

## Review

# Review on factors affecting the quality and antioxidant properties of tomatoes

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Postharvest losses in tomatoes are not only quantitative but also qualitative losses which directly can have a negative impact on consumer's preference, nutritional quality and income of producers. Therefore, it is important to identify factors that can affect the postharvest quality and antioxidant composition of tomatoes. Tomato quality is an outcome of several factors including cultivar selection, environmental conditions where it grows and preharvest practices carried out during production. Preharvest practices carried out during production that affect the postharvest quality need to be considered thoroughly. Harvesting at proper maturity stage and ripening conditions are critical and must be carefully established for each cultivar. Knowledge of preharvest factors that affect the quality and antioxidant composition of tomato fruits and acquiring the skill of management can play a role on the production of best quality fruits at harvest, which in turn directly affect postharvest quality and nutritional composition. Therefore, it is of great significance to know the preharvest factors that can help to produce superior quality tomato fruits and equally important to use proper postharvest handling and management technologies, to maintain the quality and nutritional composition of the fruits after harvest. This review is therefore conducted to emphasize on some preharvest and postharvest factors that can affect the postharvest qualities, antioxidant properties and shelf life of tomatoes.

**Key words:** Antioxidant activity, ascorbic acid, environmental factors, lycopene, storage.

## INTRODUCTION

The tomato (*Lycopersicon esculentum* Mill.) is a vegetable crop that belongs to Solanaceae family and believed to have originated from the Andean region of South America. Cultivation of tomatoes was expanded to large scale due to its increased popularity during the last half-century (Preedy and Watson, 2008). Tomato is an economically important vegetable crop with worldwide production of 164.5 million tonnes having a value of

\$59.88 billion. China leads world tomato production with about 50.5 million tonnes followed by India with 18.2 million tons (FAOSTAT, 2013) (Table 1).

The compositions of tomatoes are 93 to 95% water and the remaining 5 to 7% includes inorganic compounds, organic acids, sugars, alcohol insoluble solids, carotenoids and lipids (Preedy and Watson, 2008). A daily intake of minimum 400 g of fruits and vegetables

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**Table 1.** Variation in the worldwide production of tomato in the last decade (Source: FAOSTAT, 2013).

Country	Production(ton)	
	2003	2013
China	28,700,000(1)	50,552,200(1)
USA	11,423,794(2)	12,574,550(3)
Turkey	9,820,000(3)	11,820,000(4)
India	7,616,700(4)	18,227,000(2)
Egypt	7,140,198(5)	8,533,803(5)
Italy	6,651,505(6)	4,932,463(7)
Iran	4,429,426(7)	6,174,182(6)
Spain	3,947,327(8)	3,683,600(9)
Brazil	3,708,600(9)	4,187,646(8)
Mexico	2,897,377(10)	3,282,583(10)
Republic of Korea	269,918	388,524
Asia	59,885,125	99,205,498
World	119,479,993	164,492,970

The numbers enclosed in parenthesis indicate the worldwide rank position by country in the related year.

(excluding potatoes and other starch tubers) is recommended for the prevention of chronic diseases and it is estimated that up to 2.7 million lives could potentially be saved each year, if fruit and vegetable consumption was sufficiently increased (WHO, 2005). Tomatoes are widely consumed in raw or processed form and can provide a significant proportion of total antioxidants such as vitamin C, lycopene, phenolics, flavonoids and  $\beta$ -carotene which can contribute to their antioxidant or free radical scavenging effects (Yahia et al., 2005; Lenucci et al., 2006).

Lycopene represents the predominant lipid soluble compound and constitutes more than 80% of total tomato carotenoids in fully red ripe fruits; other carotenoids in tomato constitute  $\beta$ -carotene which accounts for approximately 7% of tomato carotenoid content (Khachik et al., 2002; Kuti and Konuru, 2005). Baranska et al. (2006) reported the amount of lycopene and  $\beta$ -carotene in the range of 2.62 to 629.00 and 0.23 to 2.83 mg/100 g, respectively in tomato fruits and various tomato products. It was also reported that tomatoes contain moderate amounts of phenolics, flavonoids and hydrocinnamic acids mainly in its skin (Martinez-Valverde et al., 2002, Minoggio et al., 2003). According to USDA nutrient data base (2016), vitamin C content in tomato is moderate (14 mg/100 g), but its contribution to diet is significant because of its high consumption.

The regular intake of an adequate amount of fresh tomatoes or tomato products on regular basis has been shown to prevent the development of variety of cancers. Evidences are strongest for cancers of the lung, stomach, and prostate gland; data were also suggestive for the benefit of cancers of the cervix, breast, oral cavity, pancreas, colorectum, and esophagus (Giovannucci,

1999; Giovannucci et al., 2002) and cardiovascular diseases (Agarwal and Rao, 1998). This protective effect has been mainly attributed to its valuable bioactive components with antioxidant properties (Borguini and Torres, 2009).

Despite the enormous benefits that can be obtained from the tomatoes, postharvest losses of up to 40% (Aidoo et al., 2014) make its production to be considered as low profitable or unprofitable in most parts of the world. These losses result in low returns to growers, processors and traders; finally affect the whole country in terms of self-sufficiency and foreign exchange earnings.

Postharvest losses in tomatoes are not only quantitative but also qualitative losses which directly can have a negative impact on many parameters like consumer acceptability, nutrient status of fruits and financial income to producers (Arah et al., 2015). Therefore, it is important to identify factors that can affect the postharvest quality and antioxidant composition of tomatoes. Tomato quality is a function of several factors including the choice of cultivar, cultural practices, harvest time and method, storage, and handling procedures (Preedy and Watson, 2008). The shelf life of harvested fruits or vegetables results from the interaction between genetic, physiological conditions, postharvest physicochemical activities and activities of fungal and bacterial organisms (Garcia and Barrett, 2006).

It is therefore of great significance to know the preharvest factors that can help to produce superior quality tomato fruits and equally important to use proper postharvest handling and treatment methods to maintain the quality and nutritional composition of the fruits after harvest. The objective of this review is therefore to emphasize on some preharvest and postharvest factors that can affect the postharvest qualities, antioxidant properties and shelf life of tomatoes.

## PREHARVEST FACTORS AFFECTING THE QUALITY AND ANTIOXIDANT PROPERTIES OF TOMATOES

Antioxidants and phytochemicals accumulate in plants in an organ specific manner and their distribution and accumulation is governed by a variety of environmental factors (temperature, light, water availability, and nutrients), preharvest and postharvest conditions and genotypes or cultivars (Brovelli, 2006). The functional quality and antioxidant constituents of tomatoes are significantly affected by environmental factors and their interaction with agronomic practices and genotypes (Dumas et al., 2003).

### Variety selection

The response to biotic and abiotic stresses is dependent on genetic characteristics and it can ultimately impact their antioxidant capacity. Evaluation of different varieties

and cultivars for selection and identification of the superior genotype for high antioxidant capacity has been a subject of active research in the last decade (Brovelli, 2006).

Kuti and Konuru (2005) investigated 40 tomato varieties on a fresh weight basis and found the lycopene content in the range of 4.3 to 116.7 mg kg<sup>-1</sup>; they reported highest lycopene content in cherry tomato types. Martínez-Valverde et al. (2002) also observed the lycopene content ranging from 18.60 to 64.98 mg kg<sup>-1</sup> fresh weight in nine commercial varieties of tomatoes produced in Spain. Tomato cultivars that contain the Crimson gene are usually found to have higher lycopene content (50.86 to 57.86 mg kg<sup>-1</sup> fresh weight) than those lacking the gene (26.22 to 43.18 mg kg<sup>-1</sup> fresh weight) (Thompson et al., 2000).

Tilahun et al. (2017a) and Giuntini et al. (2005) reported that the phenolic content of tomato fruits has been significantly affected by the cultivar. Abushita et al. (1997) reported large variation in vitamin C content (210 to 480 mg kg<sup>-1</sup>) of tomatoes cultivated in Hungary. George et al. (2004) also observed significant differences of vitamin C contents among 13 tomato cultivars with higher levels of vitamin C in cherry tomatoes; they reported values ranging from 84 to 324 mg kg<sup>-1</sup> fresh weight in the pulp and 90 to 560 mg kg<sup>-1</sup> fresh weight in the peel. It has also been noted that cherry tomatoes often contain than other varieties. In contrast, Abushita et al. (2000) found no high differences between cultivars for fresh consumption and those for processing in vitamin C content.

## Environmental factors

Most suitable environmental conditions for production of tomatoes have high altitudes with low humidity and high light intensity. In regions having altitudes of 500 to 900 m, tomatoes can be cultivated for the whole year. If the altitude is less than 300 m, it is preferably cultivated in the winter and at altitude above 1200 m, it is best cultivated in the summer (Preedy and Watson, 2008).

The content of soluble solids and yield are dependent on edaphoclimatic conditions of the cultivation region (Preedy and Watson, 2008). To depict a total interaction between plant genotype and environment, Scalzo et al. (2005) suggested to characterize crops on the basis of total antioxidant capacity rather than a single specific antioxidant compound.

## Temperature

Among climatic factors that affect tomato cultivation, temperature should be emphasized due to its effect on net assimilation rate. Greater growth efficiency is observed when the temperature is between 18 and 28°C (Jones et al., 1991). Temperature may also influence the

distribution of photo assimilates between the fruits and the vegetative part of the plant (Preedy and Watson, 2008). At high temperature distribution of photo assimilates is favored towards fruits at the expense of vegetative growth (De Koning, 1989). Similarly, the movement of water to the fruit increases with temperature, provided that there is no shortage of water. Temperature at 15°C or lower, considerably reduce the absorption of water by the fruit (Dorais et al., 2001). Temperature influences cellular structures and other components that determine the quality of the fruit such as color, size, and organoleptic properties. High temperatures hasten the development of the fruit and reduce the time necessary for its maturity (Dorais et al., 2001).

The optimum temperature range for lycopene formation was reported to be between 12 and 32°C; but within the above mentioned range, optimum levels vary with variety, cultivar and other environmental and growth conditions of tomato plants (Dumas et al., 2003). The temperature range ideal for the formation of lycopene is 20 to 24°C during the day and around 18°C at night. Sufficiently, high temperature along with dense foliage to protect fruits from direct exposure to the sun is an appropriate condition in enhancing lycopene synthesis. The rate of lycopene synthesis was inhibited at both high (> 30°C) and low temperatures (< 12°C) (Dumas et al. 2003).

Temperatures above 30°C inhibit the formation of lycopene and favor the formation of other carotenoids, which gives yellow to orange color to the fruit (Preedy and Watson, 2008). Toor et al. (2006) reported negative effect of high temperature on lycopene content during the summer months. Raffo et al. (2006) also observed negative effect of hot temperatures of midsummer in the Mediterranean basin on lycopene accumulation in tomato fruits. Kuti and Konuru (2005) evaluated 40 tomato varieties under greenhouse and field conditions; lower lycopene content was reported for cherry tomatoes grown in the greenhouse because of temperatures over 32°C in most cases. Cooling of the green house during high solar radiation in summer months may help to increase the lycopene content of tomatoes.

Direct correlation between temperature and ascorbic acid was reported by Raffo et al. (2006) and the outcome was attributed to cultivar, salinity and sunny climate. Liptay et al. (1986) reported that tomatoes grown at low temperature had lower quantities of Ascorbic acid (AA) when compared to the quantities at higher temperatures.

## Relative humidity (RH)

Buschermohle and Grandle (2002) reported that the ideal humidity level for tomato plants should be between 65 to 75% during the night and 80 to 90% during the day. The ranges of relative humidity which tend to optimize crop yield and quality have been defined in terms of the vapor pressure deficit (VPD), a term referring to the difference between the saturated and the actual vapor pressure.

VPD is the main factor controlling water uptake by the plant, because it determines water vapor differences between the plant roots and leaves and, thus, the water movement between these two points.

Independent of temperature, VPD expressed in kPa, predicts plant transpiration rate. VPD had a significant effect on the hourly and daily water uptake rates of tomato plants. Trigui et al. (1999) reported that, by using VPD as the only controlled variable, the hourly water uptake rate was increased by 35 to 50%. Increases in water uptake up to 800 mL per plant per day, led to an increased crop yield. Composition of the fruits is also affected by relative humidity of the air. Very low relative humidity (15 to 22%) condition affect the photosynthetic ratio due to the closing of the stomata which result in reduction of plant growth, fruit size and total production. There is a decrease in plant transpiration and a decrease in the absorption of nutrients under high relative humidity conditions (Dorais et al. 2001). Harel et al. (2014) reported that, in the hot Mediterranean summer months, using low pressure fogging system and achieving the mean daily (day/night) temperature of up to 26°C and 70 RH% during day time, benefits pollen quality and fruit sets which in turn increases the yield and quality of tomatoes.

### Solar radiation

In plants, carotenoids exist in cellular plastids and are associated with light-harvesting complexes in the thylakoid membranes or present as semi crystalline structures derived from the plastids (Kopsell and Kopsell, 2006). Of the total luminous radiation that reaches the plant in a greenhouse, about 10% is reflected, 10% transmitted and approximately 80% absorbed; from the absorbed radiation, a small proportion (5%) is used in biological reactions such as photosynthesis and the largest proportion is dissipated by transpiration or convection (Dorais et al., 2001).

Environmental factors have less impact on greenhouse grown tomatoes than those grown in the field. However, changes in solar radiation during different seasons may affect the contents of soluble sugars (Davies and Hobson, 1981) and antioxidant components of greenhouse grown tomatoes (Dumas et al., 2003; Toor et al., 2006). The level of antioxidants in greenhouse grown tomatoes and field grown tomatoes may vary due to relatively less ultraviolet radiation received by greenhouse grown tomatoes (Davey et al., 2000; Stewart et al., 2000).

Ascorbic acid accumulation in tomato fruit have been found to be favored by light exposure and water stress (Lee and Kader, 2000; Dumas et al., 2003). An increase of 60% in the ascorbic acid content of ripe fruit resulted when plants were transferred from the shade to sunshine at mature green stage (Liptay et al., 1986).

On the contrary, lycopene synthesis is severely inhibited by the exposure to intense solar radiation, which

has been suggested that radiation injury to tomato fruit might be due to the general effects of overheating on irradiated tissues (Dumas et al., 2003). Low light intensity reduces the synthesis of pigments, resulting in plants with uneven coloration. Although the formation of carotenoids in mature fruits does not require induction by light, shaded fruits have lower content of carotenoids (Dorais et al., 2001).

Phenolic content of tomato fruits has been reported to be significantly affected by spectral quality of solar UV radiation (Luthria et al., 2006).

### Growing media

One of the key factors for plant growth, yield, fruit quality and storability is the growing medium used for cultivation (Kowalczyk and Gajc-Wolska, 2011). Growing media are used to provide aeration and water, allow for maximum root growth and physical support of the plant. Growing media should have large particles with adequate pore spaces between them (Bilderback et al., 2005). Soilless culture is used to avoid problems associated with: decreasing fertility of natural soils, disease limitations and increase in salinity.

Limitations like material disposal and raising cost retard the development of soilless culture. The solution that might help to solve these problems is using different substrate materials which are locally available and less costly than those imported, with no limitations of pollution, but with adequate physical and chemical properties (Tzortzakis and Economakis, 2008). Tzortzakis and Economakis (2008) reported that adding maize shredded stems in perlite and pumice led to higher yield and better fruit quality; they also reported that mean fruit weight, fruit firmness, total soluble solids (TSS), titratable acidity (TA), carotenoids and ascorbic acid, were differently affected by substrate. Kowalczyk and Gajc-Wolska (2011) also reported the suitability of coconut fiber, wood fiber and rock wool for tomato soilless cultivation. Ghehsareh et al. (2011) reported the suitability of coco peat and perlite for growing of some plants, especially for vegetables; they also investigated that coco peat and date palm peat media had similar properties and did not have significant differences on qualitative and quantitative indexes in tomato fruit.

### Management practices

Water management is a critical factor influencing lycopene accumulation. Controlled level of salinity in irrigation water, by irrigating with saline water containing NaCl up to 0.25% (w/v) has been reported to increase the carotenoids concentration, lycopene and antioxidant activity of tomatoes (De Pascale et al., 2001). Fanasca et al. (2006) reported that high proportion of K and Mg in the nutrient solution increased the quality and antioxidants content (especially lycopene) of tomato fruit, whereas a

high proportion of Ca increase fruit yield and reduced the incidence of blossom end rot.

Fanasca et al. (2006) observed a negative correlation between fruit tissue Ca and lycopene content. Toor et al. (2006) also reported the reduction in lycopene content as high calcium and chloride as well as low sulfur levels in fertilizers used. This could possibly be due to the simultaneous decrease in K absorption that occurred because of cationic competition or a possible Ca influence on ethylene biosynthesis (Fanasca et al., 2006). Tomatoes grown in nutrient solution at a low nitrogen dosage showed the highest lycopene content (Dumas et al., 2003). However, On the contrary, tomatoes grown in nutrient solution at higher rate of phosphorus or potassium supply greatly increased the lycopene content (Dumas et al., 2003; Fanasca et al., 2006).

High N concentration in the nutrient solution favors plant leaf area development thereby decreases light penetration in to the canopy and vitamin C content in the fruit (Locascio et al., 1984). Toor et al. (2006) observed that vitamin C contents of tomatoes grown on ammonium-fertilized treatments were higher than tomatoes grown on nitrate-fertilized treatments. Additionally, it was stated that the effects of N application on vitamin C in tomato fruits were a function of intensity of light and time of the fertilizer application. Dong et al. (2004) reported that spraying Ca solution on the leaves of 3 week old plant did not significantly affect vitamin C content. However, vitamin C synthesis in tomato fruits was greatly enhanced by spraying Ca solution on the leaves during anthesis.

It is widely stated that, higher electrical conductivity (EC) growing condition resulted in significant increases in lycopene concentration. Lycopene content of tomato fruits increased from 43 mg kg<sup>-1</sup> for EC 3 dS m<sup>-1</sup> to 58 mg kg<sup>-1</sup> for EC 10 dS m<sup>-1</sup> on a fresh weight basis (Krauss et al., 2006). De Pascale et al. (2001) observed an increasing trend of lycopene content up to an EC of 4.4 dS m<sup>-1</sup> and decreasing trend of lycopene content above 4.4 dS m<sup>-1</sup>. The response of tomatoes to high EC in terms of an increase in total lycopene was shown to be cultivar specific, varying from 34 to 85% (Kubota et al., 2006). To enhance lycopene concentration of tomato fruits, an increases in EC can be reached not only by adding NaCl to a nutritional solution, but also by applying water stress caused by limited irrigation, that is, by increasing the strength of the nutrient concentration (Krauss et al., 2006). Evidences suggest that water and salt stress cause ethylene synthesis and could be central to the increase in lycopene deposition within the flesh of the tomatoes (Kubota et al., 2006). Increased EC also leads to higher contents of vitamin C in tomato fruits. De Pascale et al. (2001) observed 60% higher vitamin C content of tomatoes grown at EC of 15.7 dS m<sup>-1</sup> than non-sanitized controls.

According to Dumas et al. (2003), shortage of water has a tendency to increase the fruit's vitamin C contents. Lumpkin (2005) also suggested that tomato fruit's

nutritional values can be improved by deficient irrigation through a concentration effect when the fruit's water content was reduced.

Lycopene content in tomatoes can also be affected by irrigation methods. Kadam and Sahane (2002) reported lycopene content of 3.2 and 2.6 mg kg<sup>-1</sup> for tomatoes grown under drip irrigation and surface irrigation, respectively.

Caris-Veyrat et al. (2004) compared tomatoes grown by the conventional and the organic agricultural practices did not find any significant difference in the carotenoid content.

### Maturity stage

Lycopene production is associated with fruit maturation (Arias et al., 2000). Tomatoes are harvested at stages of maturity ranging from mature-green stage to full-ripe based on the market destination and production area. Tomatoes are highly perishable and anticipating harvest before the climacteric rise is considered as the best strategy to prolong shelf-life and reduce spoilage rate (Saltveit, 2005a).

Soluble sugars, organic acids and volatile compounds determine the taste of tomato. There is an increase in TSS and a decrease of TA during tomato ripening. The main components of TSS in domesticated tomatoes are fructose and glucose, while some wild tomato species accumulate sucrose. Citric acid is considered as the main organic acid which is responsible for acidity of tomatoes and it decreases from green to red ripening stage (Carrari and Fernie, 2006). Lycopene has been suggested as a good indicator of the ripening stage. Kaur et al. (2006) reported that at the breaker stage, when coloration becomes evident, lycopene starts to accumulate and its concentration increases up to 500-fold in ripe fruits with varying ranges among cultivars.

Buta and Spaulding (1997) reported a declining trend of phenolics as the fruits proceed from earliest stage of tomato development to fruit ripening, as well as during post-harvest ripening, but Slimstad and Verheul (2005) stated that the content of total phenolics remained stable during ripening. Mondal et al. (2004) reported the results obtained for oxidative stress and antioxidant enzyme systems at different stages of two tomato cultivars and they proposed that, during the early stages of fruit ripening, efficient antioxidant system protects the tomato fruits against the damaging effect of progressive oxidative stress but oxidative damage occurs at the later stage due to decreased activities of the ROS scavenging enzymes. Caputo et al. (2004) proposed that the decrease in total antioxidant activity from deep red stage to overripe stage was perhaps due to antioxidant depletion caused by fruit defense mechanisms against ROS, which are produced in large amounts during the climacteric rise. Antioxidant activity was measured by Lana and Tijsskens (2006) as

inhibition of lipid peroxidation in rat liver microsomes which found that, the antioxidant activity of methanol extracts increased as maturity progress from mature-green stage to turning stage and decreased afterwards. Contrary to what was reported by Caputo et al. (2004) and Lana and Tijssens (2006), no change in hydrophilic antioxidant activity was observed by Cano et al. (2003) during ripening of tomato.

### Ripening conditions

Since fully ripened tomatoes cannot stand the handling necessary to move them from field to the consumer, it is a standard procedure to harvest mature green or breaker stage tomatoes and to ripen them in transit or at destination (Kader et al., 1977). However this practice may negatively affect taste and nutritional quality as the fruits are picked at mature green stage or before turning to red color, although able to continue the ripening process, develop poor eating and nutritional traits when fully ripened (Kader, 1986).

Changes in antioxidant activity due to ripening are likely to be different whether the fruits ripen on vine or off vine (Giovanelli et al., 1999). According to Giovanelli et al. (1999), ripening conditions affected both the antioxidant accumulation kinetics and final content; tomato fruits picked at the full ripe stage, had lower level of antioxidants (lycopene,  $\beta$ -carotene and ascorbic acid) than those picked at mature green stage and ripened off vine. However, Tilahun et al. (2017b) reported that breaker-stage tomatoes can be postharvest-ripened under room conditions without affecting their marketability and nutritional components.

### POSTHARVEST FACTORS AFFECTING THE QUALITY AND ANTIOXIDANT PROPERTIES OF TOMATOES

Fruit remains alive even after being harvested and keeps respiring and transpiring as if it was on the mother plant. The climacteric rise of ethylene which makes the tomato fruit palatable also promotes senescence of the fruit. The goal of any postharvest handling practice or treatment is to manage the concentration and timing of ethylene synthesis so that, the fruit reaches the consumer at optimal eating quality (Beckles, 2012). The following are postharvest factors affecting the quality and antioxidant properties of tomatoes.

#### Pre storage treatments

Tomato ripening is controlled by plant hormone ethylene, which starts on the plant and follow after detachment. It involves wide range of physical, chemical, biochemical and physiological changes. These changes occur relatively quickly after harvest and the fruits reach an

over-ripe and unmarketable state. Thus, in order to delay these changes, technologies is focused on controlling the biosynthesis and action of ethylene. Hoeberichts et al. (2002) reported that treating tomato fruit with 1-methylcyclopropene (1-MCP), a potent inhibitor of ethylene action at a concentration ranging from 150 to 50  $\text{nl l}^{-1}$  at the start and at the end during the 20 h treatment, delayed color development, softening, and ethylene production of mature green, breaker, and orange stages. It is also supported by Wills and Ku (2001), which state that an application of 5-100  $\mu\text{l l}^{-1}$  1-MCP to ripe tomatoes for 2 h resulted in an increase in postharvest life; with an exposure to 20  $\mu\text{l l}^{-1}$  giving a 25% increase in postharvest life.

Occurrence of chilling injury on tomatoes can be alleviated by mild heat treatment prior to storage. Studies have shown that heat treatments can alleviate chilling injury symptoms by reducing decay, loss of firmness and electrolyte leakage. For this purpose, hot water dips or hot air treatments have been used (Saltveit, 2005b; Polenta et al., 2006), with several combinations of temperature (38 to 45°C) and duration (0.5 to 72 h).

Mujtaba and Masud (2014) reported that tomato fruits treated with 2% calcium chloride, packed in ventilated 0.6 mm polyethylene cover was found to be highly effective in controlling storage losses as well as in maintaining the quality produce during storage. Pila et al. (2010) also reported the significant impact of 0.1% gibberellic acid, 1.5% calcium chloride and 0.4 mM salicylic acid as pre storage treatment for prevention of decay, prolonging shelf life and on preserving valuable attributes of tomatoes; presumably due to their effect on inhibition of ripening and senescence. Different studies indicated that, the rate of senescence in fruits is affected by the amount of calcium in the plant tissue. Exogenous application of calcium, maintains cell wall integrity and protects it from degrading enzymes (White and Broadley, 2003) which enhance better linkages between pectic substances within the cell wall whilst, increasing the cohesion of cell walls (Demarty et al., 1984).

Treating harvested mature green tomato fruits with brief red light, stimulate lycopene accumulation 2.3-fold during fruit development. This red light which induced lycopene accumulation was reversed by subsequent treatment with far red light (Alba et al., 2000). Edible coatings like wax, milk proteins, celluloses, lipids, starch, zein, and alginate have been used to prevent commodity deterioration. Morillon et al. (2002) reported that, tomatoes coated with alginate or zein (at 5 or 10% w/v) reduced the softening and increased color  $a^*$  values after 9 days of storage at 20°C as compared to non-coated fruits.

#### Temperature

Temperature is the most important environmental factor in the postharvest life of tomatoes due to its dramatic effect on the rates of biological processes (Mostofi and

Toivonen, 2006). According to Kader (2002), temperature management is the most effective tool for extending the shelf life of fresh horticultural commodities. No matter how carefully grown, tomatoes do not fulfill their full economic or nutritional potential unless handled at suitable temperatures after harvest. Under ambient temperature, tomatoes ripen rapidly and become unmarketable in a short period due to an increased rate of respiration (CO<sub>2</sub> production) at high temperature. CO<sub>2</sub> production with other factors like O<sub>2</sub> levels at ripening stages can trigger ethylene production in stored tomatoes.

The use of low temperature is effective in delaying and/or reducing the ethylene production, but tomato fruits are sensitive to chilling injury (Cheng and Shewfelt, 1988). Postharvest recommendations indicate that tomatoes should be stored at 10°C or higher to avoid chilling injury (Roberts et al., 2002) and even 10°C may be detrimental to tomato flavor quality (Maul et al., 2000). Chilling injury symptoms include failure to ripen which develop full color and flavor, irregular color development, excessive softening, surface pitting, and increased decay (Cantwell, 2010; Sargent and Moretti, 2004).

During postharvest storage, increase in lycopene concentration has been reported and the enhancement was higher as the temperature increased (Toor et al., 2006). Suslow and Cantwell (2002) recommended a storage temperature of 12.5 to 15°C, 10 to 12.5°C and 7 to 10°C for mature green, light red and firm ripe maturity stages, respectively. Alban (1961) also suggested storage temperature of 10 to 13°C for pink-red to firm-red greenhouse-grown tomatoes. Ripening temperature of 18 to 21°C for standard ripening and 14 to 16°C for slow ripening was suggested by Suslow and Cantwell (2002).

### Relative humidity (RH)

Water loss from fresh produce is predominantly caused by the amount of moisture existing in the ambient air which is expressed as relative humidity. Tomato fruits have very high water content (Preedy and Watson, 2008) and susceptible to shrinkage after harvest. Fruit shrivel may become evident with any small percentage of moisture loss.

The optimum relative humidity values that are recommended for maximizing postharvest quality and to prevent water loss (desiccation) of tomatoes range from 90 to 95% (Suslow and Cantwell, 2002). Storage of tomato fruit at a lower relative humidity can result in shriveling. On the other hand, completely saturated atmospheres of 100% relative humidity should be avoided, as it encourages fungal development.

### Gas composition in storage and package

Combination of different gases in storage and package

influences shelf life of tomato fruits. Low oxygen (3 to 5%) atmospheres are used to slow tomato ripening while high levels of carbon dioxide more than 5% are considered damaging for tomatoes. Low O<sub>2</sub> injury is characterized by uneven ripening and off-flavors due to increases in ethanol and acetaldehyde. A very low supply of oxygen can have a detrimental effect on fruits by causing anaerobic respiration (Kader and Saltveit, 2003).

Carbon dioxide concentrations higher than 5% may cause surface discoloration, softening, and uneven coloration (Sargent and Moretti, 2004). Suslow and Cantwell (2002) reported that CO<sub>2</sub> (above 1%) retards the action of ethylene in stimulating ripening. The optimal atmosphere needed to inhibit senescence in mature green/breaker and pink/red fruit of tomatoes is 3 to 5% of oxygen, but for carbon dioxide 1 to 3% and 1 to 5%, respectively (Artés et al., 2006).

### CONCLUSIONS

As all other horticultural crops, quality management of tomatoes starts from the field and should continue until it reaches the final consumers. Preharvest practices carried out during production should be considered thoroughly as they in part affect the postharvest quality. Knowledge of preharvest factors that affect the quality and antioxidant composition of tomato fruits and acquiring the skill of management can play a role on the production of best quality fruits at harvest, which in turn directly affect postharvest quality and nutritional composition.

The postharvest quality status of the tomato fruit depends on cultivar selection, environmental conditions where it grows and preharvest practices carried out during production. Harvesting at proper maturity stage and ripening condition are critical and must be carefully established for each cultivar. Due to high water content and climacteric nature, tomatoes are highly perishable and are subjected to rapid quality loss after harvest. Using best postharvest handling practices, pre storage treatments, storage at optimum conditions to maintain the quality after harvest is also critical.

It has seen by this review that the quality and storage life of tomatoes after harvest depends not only on the postharvest factors alone but also on preharvest factors during production. Both factors need to be managed properly to reduce quality loss which is a major challenge for tomato producers and handlers. Many of the studies available in the literature were carried out on certain cultivars and the data hardly apply to the cultivars commonly used currently. Studies on the most commonly grown cultivars on the specific area of production could benefit both the growers and consumers.

### CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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