2007b; Mutari and Debbie, 2011). Transport bottlenecks and delays occasioned by poor road quality, weather and poor coordination of transport operations can cause further losses especially if the products are held in collection points that do not have cooling facilities (Njenga, 2015). Tomato fruits continually function physiologically on transit and these physiological functions lead to quality deterioration during transport especially in high temperature and low relative humidity conditions (Mashau *et al.,* 2012). Long transit times and poor temperature management during transportation of tomatoes are also important factors that can cause accelerated metabolic and enzymatic processes leading to loss in market value and increased risk of mechanical damage (Vursavuş and Ozgüven, 2004). Bruised tomatoes provide entry wounds for spoilage and pathogenic microorganisms to infect these sites or internalize in the intact tissues (Çakmak *et al*., 2010; Mutari and Debbie, 2011). The effect of this is not only economic losses but also risks that can lead to health problems associated with the consumption of contaminated tomato products.

Mechanical damage and bruising of tomatoes during transportation is due to a variety of forces subjected to the fruits during freight which include: vibrational, abrasive forces, impact, compressional and cutting forces (Çakmak *et al.*, 2010; Aba *et al.,* 2012). During transportation, vibrational forces from the vehicle due to abrupt changes in the road profile causes the fruit to move randomly within the packaging units and depending on the intensity, direction and duration of the displacement, these forces may reach thresholds that cause damage hence loss of quality (Çakmak *et al*., 2010). Vibration also causes tomato fruit to rotate and rub against the surfaces of other fruit and packaging units causing abrasion, bruising and softening (Çakmak *et al*., 2010; Aba *et al.*, 2012). Cuts can occur when the fruit is pushed or rotated onto the sharp edges of packaging units (Çakmak *et al.,* 2010). The level of damage caused by vibration on tomato fruit is linked to the frequency, amplitude and the duration of vibrational force (Vursavuş and Ozgüven, 2004) as these parameters influence the amount of energy available to cause damage (Idah *et al*., 2007a).

Vibration bruising and abrasion damage causes increased fruit moisture loss, discolouration and wounding (Mutari and Debbie, 2011). Fruit injuries have been known to trigger heightened metabolic processes that accelerate deterioration in quality and reduction in shelf-life (Mutari and Debbie, 2011; Mashau *et al.*, 2012). Bruised tissues suffer from enzymatic breakdown of affected areas including cell walls leading to rapid degradation of cell wall polysaccharides (Li *et al*., 2010). The result of this breakdown is notably softened spots on the fruit surface (Li *et al.*, 2010). Overloading fruit in wooden crates further causes excessive compressive stresses to the fruit at the bottom leading to deformation as well as accumulation of field and respiration heat, resulting in significant losses (Arah *et al.,* 2015). Studies by Çakmak *et al*. (2010) have reported high degree of mechanical damage in products that were transported through highways than rough roads due to high acceleration and long transportation time. It has also been shown that an increase in the transportation distance increases the proportion of fruit damaged during freight (Vursavuş and Ozgüven, 2004). Mutari and Debbie (2011) in a study that simulated the damage on tomato fruit due to different transportation conditions observed that damaged fruit produced higher ethylene content, had higher respiration and weight loss compared to undamaged fruit. Damaged fruit also recorded significantly lower firmness values compared to undamaged fruit. They attributed this observation to the increased metabolic processes in damaged fruit leading to water loss and hence the loss of turgidity by the cells resulting in their collapse when pressure is applied. They recommended maintenance of cold chain during transportation and cushioning packaging units. The varietal response and effect of fruit maturity at harvest on damage response was also recommended as aspects of the experiment that needed further research. There also needs to be further research on the effect of fruit shape on the bruise susceptibility of tomato fruit (Li *et al*., 2010).

The internal structure of tomato fruit has also been shown by Li *et al*. (2010) to be a factor influencing the mechanical damage susceptibility of the fruit. Although the mechanism through which internal locular structure effects bruise susceptibility was not established, it was observed that four locular tomato fruits had a significant effect on the degree of mechanical damage, while three locular fruit had no significant effect (Li *et al*., 2010). Other studies have also shown that the level of mechanical damage depends on the maturity at harvest with red-ripe tomatoes being more susceptible to damage than green fruit (Arah *et al*., 2015).

The effect of mechanical damage on ascorbic acid (AA) content of tomato has shown that bruised tomatoes have lower AA content than undamaged tomatoes (Moretti *et al*., 1998; Aba *et al*., 2012). However, a similar study by Sablani *et al.* (2006) reported inconclusive observations. There is therefore the need for further research on the effect of various transportation conditions, on the chemical and nutritional quality of tomato fruit.

Impact of packaging materials and handling conditions during transportation of tomatoes

During transportation of tomatoes, good packaging units should cushion the products against deformation and bruising, offer protection against moisture loss, pathogens, predators and insulation from extreme temperatures (Arah *et al*., 2015). Packaging units are also important for containment of tomato fruit, they offer structural support, hence are important agents through which product damage can be mitigated during transportation. Unsuitable packaging materials have been identified as one of the key contributors of mechanical damage on tomatoes during transportation (Idah *et al.*, 2007b; Li *et al.*, 2010).

The configuration and properties of the material surfaces that are used to package tomatoes are particularly important since they transmit the forces from the road-vehicle system to the fruit. Baskets woven from palm and jute bags have been reported to be the common packaging units used for long distance transportation of tomatoes to markets in Nigeria, where they also double up as a pricing units (Idah *et al*., 2007b; Çakmak *et al.*, 2010). Some studies have also reported that wooden crates and woven baskets are the commonly used packaging materials used to transport tomatoes in Africa (Arah *et al*., 2015). However, it has been established that they have poor ventilation and this has been reckoned to be the cause of decay and other forms of tomato spoilage (Idah *et al.*, 2007b; Çakmak *et al*., 2010). Fruit cushioning from vibrations by these packaging units has also been reported to be poor leading to high incidences of mechanical damage. It has been shown that the position of tomatoes in the packaging unit also affects the degree of mechanical damage on the fruit (Çakmak *et al*., 2010; Aba *et al.*, 2012). Fruit positioned at the top layer in bulk bins suffered more damage due to relatively higher vibrational energy they receive causing them to rotate and impact on each other (Vursavuş and Ozgüven, 2004). A study by Aba *et al.* (2012) that simulated the intensity of vibration and degree of damage on tomato fruits in a plastic container and traditional woven basket, showed severe damage on fruit located at the bottom and the sides of the traditional basket. On the other hand, damage on the fruits was localized near the upper surface of plastic basket. Studies that compared the degree of protection offered by different packaging units to various fresh fruits such as apples and figs have shown the importance of vibration transmissivity by these units (Vursavuş and Ozgüven, 2004; Çakmak *et al.*, 2010). In a study by Aba *et al.* (2012), traditional woven palm basket showed a higher vibration transmissivity of 0.22 g compared to plastic basket that recorded 0.20 g. The fruit in traditional basket had significantly higher bruise dimensions that those in the plastic basket (Aba *et al.*, 2012). In addition to damage, packaging materials made from woven palm material and lined with grass can potentially cause transmission of microbial contaminants to the fruit (Ofor *et al.*, 2009). Hard and rigid materials such as wooden crates have been reported to have a high vibrational transmissivity hence causing more damage than other materials (Vursavuş and Ozgüven, 2004).

The type of surface of the packaging units, particularly its hardness affects the degree of damage on tomato fruit during transportation. A study by (Idah *et al*., 2007a) where damage on tomatoes was simulated by dropping fruit onto wood, metal, foam, plastic and cardboard surfaces showed that fruit dropped on wood, metal and plastic surfaces suffered severe damage while foam inflicted the least damage. The information from the study is particularly useful for designers of packaging units of tomatoes and other fresh fruits.

Rough handling during transportation of tomatoes, including subjecting fruit to drop heights exceeding 1.4 m when transferring produce from containers have been shown to be a one of the causes of mechanical damage to tomato fruit (Idah *et al*.,

Figure 1. A Pictorial view of various packaging materials used in South African tomato industry. Cardboard boxes (A) are commonly used by commercial and emerging growers for transporting fruit to the retail markets. Bulk bins (B) are used by commercial growers to transport fruit from the field to pack houses. Plastic crates (C) are used during harvesting by commercial growers (see B) and transportation of fruit from the farm to pack houses by emerging farmers. Wooden crates (D) were previously used by emerging farmers to transport tomato fruit to the market.

2007a; Mutari and Debbie, 2011). Processes in pack houses and other bulk handling units should therefore be cognisant of this. Analysis of the movement of fruit during pack house operations using TuberLogs® could provide valuable information on the areas where excessive dropping of tomatoes may be occurring.

In South African tomato supply chains, fruit is commonly transported using plastic bulk bins, plastic crates and recyclable carton boxes. Some of these packaging units are shown in Figure 1. Some emerging farmers still use wooden crates to transport tomatoes. There is, however, need to assess the level of damage these packaging units inflict on tomato fruit and pursue avenues of redesign or suggest new materials in order to minimize fruit damage. Tomatoes in South African supply chains are typically transported in bulk bins using tractors and trucks to pack houses where they are pre-cooled prior to processing. After processing, the graded and packed tomatoes, typically in boxes, are transported in non-refrigerated trucks to marketing points (commonly fresh produce markets) or supermarkets and other retail outlets. The road networks are typically rough roads in and around the farms. Major roads commonly termed as national roads, connect the pack houses to their markets. Commercial farmers typically use larger trucks compared to emerging farmers who

Figure 2. Transportation of tomatoes by a commercial producer in South Africa through a farm road (A), with B depicting hired trucks used by emerging farmers. C shows a wooden crate and grass used as cushioning material during transportation of tomato fruit in Tanzania (Njenga, 2015), while D shows the poor road infrastructure and some of the transport systems used by farmers in Kenya to transport produce (Njenga, 2015).

commonly use hired trucks. The South African tomato transportation practices and infrastructure compares well to the systems used in many developed countries bar the transportation in non-refrigerated conditions. Other African countries however, use poor packaging materials and have poor road infrastructure leading to considerably high postharvest losses. A comparison of some of the transportation infrastructure and packaging materials used in South Africa and other African nations are shown in Figure 2. Under South African conditions, transportation is done over long distances due to centralization of production zones in the northern parts of the country. This makes transportation a critical operation in South African tomato supply chains.

Emerging trends in postharvest quality management of fresh tomato in South African supply chains

Packaging of tomatoes prior to transportation as previously discussed, not only facilitates handling but also protects them from physical, mechanical as well as other agents of damage. Other processing operations prior to freight also play a critical role in ensuring quality standards are met and go a long way in improving the shelf-life of tomatoes delivered to different markets. Pre-cooling for instance, ensures that field heat and heat due to fruit respiration is removed from tomatoes after harvesting, before they are packaged and transported. Pre-cooling of tomatoes and other FFV is a discipline of study on its own and cannot be exhaustively discussed in the present review but its importance is worth mentioning nonetheless (Cherono *et al*., 2017). Disinfection of tomatoes is also important for the reduction of microbial population on fruit surfaces to levels that are safe for human consumption. Storage practices that maintain the cold chain, scrub excessive accumulation of ethylene and control gaseous composition are some of the other important practices prior to transportation that determine the quality of tomatoes received downstream the supply chain. These handling and processing operations prior to tomato transportation are in no way exhaustive and will vary depending on the supply chain in question. It is however, important to note that regardless of the careful planning and excellent execution transportation operations in tomato supply chains, these pre-transportation operations also contribute to the overall quality of fresh tomatoes when they reach the market.

The extension of shelf-life of fresh tomato has been intensively researched in a bid to enable transportation of high quality fresh tomato fruit to distant markets. Advances in the understanding of the physiology of tomato ripening and the underlying biochemical, chemical and genetic signals that control this process have yielded various approaches that enable the maintenance of tomato quality over reasonably long periods of time. The following sections present a summary of the some of the recent technologies that are currently in use.

Biotechnological and biocontrol approaches

The commercial control of tomato ripening has been realized through the careful selection of slow or early ripening varieties (Matas *et al*., 2009). Targeting of some of the complex network of transcriptional factors that control ripening due to new insights in genetic engineering, has proven to be a promising approach towards addressing issues associated with the quality and shelf-life of tomato fruit (Matas *et al*., 2009). However, some of the commercial transgenic tomato varieties have altered nutrient composition, flavour, genetic instability and undesirable texture as a result of incomplete ripening (Matas *et al*., 2009). Intellectual property (IP) restrictions, negative consumer attitudes, health and environmental concerns have limited the commercial application of these technologies (Falk *et al*., 2002; Matas *et al*., 2009; Siddiqui *et al*., 2014). The long-term safety of genetically engineered tomato and a myriad of regulatory hurdles (Redenbaugh *et al*., 1993; Falk *et al*., 2002) further complicates its adoption. Direct methods of managing, for instance, the effect of exogenous ethylene during transport of tomato using ethylene scrubbers, or ozone lamps in cold storage units may be a more practical approach for commercial entities.

Research in the use of biocontrol agents as microbial antagonists that competitively control yeasts and bacterial contamination in tomato is still at its infancy South Africa, and its application in commercial set-ups is yet to be tested. However, biocontrol agents such as B-13 have been commercially successful in controlling a broad range of microbial pathogens in citrus (Liu *et al*., 2010). Some of these biocontrol products have been registered for use in controlling a range of postharvest spoilage agents in South African citrus industry.

Surface disinfection

Surface decontamination using different sanitizing agents, thermal and radiative sources not only reduces the microbial burden that often causes spoilage, but also removes pests and insects from the fruits, and, in turn improves the postharvest shelf-life of fresh tomato fruit (Venta *et al*., 2010). Hot water, chlorine and trisodium phosphate, are some of the oldest sanitizing agents that have shown varied success in the control of microbial contamination and decay in fresh tomato (Sapers and Jones, 2006; Chaidez *et al*., 2007). Surface sanitizers are generally regarded as effective if they can reduce the microbial load on tomato fruit surface by at least 2 log CFU/g (Chaidez *et al*., 2007).

Ozonated water has been tested as an alternative to chlorine that is perceived to have environmental and health concerns (Chaidez *et al*., 2007; Venta *et al*., 2010). The study by Chaidez *et al.* (2007) compared the efficacy of using chlorinated and ozonated water, using two application methods to decontaminate inoculated *Salmonella* on tomato fruit surface. Spraying achieved comparable results of 2.5-3 log CFU/g reduction for both methods, while immersion of tomato in ozonated water achieved lower reductions compared to immersion in chlorinated water. Venta *et al.* (2010) reported that ozone treated fruits were firmer and had less weight loss compared to the control group after 16 days of storage. Tzortzakis *et al*. (2007) also demonstrated that low-level ozone atmospheric environment in cold storage of tomato is capable of not only preventing disease onset and proliferation, but also maintaining fruit quality especially in terms of firmness and taste. The use of electrolyzed water has been reported by Islam *et al*. (2015) and (Deza *et al*., 2003) to be useful in decontamination of *E.coli* from tomato to levels of <1 log CFU/g. Other recently assessed chemical sanitizers include chlorine dioxide, bromine, iodine, acids and quaternary ammonium compounds (Goodburn and Wallace, 2013). Although research has shown that ozone treatment is an effective surface disinfectant, scrubs ethylene and induces fruit defences, its use has been limited to a few large tomato producers in South Africa.

Pulsed light (Aguiló-Aguayo *et al*., 2013), ultrasound Brilhante São José and Dantas Vanetti (2012) sonic treatment (Gündüz *et al*., 2010), UV and gamma radiation (Mukhopadhyay *et al*., 2013; Mukhopadhyay *et al.*, 2015) are some of the emerging surface disinfection methods attempted on fresh tomato that have achieved varied levels of success. Most of these treatments are yet to be adopted in South African tomato industry.

Anolyte water has been established by Workneh *et al*. (2012) as a novel disinfectant on tomato, but there is need to further integrate it with other pre-storage treatments to improve its efficacy. There is need to also develop and test suitable application technologies that can enable it to be adopted by the tomato industry.

Edible coatings

Edible coatings play the dual role of improving the shelf-life of tomatoes and other fresh fruits by modifying the atmosphere around the products hence reducing respiration, water loss, as well as preserving their texture (Dávila-Aviña *et al.*, 2014). In some cases, edible coatings exert antimicrobial effects (Dávila-Aviña *et al*., 2014). This area has recently received considerable attention due to the environmental friendliness of the technology and accrued health benefits it passes on to consumers. Some of the edible coatings that have been investigated on tomato include mineral and carnauba oil (Dávila-Aviña *et al*., 2014), chitosan (Ramos-García *et al*., 2012), essential oils (Sivakumar and Bautista-Banos, 2014), bee wax (Fagundes *et al.*, 2014) and gum Arabic (Ali *et al*., 2013). These publications depict surface coats as a viable alternative to some of the chemical treatments that present environmental and health concerns. In South Africa, edible coatings have been extensively investigated by Bill *et al.* (2014) and have shown potential in controlling postharvest diseases in avocado. However, the use of edible coatings is yet to be adopted by the South African tomato industry.

Packaging

Tomato packaging is one of the principal means of extending its shelf-life. Packaging materials have barrier properties on foods that control the rate at which low molecular compounds enter and leave the package (Muratore *et al*., 2005). Extension of tomato shelf-life can be achieved through ripening retardation by sealing the produce in packaging films that alter the gas composition around them with time, and is termed as modified atmosphere packaging (MAP) (Ali and Thompson, 1998). MAP results in an increase in CO_2 concentration and the reduction in O_2 inside the fruit packaging, hence reducing respiration, resulting in a reduction in the rate of fruit softening (Ali and Thompson, 1998; Workneh *et al.*, 2009). Ali and Thompson (1998) showed that tomatoes packaged in plastic films softened at a lower rate, had lower weight loss and decay, compared to the control. The treated samples, however, had comparable colour to the control group and did not exhibit negative physiological attributes during storage. Similar observations have also been reported by Workneh *et al*. (2012).

The use of biodegradable biofilms has recently generated interest due to their sustainability, suitability and the accrued antimicrobial properties as opposed to synthetic materials (Muratore *et al*., 2005). Active biofilm packaging has also been reported by García-García *et al.* (2013) to actively absorb ethylene and reduce tomato fruit ripening. MAP with cold storage can significantly increase the shelf-life of tomato making its transport to distant markets possible (García-García *et al*., 2013). MAP packaging, however, has to be designed to achieve required modified atmospheric (RMA) gas composition to meet these objectives, often a difficult target to achieve. Low density polyethylene (LDPE), polyvinyl chloride (PVC) and polypropylene are some of the MAP packaging materials commonly used (Kantola and Helén, 2001).

Controlled atmosphere (CA) can also be used to extend the shelf-life of tomato, whereby, systems continually monitor and adjust the gas composition surrounding the products to optimal levels (Gorris and Peppelenbos, 1992). This system is, however, used in bulk storage of valuable fresh fruits as it is expensive to set up, run and maintain. The use of vacuum packaging with refrigeration has also been suggested by Gorris and Peppelenbos (1992).

Temperature and humidity control

Humidity and temperature control are the most common approaches used to extend the shelf-life of fresh tomatoes in South African supply chains. Low-temperature storage is widely used since higher temperatures increase fruit respiration and shortens their shelf-life (Pinheiro *et al.*, 2014). The storage temperature of fresh tomato fruit depends on the maturity stage and cultivar (Medeiros *et al.*, 2012; Pinheiro *et al*., 2013; Pinheiro *et al.*, 2014). It has been generally known that temperatures lower than 13°C induce chilling injury in tomato (McDonald *et al*., 1999).

Pinheiro *et al*. (2013) showed that the kinetics of tomato quality degradation greatly depended on storage temperature and duration. High temperature, low RH and extended storage conditions lead to the loss of valuable nutrients in tomatoes, especially vitamins (Sablani *et al*., 2006). It is widely accepted that vitamin C is the most thermo-sensitive nutrient compound in tomato fruit and shows a gradual decrease with increase in storage temperature (Sablani *et al*., 2006).

Alternative cooling systems in South Africa are being developed such as evaporative cooling systems for use off the grid. Combination of these cooling systems with other postharvest preservation technologies has proved successful. Such studies have been reported by Workneh *et al.* (2009).

Integrated postharvest management approaches

Integrated postharvest technology harnesses the synergy from a series of treatments that are beneficial to the postharvest shelf-life of a product. Treatment combinations of packaging (e.g. MAP, CA etc.), temperature and humidity control, surface decontamination, application of genetic and hormonal control technologies and surface coats with edible coatings may be used as a set of integrated post-harvest treatments (Workneh *et al*., 2012; Mukhopadhyay *et al*., 2015).

Integrated postharvest treatments have shown remarkable success in their application to retard quality loss in tomato (Ali *et al.,* 2004). For instance, 1-Methylcyclopropene (1-MCP) and MAP compared to either treatment alone were reported by Sabir and Agar (2011) to significantly reduce weight loss, maintain colour, firmness and lycopene content of pink and red tomato fruit for up to 21 days. Workneh *et al.* (2009) also reported that MAP and storage temperature control using evaporative cooling, reduced weight loss and the rate of ripening of stored tomatoes resulting in a significant improvement of its marketability. This emerging research niche still has potential, especially in cases where novel environmentally friendly treatments that confer health benefits to consumers are used (Stevens *et al.*, 1997).

Modelling approaches in tomato supply chain planning

Tomato supply chains have become increasingly complex due to integration of FFV value chains into national, regional and international sourcing networks. The perishable nature of tomato fruit that makes its shelf-life short, constraints in the utilization of available resources and uncertainties associated with the management and supply of fruit to distant market makes conventional planning methods that rely on past experiences unreliable (Ahumada and Villalobos, 2011). For this reason, it has been particularly reported that the transportation phase during the supply of fresh foods generates the highest amount of waste due to sub-optimal handling and storage leading to appreciable deterioration in quality (Shukla and Jharkharia, 2013). The need for quality fresh tomatoes to reach distant markets further makes planning models important tools in fresh food supply chains.

Models in supply chain planning can be used to aid strategic, tactical or operational decisions. A review by Ahumada and Villalobos (2009) gives a detailed classification of models used for planning agri-food supply chains. Similar work has been also done more recently by Shukla and Jharkharia (2013). Some of the key objectives of supply chain planning are: to reduce production and operational costs, achieve improved food quality, reduce food waste and increase sustainability of fresh food supply chains (Soysal *et al*., 2012). Supply chain models are therefore, designed with the goal in mind.

An overview of the use of planning models in tomato supply chains

The use of planning models in tactical operations including harvesting, transportation and distribution of fresh produce has received considerable attention recently. The main goal of a majority of these models is to maximize profits through efficient use of resources, reduction of operating costs and maximum utilization of existing capacity (Ahumada and Villalobos, 2011). For instance, the work by Osvald and Stirn (2008) that employed a model for distribution of vegetables reduced associated costs by 27% by minimizing the distribution costs of vehicles used and distances travelled while minimizing quality loss. The loss in quality was represented by a linear function that was related to the time the products spent on the road during transportation, where product colour was used as a surrogate used to assess the overall quality of tomato, and constraints of acceptable quality by consumers imposed based on this parameter. The model enabled selection of the best means of transport with the least loss in quality, minimum costs and the least delivery time. This model was formulated as a mixed integer program (MIP) and implemented in CPLEX® solver. Most of the planning models are also aimed at ensuring timely delivery of fresh produce based on deterministic assumptions and demand that does not incorporate uncertainty (Ahumada *et al.*, 2012; Soysal *et al.*, 2012). There has been increased interest in planning models that incorporate uncertainty since a majority of real-life scenarios involve uncertain weather conditions, yield, demand and product prices (Soysal *et al.*, 2012). Some of the planning models have incorporated uncertainty in crop yields and market prices (Soysal *et al.*, 2012), uncertain juice acidity parameters in blending of fruit juices from different sources (Munhoz and Morabito, 2014) and more recently a planning model that considered uncertain demand from consumers when selecting the best growers to supply tomatoes to different grocery shops (Mateo *et al.,* 2016).

With respect to transportation, the major parameters that are commonly determined by planning models are the routes to take, quantities of products to be supplied through each route and selection of transportation mode from a range of options depending on the attributes of each (Tsolakis *et al.,* 2014). Models that have transportation components are often geared towards supply of goods of superior value to consumers at competitive prices while complying with a host of pre-set regulations and performance criteria (Tsolakis *et al*., 2014). A study by Rong *et al.* (2011) developed a supply planning model that minimized the total costs which included; production costs, transportation costs, cooling costs for transportation and storage facilities, storage costs and waste management costs. The problem was formulated using a mixed-integer linear model and implemented in CPLEX® solver. Its objective was to choose the best distribution network that met consumer quality constraints based on distribution and storage temperature profile of the products while minimizing the overall supply costs. The study however took a deterministic approach and did not factor aspects of temperature abuse.

Modelling tomato quality changes during transportation and storage

In general, two broad approaches have been used to model food quality attributes. The systems approach focuses on the totality of food quality attributes in a broad sense and enables prediction of a wide scope of food quality changes during their movement in the supply chain (Vorst, 2000). On the other hand, process-oriented approaches usually break down the problem (decomposition) in order to capture biological, chemical, physical and biochemical processes occurring in fresh foods (Tijskens and Schouten, 2014). All fundamental knowledge is used to predict the future behaviour of the product under any circumstances (Tijskens and Schouten, 2014). Sloof *et al.* (1996) presented a procedure for conceptualizing a quality change model involving three systems; product behaviour (dynamic model) coupled to the quality assignment model and an environmental model. This approach presents distinct advantages as opposed to methods where block systems are used. For instance, such procedures yield models that can be used in other applications with appropriate adjustments.

Some researchers have considered fresh tomatoes as a system having a fixed shelf-life while others have modelled with the notion of variable perishability as a function of the prevailing environmental conditions (Rong *et al*., 2011). The firmness and colour of tomato are the most important quality attributes to consumers (Schouten *et al.,* 2007a). These parameters have been widely modelled as quality indicators of tomato stored under different environmental conditions (Schouten *et al*., 2007a; Schouten *et al*., 2007b). Equations (1) and (2) are tomato quality deterioration models developed by Schouten *et al.* (2007a). Equation (1) and (2) gives the colour and firmness changes, respectively, as function of time.

$$Red(t) = Red_{max} + k_{pre}.\Delta t_C \frac{factor\ 1.\ factor\ 2}{factor\ 2 + (Red_{ref} - Red_{min})e^{factor\ 1(k_{Rpre}.\Delta t_C - k_{Rpost}.t)}} \quad (1)$$

$$F(t) = (F_{ref} - F_{fix})e^{-k_{Fpost}.t - k_{Fpre}\Delta t_F} + F_{fix} \quad (2)$$

Where Red(t) is the development of red pigment at a given time t after harvest, Red_{max} in 1000/G is the asymptotic colour value at +∞, Red_{min} in1000/G is the asymptotic colour value at -∞, G is the green colour intensity, k_{Rpre} the reaction rate constant during pre-harvest, Red_{ref} arbitrarily chosen reference colour during post-harvest, Δt_C is the colour biological age in days needed to change the colour from Red_{ref} to Red_0 and k_{prec} is the rate of formation of red colour precursor compounds. factor 1= $Red_{max}+k_{Prec}.\Delta t_c-Red_{min}$, factor 2= $Red_{max}+k_{Prec}.\Delta t_c-Red_{ref}$ and R_0 is the colour at harvest. kRpre is assumed to be equal to k_{Rpost} at the mean growth temperature over the last six weeks prior to harvest. k_{Fpre} and k_{Fpost} is the reaction rate constant for the firmness breakdown before harvest and after harvest, respectively, F_{fix} invariable part of firmness at infinite time, F(t) the firmness decay after harvest with respect to time t, F_{ref} an arbitrary reference firmness and Δt_F the firmness biological age in days needed to change the firmness from F_{ref} to F_0. F_0 is the firmness at harvest.

All the rate constants are temperature dependent and follow the Arrhenius law given by Equation 3.

$$K = K_{ref}.e^{\frac{E_a}{R}.(\frac{1}{T_{ref}} - \frac{1}{T})} \quad (3)$$

Where T, T_{ref}, E_a and R are the absolute temperature (K), arbitrarily chosen reference temperature, activation energy ($J.mol^{-1}$) and universal gas constant ($8.314J.mol^{-1}.K^{-1}$), respectively.

Other quality models for tomato and other FFV products have been developed by Schouten *et al.* (2002), Munhoz and Morabito (2014), and applied in predicting the shelf-life and keeping quality of tomatoes and various FFV.

The work by Giannakourou and Taoukis (2003) represented the vitamin C loss in frozen vegetables using first order reaction kinetics given by equation 4 as,

$$C = C_0 . e^{-kt} \tag{4}$$

Where C_0 and C are the initial concentrations of vitamin C and concentration of vitamin C at time t, respectively and k is the reaction rate constant of vitamin C loss.

Their kinetic model allowed the predication of the remaining shelf-life of frozen vegetables under non-isothermal conditions, mimicking the realities of fluctuating temperature during distribution of fresh fruits and vegetables. This model, however, considered only the thermal effect that can occasion vitamin C losses and used room temperature to model the kinetics of vitamin C. A similar study by Amodio *et al.* (2015) developed shelf-life models of fresh rocket based on the degradation kinetics of vitamin C under isothermal and non-isothermal conditions at various storage temperatures. The study showed that vitamin C degradation kinetics closely followed the trends in the overall quality score. These models are potentially useful for planning the distribution and storage of FFV, especially tomato fruit that has vitamin C as one of its important nutrients. The good correlation of internal quality and the overall appearance make these models important tools in predicting the overall quality of FFV since they give an indication of the nutritional and physical quality.

Batch models describe the changes in quality attributes of products or an individual product using probability theory as a function of time by combining quality models (Tijskens and Schouten, 2014). This approach allows the estimation of the biological age of each product in a batch along the supply chain. Biological age, in this case, is the time necessary for a property (e.g. colour or firmness) to change from an initial condition to an arbitrarily selected reference (Schouten *et al*., 2007a, 2007b). Batch models that combine firmness and colour with consumer limits in fresh tomato supply chain have been used by Schouten *et al*. (2007b) to provide purchase periods between which batches change from acceptable (unripe-ripe) and ends when a batch becomes unacceptable (ripe-overripe).

Conclusion

This review has shown the critical role transportation plays on the postharvest quality changes of tomato fruit. The importance of transportation systems and conditions during supply of tomatoes, will become even more critical as supply chains in emerging markets become more integrated and coordinated. The mechanics of tomato fruit damage under an array of transportation conditions (road quality, transit time, vehicle-systems used, packaging materials etc.) are important in implementing sustainable tomato supply chains. Literature shows there is need to use analytical tools to plan distribution of tomato fruit in South Africa and other emerging economies in such a manner that these supply chains operate efficiently, delivers quality fresh tomatoes at competitive prices in a sustainable way. In this way, supply chain planning models are critical in ensuring efficient performance of fresh tomato value chains. The development of nutrient loss kinetics under various storage and transportation conditions is one of the important ingredients missing in supply chain planning models. For instance, the degradation kinetics of vitamin C has been well researched and reported for various fruits and vegetables and used to predict their shelf-life, but its use in modelling fresh tomato nutrient changes in supply chain planning has been limiting. Integrating multiple nutrient degradation kinetics in tomato supply chain planning models will potentially improve the usefulness of such models. The inclusion of road quality as a contributing factor to fruit damage in tomato supply chain models has not been considered as an addition to environmental factors. The varietal effects and maturity at harvest are some of the other parameters that can be included in tomato supply chain planning models to advance their practicality and usefulness.

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