Tomato Production for Human Health, Not Only for Food

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Abstract The concept of growing crops for health rather than only for food or fiber is becoming a major issue. Since standards of living have improved, food availability and connection between plant production practices and human health are launching new issues of dietary supplements, functional foods and plant-produced recombinant proteins. Consumption of fruits and vegetables is also beneficial to human health since fruits reduce the risk of developing cancer and cardio-vascular diseases. Although tomato have for many years been bred and grown for food, the development and production of health-beneficial tomatoes is of research interest. However the effect of production management practices, processing and storage conditions on quality and health aspect of tomato is not well-known.

Tomato, *Lycopersicum esculentum* L., is one of the world's major vegetables, with an excellent source of health-promoting compounds such as various nutrients, secondary metabolites, ß-carotene, lycopene, vitamins C and E, flavonoids and various phenolic compounds. Dietary intake of tomato and tomato products containing lycopene have been shown to be associated with decreasing risk of cardiovascular diseases and certain types of cancer. Maximizing tomato fruit quality, nutritional contents and mentioned phytonutrient in tomato can be affected by (i) environmental factors such as radiation, temperature, humidity, atmospheric CO_2, air pollutants, soil properties, water quality, mineral nutrition, salinity, mechanical and pest injuries; (ii) agricultural practices and cropping system, and (iii) genetics and seed genotype. The nutrition quality and human health related properties of tomato fruits, especially carotenoids, flavonoids, phenols and antioxidant compounds, are strongly

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affected by light, temperature, air CO_2 content, air pollutants, water rate and availability, irrigation regim and system, salinity and other quality aspects of water, soil structure, soil physical and chemical characteristics, mineral and organic fertilizers and soil organic matter. Those quality values of tomato fruits are developing during ripening stages and thus ripening is a very important stage. Appropriate processing approach and post-harvest storage conditions can also give tomato a higher quality value. In most cases, organic production and low input systems produced tastier and more flavoured fruits, containing higher lycopene, organic acids, phenolic and ascorbic acids, secondary metabolites, vitamin C and E compared to conventional tomato.

Keywords Antioxidants • Human health • Lycopene • *Lycopersicum esculentum* • Phytonutrients • Secondary metabolites

1 Introduction

Rapid changes in diets and lifestyles that have occurred with industrialization, urbanization, economic development and globalization, have accelerated over the past decade. This had a significant impact on the health and nutritional status of human populations, particularly in developing countries and in countries in transition. While standards of living have improved, food availability has expanded and became more diversified. Rediscovery of the connection between plants and health is responsible for launching a new generation of botanical therapeutics that include plant-derived pharmaceuticals, multicomponent botanical drugs, dietary supplements, functional foods and plant-produced recombinant proteins (Raskin et al. 2002). The consumption of fruits and vegetables is beneficial to human health, since they reduce the risk of developing serious diseases such as cancer and cardio-vascular disease (Dumas et al. 2003). A healthy diet is an important factor in preventing chronic diseases and improving energy balance and weight management (Dorais et al. 2008).

Consumer's interest in the quality of vegetable products has increased in recent years worldwide. There are studies have documented methods for achieving a high-quality vegetable product. The quality of the harvest fruit is of major concern to growers because fruit is regarded according to external attractiveness (e.g., colour, size, shape and skin defects) or internal characteristics such as taste and texture (Fleisher et al. 2006; Shi et al. 2002). Fruits and vegetables are rich in dietary vitamins, minerals and fiber and are the primary source of flavonoids in the diet (Mitchell et al. 2007). The factors which strongly influence the quality of tomato fruits are climate, soil, and crop management (Dadomo et al. 1994). Good quality does not always require higher growing costs, because a lower input is often better.

Tomato (*Lycopersicum esculentum* L.) is one of the most popular and extensively consumed vegetable crops worldwide. It is one of the most extensively marketed vegetable foods, with a worldwide production of 126 million Tm in 2005. Tomato fruits constitute an excellent source of health-promoting compounds due to the balanced mixture of minerals and antioxidants including vitamins C and E, lycopene, ß-carotene, lutein and flavonoids such as quercetin (Beecher 1998; Dorais et al. 2008). In particular, the consumption of tomatoes and its products have been associated with a lower risk of developing digestive tract, prostate cancer (Giovannucci et al. 1995; Shi and Le Maguer 2000), chronic degenerative diseases such as certain types of cancer (Giovannucci 1999) and cardiovascular diseases (Pandey et al. 1995; Agarwa and Rao 2000). Antioxidant components of tomatoes reported to be influenced by different factors such as cultivar, growing conditions, season, harvesting stage and ripening on-and off-vine (Abushita et al. 1997; Davies and Hobson 1981; Giovanelli et al. 1999; Toor et al. 2005, 2006b).

Objective of the present study was to update the knowledge available and to review the recent literatures of the main factors that can improve the nutritional quality and quantity of tomato and consequently their beneficial roles in human diet. The effects of environmental factors and agricultural practices on the beneficial components of tomato fruit such as nutrient qualities, lycopene, vitamin C, vitamin E and the main phenolic antioxidant compounds were studied.

2 Tomato Quality and Human Health

In addition to tomato quantity which is more important for producers, the quality of tomato fruits, nutrient composition, soundness, taste, size, dry matter content, colour, viscosity, etc are also important for many producers and consumers (Dumas et al. 2006). Tomato has several components that contributing to human health (Huyskens-Keil and Schreiner 2004; Tonucci et al. 1995). Two main carotenoids are present in tomato: lycopene, which is the major carotenoid compound (90–180%) giving the red colour to the fruit (Nguyen and Schwartz 1999), and ß-carotene, which is 7–10% of the total carotenoid content (Gould 1974). Moreover, carotenoids are a major class of compounds providing precursors to essential vitamins and antioxidants (Dorais et al. 2008). The content of carotenoids in tomatoes is important, not only due to the colour they impart, but also due to their acknowledged health benefits. Lycopene is a hydrocarbon carotenoid, $C_{40}H_{56}$, with molecular weight of 537. In nature, it is most abundantly found as the red pigment of watermelon and tomato. It is a natural antioxidant due to its ability to act as a free radical scavenger. It has the highest singlet oxygen quenching rate of all carotenoids in biological systems (Di Mascio et al. 1989; Tinker et al. 1994). The amount of this carotenoid in raw tomatoes depends on the variety, stage of maturity and the environmental conditions during cultivation (Shi 2000). Therefore, considerable work has been conducted to increase their levels in tomatoes through breeding programmes or ripening intervention technologies during post-harvest storage (Liu et al. 2009; Rosati et al. 2000).

Tomato fruits contain phenolic compounds, which also exhibit a strong antioxidant activity (Shahidi and Wanasundara 1992). Since the taste, colour and nutrient qualities of tomatoes can also depend on their antioxidant contents, further insights into the factors likely to affect their composition should help to define the quality of tomatoes more clearly (Dumas et al. 2003; Gitenay et al. 2007). Antioxidants are believed to be important in the prevention of disease such as cancer and cardiovascular disease. Lycopene is one of the main antioxidants to be found in fresh tomatoes and processed tomato products (Dumas et al. 2003). Lycopene content also accounts for the redness of the fruits, which is one of the main qualities for which industry and consumers now look. Other carotenes (such as ß-carotene), vitamin C, vitamin E and various Phenolic compounds are also thought be health-promoting factors with antioxidant properties (Dumas et al. 2003).

Antioxidant and free radical-scavenging properties of polyphenol compounds in several plant extracts reported, suggesting possible protective roles of polyphenol compounds in reducing risk of cardiovascular diseases in humans (Velioglu et al. 1998). Moreover, tomato contains flavonoids, in particular rutin and naringenin. Some papers pointed out those tomato flavonoids, due to their high antioxidant power and to the significant biological activities, can have a substantial role in the health benefits attributed to the tomato consumption (Bourne and Rice-Evans 1999; Hertog et al. 1993). High intake of tomato juice prevents low density lipoproteins (LDL) oxidation and thiobarbituric reactive species (TBARS) formation in healthy men (Bub et al. 2000; Gitenay et al. 2007). Studies showed that lycopene exhibits antioxidant activities (Di Mascio et al. 1989), suppresses cell proliferation (Levy et al. 1995) and interferes with the growth of cancer cells (Clinton et al. 1996; Giovannucci et al. 1995). The beneficial effects of tomato consumption are generally attributed to carotenoids, which are able to reduce the risk of certain types of cancer, cardiovascular disease, arteriosclerosis, cataract formation and age-related macular degeneration (Clinton 1998; Dorais et al. 2008; Hadley et al. 2002; Heber and Lu 2002; Giovannucci et al. 1995; Giovannucci and Clinton 1998; Sandstrom et al. 1994; Weisburger 1998). Several epidemiological studies have reported that the dietary intake of carotenoids reduces the incidence of degenerative diseases, including heart disease and cancer. Lycopene, through tomato sauce consumption, reduces leukocyte and prostate tissue oxidative DNA damage and decreases prostate specific antigen (PSA) level in prostate cancer patients (Chen et al. 2001; Gitenay et al. 2007).

In conclusion, nutrient qualities, antioxidant contents, taste and colour of tomato fruits can depend on the contents of their lycopene, ß-carotene, vitamin C, vitamin E, flavonoids and various phenolic compounds. These tomato compounds have antioxidant activities, reduce risk of cardiovascular diseases, arteriosclerosis, cataract formation, leukocyte, prostate cancer; suppress cell proliferation and interfere with the growth of cancer cell.

3 Tomato Quality, Environmental Factors and Agricultural Practices

For field tomato crops, changes in nutritional value are often described in terms of variation in geographic location or season, which include interactions among several factors, making interpretation difficult. For example, higher altitudes reduce temperature but increase visible and UV light, which may increase the level of certain phytonutrients such as carotenoids since their major function is to absorb light during photosynthesis and to protect cells against excessive light. On the other hand, carotenoids in the fruit of protected tomato crops were found to be higher at the end of the harvest period than at the first harvest in May (Auerswald et al. 1996). This could be partly due to differences in light but also to the poorer plant water status in older plants. Therefore, a better understanding of the interaction among environmental factors, agronomic practices and cultivar is required. The two best-known environmental factors influencing the quality value of tomato are light and temperature.

3.1 Light

In tomato plants, dry matter production and quality of fruits are influenced directly by photosynthetic activity of leaves. Light has the most profound effect on the fruit sugar concentration. Generally, more sunlight reaching the fruit results in higher sugar content. As a consequence, greenhouse tomatoes grown during the winter months contain substantially less sugar than field-grown tomatoes in the summer (Mikkelsen 2005). Also, phytonutrients of tomato such as vitamin C, carotenoids and phenols are strongly affected by the intensity, duration and quality of radiation. For example, several studies showed that antioxidants such as vitamin C, lycopene, ß-carotene and phenols increased with light intensity (Amiot et al. 2007; Ju et al. 1999; Lee and Kader 2000; McCollum 1954; Merzlyak et al. 2002). Although light is not essential for the synthesis of ascorbic acid, the amount and intensity of light during the growing season influences its content in the fruit because ascorbic acid is synthesized from sugars supplied through photosynthesis (Lee and Kader 2000). In fact, positive correlations were observed between fruit sugar content and vitamin C and lycopene content (Gautier et al. 2005). Similarly, even though the formation of carotenoids in ripening tomato fruit does not require induction by light, but light plays a fundamental role in determining the content of carotenoids. On the other hand, the biosynthesis of anthocyanins in maturing fruit is a light-dependent process (Lancaster 1992) requiring a photomorphogenic signal mediated by photoreceptors. The involvement of a UV-B photoreceptor, phytochromes or cryptochromes has been suggested (Adamse et al. 1989; Giliberto et al. 2005; Kerckhoffs et al. 1992; Mol et al. 1996; Ninu et al. 1999). Sufficient energy of light is also important to promote photosynthetic production of carbohydrates, which are the substrates for flavonoid biosynthesis via the shikimic acid and phenylpropanoid pathways. Formation of flavonol glycosides such as kaempferol and quercetin also requires light, but not all phenolic synthesis is responsive to light (Dorais et al. 2008).

Tomato is a climacteric fruit and continues to ripen after harvest. During ripening, the green pigment chlorophyll degrades and carotenoids are synthesized. Light duration also affects phytonutrient levels. Even though light is not required for the ripening of tomato picked at the breaker stage, fruit exposed to an 8 h photoperiod failed to develop lycopene levels as high as those in 24 h exposed fruit (Cox et al. 2003).

Carotenoids, particularly lycopene and ß-carotene, represent the primary components of ripe fruit pigmentation in tomato pericarp and are responsible for the characteristic colour of ripe tomatoes, conferring deep red and orange colours, respectively. These carotenoids largely influence the quality perception of fresh tomatoes (Liu et al. 2009). Alba et al. (2000) reported that red light treatments (six 40W Gro-lux lamps) increased lycopene accumulation 2.3-fold in tomatoes and that red light-induced lycopene accumulation was reversible by far-red light treatment. Red light treatment increased the carotenoid content and red color of tomatoes, with varying effects on tomato firmness (Lee et al. 1997). Schofield and Paliyath (2005) and Liu et al. (2009) showed that the lycopene contents of the tomatoes were increased greatly by red light treatment, compared to those of control tomatoes. Sun light had the least impact on tomato lycopene content but red light stimulates carotenoid accumulation in tomato, while far-red light stops the production of carotenoids such as lycopene, probably from fruit-localized phytochromes (Alba et al. 2000; Thomas and Jen 1975).

In contrast, under excessive solar radiation or UV radiation of only a few hours, photo-oxidative damage or photoinhibition may occur and reduce lycopene synthesis as well as vitamin C content of tomato fruit (Adegoroye and Jolliffe 1987; Prohens et al. 2004). Torres et al. (2006) observed, either with or without UV radiation, that tomato fruit exposed for 5 h to high solar irradiance had 30% less ascorbic acid and 20% less dehydroascorbic acid in the fruit exocarp, suggesting a partial degradation of the entire ascorbate pool. They also observed a decrease in total carotenoids after 5 h of exposure, with a significant interaction between duration of exposure and intensity of UV radiation. Moreover, UV light seems to have a physiological effect on tomatoes, to our knowledge there are no reports on the effect of UV light treatment on the concentration of the major carotenoids in tomatoes (Liu et al. 2009). The UV-C treatment also increased the lycopene content of tomatoes during storage. Liu et al. (2009) demonstrated that the sun light treated tomatoes had a 1.5-fold increase in lycopene content at day 21 of storage, when compared to that of untreated control tomatoes. This indicates that light (especially at UV-C wavelengths) might be a specific regulator of carotenoid synthesis and accumulation in tomatoes during postharvest storage (Liu et al. 2009). Even though the production of flavonoids and other phenylpropanoids may be stimulated to protect plant tissues from UV damage (Dixon and Palva 1995; Ubi 2004), natural UV radiation does not always affect flavonoid accumulation. Torres et al. (2006) found that tomato exocarp had no detectable changes in concentrations of flavonoids (quercetin, kaempferol, or naringenin enantiomers) as the duration of exposure increased.

Therefore, The quality of tomato fruits especially carotenoids, phenols and antioxidant compounds rates are strongly affected by various aspects of light such as intensity, duration, UV radiation and quality of radiations. Thus tomato quality differs in different climatic conditions and cropping systems such as protected production system or field production. However, the effects of light also depends on field conditions e.g. crop and weed densities, crop residues and mulches, plant population and shading screens that influence light interception and consequently fruit phytochemical content and its quality value related to human nutrition.

Interference of weeds with light in an organic tomato field

3.2 Temperature

Temperature has a direct influence on plant metabolism which has effect on tomato fruit development and its nutritional value (Dorais et al. 2001a; Heuvelink and Dorais 2005).

Fruit temperature affects final fruit composition (Gautier et al. 2008). Air temperature is known to influence tomato production scheduling and, during commercial production, the timing, magnitude and duration of temperature changes can be significant (Fleisher et al. 2006). Tomato plants have, within certain limits, the ability to integrate temperature (Adams et al. 2001). Plants exposed to a fluctuating temperature regime often suffer no overall loss of yield when compared with those grown in a constant regime having the same mean temperature (DeKoning 1990; Hurd and Graves 1984; Khayat et al. 1985). However, fluctuations in temperature may affect the pattern of crop yield as the rate of developmental events such as fruit maturation is determined largely by temperature (Hurd and Graves 1985). DeKoning (1994) indicated that the sensitivity of fruits to temperature interacted with their stage of development, with fruits being less sensitive to temperature in the middle stages of their development. Furthermore, temperature extremes can inhibit the ripening process (Lurie et al. 1996). Temperature affects not only the time of fruit ripening but also the rate of fruit growth. Pearce et al. (1993) found that in the short term the expansion of tomato fruits was closely related to temperature and did not appear to be limited by assimilate supply. Elevating the temperature often increases the fruit growth rate, but it has a greater effect in hastening maturity and, as a result, the final mean weight of tomato fruits is reduced (Hurd and Graves 1985). Adams et al. (2001) suggested that fluctuations in weekly fruit yields may well result from fluctuations in temperature due to the increased sensitivity of mature green fruits to temperature. Low temperatures reduced absolute volume growth rates and delayed the time at which the absolute growth rate became maximal. Temperature also affected the shoot dry matter content and partitioning (Adams et al. 2001).

In the literature available, the main information about the effects of temperature on the antioxidant content of tomato fruit is basically related to the caretonoids (Dumas et al. 2003). Tomatoes exposed to direct sunlight in the field often develop a poor colour, mainly because the fruit exposed to high temperatures have low lycopene content (McCollum 1954). The rate of lycopene synthesis and other carotene content drastically (not that of ß-carotene) reduced at 30°C in fresh tomatoes (Baqar and Lee 1978; Grierson and Kader 1986). In the fruit pericarp sections stored at various temperatures (Hamauzu et al. 1998) the biosynthesis and accumulation rates of phytoene and lycopene were first, whereas those of ß-carotene were low at 20°C. At 30°C, the rates for both lycopene and ß-carotene were higher and the rate for phytoene was low (Dumas et al. 2003). Gautier et al. (2005) reported decreases in sugar and lycopene content in cherry tomato when fruit temperatures were increased by approximately 1°C following fruit-set through harvest under high fruit load.

Tomato fruits are rich in polyphenols, which is the largest part of phenolic compounds like flavonoids and phenylpropanoids. At 35°C compared to 25°C the phenol level was doubled (Helyes et al. 2006). George et al. (2004) measured huge variance among polyphenol (104 – 400 mg·kg^{-1}) content of different tomato varieties. Temperature had a significant influence on the biosynthesis of lycopene and ß-carotene during ripening (Krumbein et al. 2006). They showed that a temperature above 20°C seems to be optimal for lycopene production in studied cultivars, whereas the lycopene content diminished with decreasing temperature to 15°C. Temperatures below 12°C strongly inhibit lycopene biosynthesis and temperatures above 32°C stop this process (Dumas et al. 2003). Fleisher et al. (2006) resulted that colour indices, soluble solids contents (SSD), acidity and viscosity at each ripening stage were significantly affected by high temperature treatments. The results indicate that short-term temperature perturbations following first fruit-set can influence the rates at which change occurred in the external appearance of fruit (colour) and in their internal characteristics. As carbon skeleton availability is required for the biosynthesis of certain phytonutrient compounds such as flavonoids and ascorbic acid, an increase in sugars through reduced respiration under lower temperatures may result in a higher level of phytochemicals. Consequently, ascorbic acid generally declines with increasing temperature, while temperature regulation of caretonoids is crop specific.

The marked effect of temperature upon the production of lycopene was first discovered by Duggar (1913). This remarkable contribution showed conclusively that a temperature of 30–37°C clearly inhibited the development of lycopene both in detached fruit and in fruit growing on the vine. The factors for reddening were not destroyed by the high temperature, for upon return to a temperature of 20°C. Lycopene formation occurs only at temperatures above 10°C and below 37°C. The optimum temperature depends on the genotype and interactions with environmental and cultural factors (Dorais et al. 2001a). On the other hand, Krumbein et al. (2006) recently observed an increase in the lycopene concentration of cherry and round type tomatoes when the temperature during the fruit ripening stage increased from 15°C to 20.3°C in fall and from 18°C to 22°C in spring. In agreement with Robertson et al. (1995) who found a maximum plateau of lycopene concentration between 18 and 26°C in cell suspension cultures. Krumbein et al. (2006) suggested that the optimal temperature for lycopene biosynthesis ranges between 20°C and 24°C. Also, Krumbein et al. (2006) indicated that temperature has a significant influence on the biosynthesis of lycopene and ß-carotene during ripening. They found that a temperature above 20°C seems to be optimal for lycopene production in the investigated cultivars, whereas a decrease to 15°C diminished the lycopene content. Generally, temperatures below 10°C or higher than 30°C inhibit the development of lycopene (Koskitalo and Ormrod 1972; Tomes 1963). Hence, cool night temperatures for field tomato crops reduce fruit carotenoids. In contrast to lycopene, ß-carotene of tomato is only slightly affected by high temperature, probably due to the conversion of lycopene into ß-carotene under high temperature conditions. Lycopene formation proceeded rapidly. For tomato, lycopene synthesis is highest when the temperature ranges between 12 and 21°C.

Gautier et al. (2008) showed that sugars and acids (linked to fruit gustative quality) were not considerably modified, but secondary metabolites with antioxidant properties were very sensitive to temperature. They demonstrated that increasing the temperature from 21°C to 26°C reduced total carotene content without affecting lycopene content. A further temperature increase from 27°C to 32°C reduced ascorbate, lycopene and its precursor's content, but enhanced rutin, caffeic acid derivates and glucoside contents. The effects of the temperature on the synthesis of other antioxidants have not yet been properly assessed (Dumas et al. 2003). Dorais (2007) found that the use of a low temperature pulse (12°C compared to 15°C, over a 2–4 h period) at the end of the photoperiod for a same 24 h average temperature (18.5°C) decreased the lycopene content of the fruit and their antioxidant activity. Consequently, the widespread use of a prenight low temperature by greenhouse growers to control plant balance may affect the health qualities of fruit at harvest. At 35°C, the rates for ß-carotene were high, but lower than at 30°C and the levels of phytoene and lycopene accumulated were both very low. It was postulated that high temperatures (35°C) specifically inhibit the accumulation of lycopene because they stimulate the conversion of lycopene into ß-carotene. Formation of lycopene depends on the temperature range and seems to occur between 12 and 32°C (Leoni 1992). However, the majority of studies on the influence of temperature on fruit quality parameters have focused on post-harvest fruit ripening (e.g., Dalaa et al. 1968;

Lurie et al. 1996). The production of lycopene is inhibited by excessive sunlight and the best conditions are sufficiently dense foliage to protect the fruit from direct exposure to the sun (Leoni 1992).

In conclusion, various aspects of temperature such as temperature regim, timing, duration, fluctuations and extremes have strong effects on production scheduling, tomato growth and development, shoot dry matter weight, carbohydrate partitioning, fruit ripening, yield, fruit colour, caretonoids, lycopene, phenolic compounds and other secondary metabolites, acidity, ascorbic acid and fruit viscosity.

3.3 Atmospheric CO_2

Atmospheric carbon dioxide (CO_2) has increased about 35% since 1800 (from 280 to 380 part per million [ppm]), and computer models predict that it will reach to much higher (IPCC 2001). The beneficial effects of elevated CO2 concentrations on biomass production of horticulture crops such as tomato are well known (Dorais et al. 2001a; Nederhoff 1994; Heuvelink and Dorais 2005). This rise in CO_2 could potentially be mitigated by plants, in which photosynthesis converts atmospheric CO_2 into carbohydrates and other organic compounds. The extent of this mitigation remains uncertain, however, due to the complex relationship between carbon and nitrogen metabolism in plants (Finzi et al. 2007; Johnson 2006; Reich et al. 2006). The enhancement of growth and yields by increasing the level of CO_2 in the atmosphere has been reported for many plant species (Kimball 1983). Atmospheric CO_2 enrichment is known to significantly enhance the growth and development of nearly all plants, implying a potential for elevated levels of CO_2 to alter the concentrations of plant constituents related to animal and human health (Idso and Idso 2001). Atmospheric CO_2 enrichment additionally appears to reduce oxidative stresses in plants and it has been shown to increase the concentration of vitamin C in certain fruits and vegetables. Significant yield increases for most plant species are observed in with CO_2 enrichment (Idso and Idso 2001). Yelle et al. (1989) showed that tomatoes accumulated starch and sugars when exposed to high CO_2 concentration.

In many crops depend on nitrate rate as their primary nitrogen source, with increasing atmospheric CO_2 concentrations and diminishing nitrate assimilation, organic nitrogen, including protein depleted and food quality suffered (Taub et al. 2008). Wheat, rice and potato provide 21%, 14% and 2%, respectively of protein in the human diet. At elevated carbon dioxide and standard fertilizer levels, wheat had 10% less grain protein (Fangmeier et al. 1999; Kimball et al. 2001). Similarly, water and assimilate influx to the fruit i.e. between the fluxes of the phloem and xylem saps and of the fruit transpiration will suffer (Guichard et al. 2001). In contrast, they showed that acids and products of the secondary metabolites that are synthesized during the maturation stages could not be linked to the water and carbon fluxes between the plant and the fruit. Based upon data, it has been determined that when the 75% increase in the CO_2 concentration doubles fruit production, it increases the vitamin C concentration of the juice of the fruit 7%. This nutritional enhancement is even greater in years when fruit production is more than doubled, due to the CO_2-enriched fruit being slightly smaller than the ambient-treatment fruit in such circumstances, which increases the vitamin C concentration of the juice of the CO_2–enriched fruit (Idso and Idso 2001). In the case of ascorbate or vitamin C, Barbale (1970) and Madsen (1971) observed CO_2-inuced increases in the concentration of this important phytochemical in both the leaves and fruit of tomato plants; Kimball and Mitchell (1981) also found that atmospheric CO_2 enrichment stimulated the production of vitamin A in tomato plants.

Clearly, there are many good reasons and experimental evidences to justify the hypothesis that increase air CO_2 content and promote the production of phytochemicals beneficial to human health (Idso and Idso 2001). It is likely, therefore that the ongoing rise in air CO_2 content will continue to increase food production around the world, while maintaining the nutritive quality of that food will be enhanced.

3.4 Air Pollutants

One of the major environmental concerns recent years is the excessive pollution of air. Air pollution is the introduction of chemicals, particular mater or biological materials that cause harm or discomfort to humans and other living organisms or damage the natural environments. The pollution has attained such unacceptable levels that vast forest areas have been damaged, agricultural production lowered and the health of the whole population endangered (Upadhyay and Kobayashi 2007). Air pollutants such as dust, ozone, sulphur dioxide, nitrous oxide, nitrite-N and ammonia decreased ascorbic acid, carotenoids and Bcomplex vitamins in many fruits mainly due to their oxidative damage to fruit DNA, proteins, synthesizing enzymes and membranes (Lester 2006). One of the physiological processes that can alter or reduce the nutritional quality and the antioxidant activity of plant products is oxidative stress (Rosales et al. 2006). Ozone can alter secondary metabolites such as flavonoids or other phenolic compounds, through changes in the activity of Phenylalanine Ammonia-lyase (PAL) and thus the status and productivity of the whole phenylpropanoid pathway (Manning and Tiedemann 1995). Carbon allocation in plants may also be affected by O_3 via effects on photosynthesis and modification of the canopy structure, and hence the environment around the fruit, which may indirectly affect their nutritional value.

Air pollutants had effects on carbon allocations, ascorbic acid and caretonoids phenolic compounds in tomato; however, there are only limited references available. Effect of air contaminants produced by volatilization of pesticides under elevated temperature on health-promoting compounds is also another aspect that has not been extensively investigated in tomato fruit.

3.5 Water and Salinity

Water deficit and poor water quality are the main factors limiting worldwide crop productivity and food quality in terms of nutritional value and food safety (Dorais et al. 2008). Changes in soil-water relations can affect the quality and the yield of crop harvests depending upon irrigation frequency and availability of soil water to the plants (Mitchell et al. 1991). The amount of water applied is dependent on irrigation schule, soil properties and evapotranspiration rates which are in turn influenced by crop environment and stage of growth. Irrigation schedule can impact positively or negatively on the growth and yield of tomato (Lecoeur and Sinclair 1996; Locascio et al. 1981; Obreza et al. 1996) depending on the amount of water applied. Therefore, it is important to determine optimal irrigation regimes that promotes yield and quality of tomato for specific localities, which are essential for successful marketing of tomato (Phill and Lambeth 1981).

Irrigating a tomato field in a semi-arid conditions of Iran

Nutritional quality of tomatoes may be affected by the amount of water applied, regardless of fertilizer management, and their irrigation system. For example, heavy rainfall may reduce the oxygen concentration in the soil, and indirectly affect the nutritional value of fruit. Depending on the production system, irrigation water is generally provided by surface and subsurface irrigation, sprinkler irrigation or micro-irrigation (Locascio 2005). Given the scarcity of high quality water in many parts of the world, deficit irrigation can constitute a sustainable tool for water conservation and reduction of leaching into ground water, as well as a plant management tool to improve the nutritional value of tomato fruit. Depending on cultivar, low soil water tension generally decreased the vitamin C content of the fruit (Rudich et al. 1977). For example, drip irrigation increased the tomato ascorbic acid content compared to surface irrigation due to a reduced amount of water available to the fruit (Mahajan and Singh 2006).

Analysis of cherry tomato produced under the influence of moderate salt stress showed increases in the lipophilic antioxidative ability and the amount of carotenoid, whereas the level of glycoalkaloid decreased (Leonardi et al. 2000). Tomato fruit is an organ with slow transpiration, and more than 85% of the water is supplied via the phloem. Water stress induced by high salinity mainly restricts the amount of water supplied to the fruit by the phloem, whereas the concentration of the phloem sap is increased (Ho et al. 1987). Under water stress conditions, increase in abscisic acid may influence ethylene production, which has an effect on the concentration of carotenoids. Salinization is generally accompanied by a decrease in yield, the use of salinized water increased healthpromoting molecules in tomato and its nutritional value (Dorais et al. 2001b). Because high salinity in the root zone impairs water uptake, the increase in health-promoting molecules may have been related to a water stress and a concentration effect. Moderate stress, however, may activate physiological antioxidant responses (Gomez et al. 1999; Smirnoff 1995) and thereby improve carotenoid levels and antioxidant activity in tomato fruit. More specifically, lycopene concentration may increase with moderate salinity due to an up-regulation of gene encoding enzymes involved in the key steps of lycopene biosynthesis, while inhibition may result under higher salinity, resulting in reduced lycopene content. However, the nutritional quality threshold varies depending on cultivar and growing conditions as well as on targeted phytonutrients. For example, under moderate salinity where greenhouse crop fruit yield was not reduced, adding NaCl to the nutrient solution to improve flavour did not affect phytonutrients such as antioxidant vitamins (ascorbic acid, a-tocopherol), carotenoids (lycopene and lutein), or flavonoids (quercetin) (Shi et al. 2002). An increase in salinity by 45% with NaCl or NaCl/KCl (1:1) did not change lycopene content, but it decreased ß-carotene and vitamin C content and increased lutein concentration by 79% (Dorais et al. 2000). With different tomato cultivars and growing conditions, however, Wu et al. (2004) observed a 34–85% increase in lycopene content on a fresh weight basis when salinity was increased from 2.4 to 4.5 $mS{\cdot}cm^{-1}$. De Pascale et al. (2001) observed that the optimum total carotenoids and lycopene content were reached when salinity was 4.0–4.4 $mS{\cdot}cm^{-1}$ (0.25% NaCl), while ascorbic acid content increased with salinity up to 15.7 $mS{\cdot}cm^{-1}$. Carotene did not change with salinity. Similar results for ß-carotene were found by other authors (Petersen et al. 1998; Krauss et al. 2006).

Salinity in non-tolerant cultivars may reduce leaf area of tomato plants, modifying the light and temperature conditions of the fruit, and thereby indirectly influencing the phytonutrient content. This genotype-dependent plant response may partly explain different results and thresholds reported in the literature. Salinity also changed mineral uptake profiles (Ehret and Plant 1999). For example, increasing water salinity from 0.5 to 15.7 $mS{\cdot}cm^{-1}$ with NaCl decreased P, K, Mg and Zn fruit concentrations due to ion competition with Na and Cl (De Pascale et al. 2001), which is undesirable. On the other hand, salinity decreased fruit nitrate content, which is desirable for food processing and human health (De Pascale et al. 2001).

In summary, water rate and availability, irrigation regim and system, salinity and other quality aspects of water are important studied water related factors that could change tomato fruit yield, quality, nutritional value, caretonoids, lycopene, ascorbic acid contents and lipophilic antioxidative ability.

3.6 Soil Conditions

Soil is the fundamental medium for crop growth in all production systems. The success of any system depends to a large extent on the soil characteristics such as nutrient supply and structural characteristics that affect rooting. Soil conditions influence crop growth indirectly by affecting weed growth, pests and diseases as well as directly by supplying water and nutrients (Ghorbani et al. 2008b). A good soil structure is very important in having a successful tomato crop. It not only affects crop productivity, it also influences the quality of fruit tomato. When a soil and consequently plant is not healthy, it won't be resistant to disease and pests. Tomatoes prefer a soil that is deep, loose, rich and with plenty of organic matter with a pH level of 6.5 to 7.0.

The effect of minerals on phytonutrients and nutritional value of tomato depends on the specific mineral, the mineral form, the plant genotype, and any possible interactions with environmental conditions and agronomic practices. In general, even though moderate application of N increases yield, N fertilizers decrease the concentration of vitamin C and carotenoids, while K fertilization has the opposite effect. Secondary plant metabolites which lack N in their structure such as lycopene, ß-carotene, phenolics and flavonols are favoured under N-limiting conditions although photosynthetic activity is not simultaneously reduced, whereas nitrogen-containing compounds are favoured when N is readily available and not limiting to growth. Phosphorous may increase the level of some phytochemicals like ascorbic acid, anthocyanins, flavonoids and lycopene, although interactions with climatic factors and growing season may occur (Bruulsema et al. 2004; Lester 2006), while boron availability affects phenolic content (McClure 1975). According to Mozafar (1994), ascorbic acid increases with increasing levels of P, K, Mn, B, Mo, Cu, Co and Zn, while ß-carotene increases with increasing levels of K, Mg, Mn, B, Cu and Zn, and B-complex vitamins increase with increasing levels of N, P and B (Lester 2006). Thus, good nutrition is vital for maintaining health and preventing disease (Hamouz et al. 2005).

Several studies demonstrated direct and indirect effects of plant nutrition on tomatoes. The enhanced nutrition treatment was found to have a significant positive effect on tomato quality, color and acceptability (Kimball and Mitchell 1981). Lowering nitrogen supply had a low impact on fruit commercial yield (−7.5%), but it reduced plant vegetative growth and increased fruit dry matter content, improving consequently fruit quality. Fruit quality was improved due to lower acid (10–16%) and increased soluble sugar content (5–17%). The content of some phenolic compounds (rutin, a caffeic glycoside and a caffeic acid derivate) and total ascorbic acid tended to be higher in fruit with the lowest nitrogen supply. It was concluded that primary and secondary metabolites could be affected as a result of a specific response to low nitrogen, combined with a lower degree of vegetative development, increasing fruit irradiance and therefore modifying fruit composition (Bénard et al. 2009). Nitrogen fertilizer has generally been thought to increase the carotene concentration in plants (Mozafar 1993) but few specific data are available in the literature in this point. A number of studies carried out during the last 50 years or so have consistently shown that increasing the N rates tends to decrease the vitamin C content of the fruit. Mineral nutrition had first been thought to have no effect on the ascorbic acid content in several varieties (Hamner et al. 1945). However, heavy N application might cause some vitamin C decrease, probably for indirect reasons, since N supply might enhance the foliage and hence the shading of the fruit on plants unevenly illuminated by direct sunshine (Dumas et al. 2003). In another study (Montagu and Goh 1990) where various forms of nitrogen at four rates were applied to tomatoes in pots, the fruit vitamin C content decreased almost linearly from about 320 $mg \cdot kg^{-1}$ fm to about 230–250 $mg \cdot kg^{-1}$ fm when the N applied was increased from 0 to 600 $kg \cdot ha^{-1}$. Therefore, supplementary N, especially at high rates, generally tends to decrease the tomato fruit vitamin C content, possibly due to the increased shading caused by the greater development of plant foliage due to high N availability. The present tendency to reduce the N supply in agriculture as far as possible for food quality and environmental reasons and to reduce the production costs may, therefore, contribute to maintaining a high vitamin C content in tomatoes. It has been reported in several papers that the vitamin C content of tomatoes could increase with the supply of combined fertilizers.

Potassium by influencing the free acid content and P due to its buffering capacity directly affects tomato quality. It was observed that potassium (K) had a significant effect on lycopene and other carotenoids (Dumas et al. 2003). Lacatus et al. (1994) showed that K and P nutrition had a positive effects on fruit sugar and acid content. Of the nutrition factors, the soil K content most affects the total acid content in the fruit. Davies and Winsor (1967) found a positive logarithmic correlation between the K level in the soil and the acid content of the fruit. Increasing the phosphorus (P) supply from 0 to 100 $mg \cdot l^{-1}$ nutrient solution under hydroponic growth conditions greatly improved the colour of fruit and increased the lycopene content (Saito and Kano 1970). Wright and Harris (1985) reported that increased N and K fertilization had a detrimental effect on tomato flavor, as scored by a taste panel (although increased acidity and soluble solid content resulted from increasing fertilization). The application of N fertilizer did not have any effect upon tomato yield, whereas application of K fertilizer did increase the yield. Application of K fertilizer was often associated with increased sugar concentration (Liu et al. 2008). Hartz et al. (2001) suggested that current soil K recommendations be adjusted upwards for maximum fruit yield and that optimizing fruit color uniformity may require a greater soil K supply than needed for maximum fruit yield. K can improve the quality of tomato by influencing carotenoids synthesis. K can improve the quality of tomato by influencing carotenoid synthesis. An early study demonstrated that total carotenoid content of tomatoes generally increased with increasing amounts of K in nutrient solution. Studies of fruit pigmentation at various stages of ripening showed that the chlorophylls generally decreased as the total carotenoids increase during ripening. At any stage of ripening, the carotenoids content of K-deficient fruit was lower than that of normal fruit (Trudel and Ozbun 1970, 1971). Lycopene content of tomato increased linearly with increasing potassium level in the nutrient solution (Serio et al. 2007). Also, the lycopene content rose sharply with increasing K fertilization which was increased by as much as 65%. The authors concluded that lycopene is the pigment most sensitive to K deficiency and that since K is as essential co-factor in protein synthesis its deficiency could lead to reduced rates of enzymatic reactions involved in carotenoid and precursor synthesis (Ramirez et al. 2009).

Therefore, soil structure, soil physical and chemical characteristics, mineral and organic fertilizers and soil organic matter influenced mainly tomato yield, secondary plant metabolites, lycopene, caretonoid, phenolics, flavonols, vitamin C, and vitamin B complex.

3.7 Chemical Pesticides, Growth and Development Regulators

In the last few decades, there has been an emphasis on reducing pesticide use, with some insecticide that represent the greatest risk to human and environmental health losing their registration and being withdrawn from use (Pierzynski et al. 2005). Tomato plants are infected by several soil-borne pathogens such as *Rhizoctonia solani*, *Pyrenochaeta lycopersiand* and *Fusarium oxysporum* f. sp. lycopersici. Their control accomplished through using chemicals such as fumigation of soils with Methyl Bromide (MeBr). This chemical contaminates the environment, affects the ozone layer, destroys the soil microflora and must be applied very season because of its null residual activity and the rapid re-colonisation of soils by the phytopathogens. Evaluation of fruit yield and quality showed that MeBr alone was not better than the other treatments when total yield or first fruit quality were evaluated.

Pest pressures, by inducing defence reactions in the plant, may stimulate the production of antioxidant compounds, especially phenolics. Synthetic pesticides either stimulate or inhibit production of phytonutrients, but little is known about the effects on the composition of the edible part (Brándt and Mølgaard 2001). It has been suggested that an increase in peroxidase activity observed after herbicide treatment may contribute to resistant to herbicides by playing a role in oxidative stress tolerance, in addition to detoxifying herbicides by catalysing their conjugation with glutathione. The effect of different herbicides on phenylalanine ammonia-lyase activity and therefore on phenolic biosynthesis has also been reported (Tomas-Barberan and Espin 2001). Moreover, applications of pesticides for pest control leads to fruit pesticide residues that may exceed the maximal level (Chavarri et al. 2004; Tsakiris et al. 2004). Soils also often have pesticide residues that can be translocated to the fruit (Gonzalez et al. 2005). Despite increasing concerns about fruit and vegetable pesticide residues by consumers, little is known about their direct effects on disease-preventing molecules in plants.

Phytohormones such as auxins, gibberellins, cytokinins and abscisic acid have been implicated in anthocyanin biosynthesis and accumulation in several plant species (Sheoran et al. 2006). Although growth regulator application may not be allowed in some countries, some reports mentioned that they can improve the health quality of tomato. For example, foliar application at the three-leaf stage of 30 lM 2-(3,4-dichlorophenoxy)triethylamine (DCPTA) increased the fruit lycopene content by 28% (Hsu and Yokohama 1991). Similarly, pre-germination seed treatment with up to 30 lM of DCPTA for 6 h increased the content of lycopene from 58 to 118 lg per g fw and of ß-carotene from 2.2 to 5.7 lg per g fw in greenhouse-grown tomato (Keithly et al. 1990).

On full-sized green tomato fruits (cv Moneymaker) at room temperature, the ethephon treatment enhanced the ripening of the fruit and ethephon combined with 2-(3,4-dichlorophenoxy)triethylamine (CPTA) resulted in faster and greater lycopene accumulation (Rabinowitch and Rudish, 1972). At 32°C, only CPTA and the combined ethephon and CPTA treatment resulted in an accumulation of red colour. Normal red fruit treated in an aqueous containing CPTA (430 mg·l^{-1}) and 1% Tween 80 as a surfactant, generally showed an increase in the rates of phytoene, phytofluene, ß-carotene, lycopene and γ-carotene syntheis at 21°C (Chang et al. 1977). At 32°C, the rate of lycopene synthesis was mulch lower and was, therefore, not stimulated by the CPTA treatment. The ability of CPTA to bring about carotenogenesis was tested in tomato cell suspension cultures (Fosket and Radin 1983). Untreated dark-grown cultured tomato cells (from callus tissues) contain low levels of carotenoids. DCPTA was applied to tomatoes as a pre-germination seed treatment at five rates, 0, 3, 15, 30, 150 μM·l^{-1} (0, 1, 5, 10 and 50 mg·kg^{-1}), for 6 h at 24°C with Tween 80 (0.1%, w/v) (Keithly et al. 1990). The lycopene and ß-carotene contents increased from 58 to 118 mg·kg^{-1} and 2.2 to 5.7 mg·kg^{-1} fm, respectively, when the DCPTA was increased from 0 to 50 mg·kg^{-1}.

In field-grown tomatoes, gibberllic acid and cycocel (2-chloroethyl trimethylammonium 3-chloride) increased the ß-carotene content of the fruit (Graham and Ballesteros 1980). Gibberellic acid and cycocel also increased fruit ß-carotene. In field-grown tomato, a 25% increase in the ascorbic acid content of the fruit was noted after applying alar solution (1,500 and 3,000 mg·kg^{-1}). Gibberellic acid, cycocel and phosphon also increased the ascorbic acid content of the fruit (Dumas et al. 2003).

3.8 Tomato Seed Genotype (Cultivar)

Identification of genotypes with high yield and high quality value, represent a useful approach to select tomato cultivars with better health-promoting properties. Breeding programs aim to accumulate the genes that increase the lycopene content and to eliminate those genes that decrease the lycopene content, while preserving the other quality characteristics (Dumas et al. 2003). Based on such data and on a literature survey on tomato composition, an index called index of antioxidant nutritional quality (IQUAN), was proposed by Frusciante et al. (2007) as a tool to address the breeding programs in selecting tomato genotype with antioxidant nutritional qualities.

The antioxidant composition as well as total antioxidant capacity has been studied with the aim to produce cultivars having high antioxidants content (Frusciante et al. 2007). The antioxidant capacity of several tomato varieties has been also tested. It has been established that the antioxidant activity of tomato extract varies with the tomato variety and the assay method used. Individual compounds found to be significantly related to antioxidant capacity are lycopene and ferulic acids

(Martinez-Valverde et al. 2002) and variation of carotenoids have been found ranging from 18.5 to 60.7 mg·kg^{-1} fm. Data from southern Italy gave 86.0 mg·kg^{-1} fm as the mean lycopene content of 24 tomato varieties in 1998 and 87.0 mg·kg^{-1} fm as that of 29 varieties in 1999. The value ranged from 34 to 150 mg·kg^{-1} in 1998 and 45 to 163 mg·kg^{-1} in 1999, i.e. about 1–4-fold (Dumas et al. 2003). Guil-Guerrero and Rebolloso-Fuentes (2009) demonstrated that colored varieties seem to be good sources of antioxidant, in good agreement with the carotenoid content found in mature stages. Moreover, the antioxidative capacity of the tomato extracts showed that the antioxidant activity of the extracts of some varieties was comparable with those of the commercial antioxidants used for similar purposes. Among the different tomato cultivars, cherry tomatoes are well known, for their good taste and flavor, and although the yield of cherry tomato is only half that compared to standard large tomatoes, it is worth cultivating this new variety, especially in organic system, due to their higher nutrient value (Hallmann 2003; Hobson and Kiby 1985).

Since many epidemiological studies approved that dietary intake of carotenoids reduces the incidence of degenerative diseases, including heart disease and cancer, considerable work conducted in order to increase carotenoid contents of tomatoes through breeding programmes or ripening intervention technologies during post-harvest storage (Liu et al. 2008; Rosati et al. 2000). Changes in the antioxidant contents at seven stages during vine and post-harvest ripening have been assessed in two genotypes (Normal red and Crimson) of tomato cv Moneymarker grown in a greenhouse by Giovanelli et al. (1999) and the results showed that at the end of the experiments, lycopene and ß-carotene concentrations (roughly 12.5–30 mg·kg^{-1} and 12 mg·kg^{-1} fm, respectively) in post-harvest-ripened tomatoes were almost twice as high as the values reached in vine-ripened tomatoes (roughly 75–80 mg·kg^{-1} and 5–7 mg·kg^{-1} fm, respectively) with the same colour (a*/b*) index.

Tomato cherry cultivar of Koralik contained significantly more nutrients than the other tomato cultivars. Organic cherry and standard tomatoes can be recommended as part of a healthy diet including plant products which have been shown to be of value in cancer prevention (Hallmann and Rembiałkowska 2007). Lycopene content of three different varieties (Daaniela F1, Delfine F_1 and cherry tomato), was compared and the highest concentration of lycopene was detected in cherry tomato (77.4 mg·kg^{-1} f.w.) while Daniela F_1 and Delfine F_1 with 59.2 and 69.6 mg·kg^{-1}, respectively, were significantly lower. This agrees with Sass-Kiss et al. (2005) who found that, fresh market varieties grown in greenhouse contained less lycopene then processing varieties grown in the field. In another study conducted by Kuti and Konuru (2005) among 40 tomato varieties, greenhouse-grown cluster and round tomato types contained more lycopene (30.3 mg·kg^{-1}) than field-grown tomato (25.2 mg·kg^{-1}), whereas cherry types had a higher content in field-grown (91.9 mg·kg^{-1}) than in greenhouse- grown (56.1 mg·kg^{-1}). The ascorbic acid content of surface-irrigated tomato grown in a greenhouse was found to be 66% higher than in those grown with surface irrigation outdoors (Mahajan and Singh 2006).

The choice of variety significantly influenced the content of bioactive compounds, particularly ascorbic acid and total phenolic (Juroszek et al. 2009). Chassy et al. (2006) demonstrated that Burbank tomatoes generally had higher levels of quercetin, kaempferol, total phenolics and ascorbic acid as compared to Ropreco tomatoes. The cultivation of long life cultivars, as e.g., Vanessa should be favored. The cultivar Vanessa is characterized by a relative high firmness of the fruit flesh and peel, but by a lower intensity of the descriptive sensory flavour attributes sweet, fruity, intensive and tomato-like compared to conventional round tomatoes and Cherry tomatoes (Auerswald et al. 1997). However, there are older references that stated the variation in the tomato fruit vitamin C content due to the variety is fairly small in comparison with those resulting from the growth conditions (Hamner et al. 1945). In tomato fruit, the total phenols present in the epidermal tissue, the placental tissue, the radial and inner walls of the pericarp and the outer wall of the pericarp did not vary significantly among three cultivars tested, Patroit, Floridade and Walter (Senter et al. 1988).

In conclusion, producing tomato cultivar with genes of higher antioxidant nutritional qualities, higher lycopene contents, ascorbic acid and total phenilic, vitamin C which are human health promoting factors in tomato, are well documented; however, it should be noted that breeding method is very important for many consumers around the world. In some agricultural systems such as organic and biodynamic systems, genetically modified seeds are not allowed to use, but seeds that are improved through natural selection and acceptable classic methods of breeding are permitted.

4 Tomato Fruit Quality and Ripeness Stage at Harvesting Time

The stage of fruit development at harvest is one of the major factors determining the quality of fruit because there is an important change in the profile of antioxidants during ripening. Growth and storage of metabolites in tomato plant occur simultaneously and may hence compete for assimilates (Kosegarten and Mengel 1998). Growth limiting factors may increase the translocation rate of assimilates into tomato fruits and hence promote storage processes during fruit ripening improving fruit quality (Veit-Köhler et al. 2001). The development of red color in tomato fruit during ripening is mainly due to the synthesis of various carotenoid pigments, particularly lycopene (Mikkelsen 2005). While ripening, the concentration of sugar, carotenes, ascorbate, rutin and caffeic acid increased whereas those in titratable acidity, chlorophylls chlorogenic acid contents decreased (Gauiter et al. 2008). Fruit ripened on the plant generally had higher phytonutrient content than table-ripened fruit. Tomato fruit harvested as green or at the breaker stage and ripened to table-ripeness, contained less ascorbic acid than fruit ripened on the vine (Betancourt et al. 1977; Kader et al. 1977). During ripening, the green pigment chlorophyll degrades and carotenoids are synthesized. Carotenoids, particularly lycopene and ß-carotene, represent the primary components of ripe fruit pigmentation in tomato pericarp and are responsible for the characteristics colour of ripe tomatoes, conferring deep red and orange colours, respectively. These carotenoids largely influence the quality perception of fresh tomatoes (Liu et al. 2009). However, Dumas et al. (2003) reported that ascorbic acid was or was not affected by the ripening stage at harvest, depending on the cultivars that was studied. Tomato plants (cv Fireball) grown in a growth chamber (16 h light period at 24°C and 8 h dark period at 18°C, relative humidity 65%), the total carotenoids in the fruit increased constantly during the ripening process from 0.1 to 70 mg·kg^{-1} fm (Trudel and Ozbun 1970). In field tomato, the fruit ß-carotene content increased regularly during ripening, whereas lycopene content increased sharply between pink and red fruit stages (Cabibel and Ferry 1980). In cherry tomato, lycopene increased during ripening by 20-fold and ß-carotene by 3-fold. Lycopene content is a good index to the level of maturation (Cabibel and Ferry 1980). Considering the seven stages of I (mature green), II (green yellow), III (yellow orange), IV (orange-yellow), V (orange-red), VI (red) and VII (deep red) (Venter 1977), lycopene values as percentages of the total carotenoids were 12, 55, 72, 82, 90 and 95% at I, II, III, IV, V, VI and VII, respectively. Thus, lycopene content changed significantly during maturation and accumulated mainly in the deep red stage (Helyes et al. 2006). In all the parts of the tomato, the total phenols tend to increase from green to mid-ripe stages (Senter et al. 1988). Changes in the phenol contents in the pulp and pericarp of the cvs Ailsa Craig and Pik-Red have been reported to depend on the stage of development (Buta and Spaulding 1997). Variation in the total phenol content at seven stages during vine and post-harvest ripening in two genotypes (Normal red and Crimson) of cv Moneymarker have been assessed by Giovanelli et al. (1999) and they found that the total phenolic compound content was higher in postharvest-ripened samples (about 100–200 mg·kg^{-1} fm; the mean various content was 92.5%) than in vine-ripened fruit (about 70–110 mg·kg^{-1} fm). There were no significant differences in the phenol levels between the two genotypes. Polyphenol content changed little during fruit ripening. They also studied vitamin C content at seven stages during the vine and post-harvest ripening of tomatoes cv Moneymarker and found that ascorbic acid content decreased from about 200 to 150 mg·kg^{-1} fm then increased to about 200 mg·kg^{-1} fm. In another study, vine-ripened tomato, ascorbic acid increased from about 200 to 250 mg·kg^{-1} fm and then decreased to roughly 150–200 mg·kg^{-1} fm. However, the total ascorbate contents have been found to be relatively constant in fruit at all stages (Grantz et al. 1995). In plum tomatoes (cv Heinz 9478), ascorbic acid content of whole fresh fruit increased from the mature-light pink stage (175 mg·kg^{-1} fm) to the mature pink (209 mg·kg^{-1} fm) and mature-red stage (256 mg·kg^{-1} fm) (Shi et al. 1999).

Tomato fruit harvested at full ripeness had higher levels of carotenoids and antioxidant activity in the water-insoluble fraction, whereas the main phenolic content and the antioxidant activity of the water-soluble fraction decrease at later stages of ripeness. Lycopene content of four tomato cultivars increased from less than 0.10 lg per g fw in green fruit to about 50 lg as fruit matured to the redripe stage and to 70 lg when the fruit became overripe, softened, and began to decay (Thompson et al.

2000). It has been observed that ß-carotene synthesis stopped after the colour of the tomato had changed from orange to red (Koskitalo and Ormrod 1972).

Conflicting data concerning the accumulation rate of ß-carotene during ripening could be attributed to different growing conditions and cultivars. Fruit bruising at the breaker stage can decrease (−37%) the total carotenoids present in the locular of the fruit when it reaches the ripe stage (Moretti et al. 1998). Phytoene and phytofluene content is linearly correlated with the ripening index and formed 6.8% of the total carotenoids at the red stage. Although fruit of full ripeness exhibited the highest level of α- and ß-carotene, chlorogenic acid (a main phenol compound) declined during ripening. On the other hand, proteins (1.0–1.3 g/100 g), fats (0.1–0.2 g/100 g), fibre (1.4–1.7 g/100 g), and ash (0.6–0.7 g/100 g) did not vary during tomato ripening (Raffo et al. 2002).

Bertin et al. (2002) showed that in July, the ripening stage of tomato did not clearly affect fruit sugar content. On the contrary, in September, a slight peak in sugar content was observed at the turning stage, depending on air vapour pressure deficit and plant fruit load. Changes in acid content during ripening are well documented in the literature. Total acidity increases during fruit development, reaches a peak at the breaker stage and then decreases (Stevens 1972). After the breaker stage, malic acid decreases more rapidly than citric acid, so that the ratio also drops (Sakiyama and Stevens 1976). Davies and Maw (1972) reported that this is due to more active turnover of malic than citric acid in red fruits. The breaker stage is defined as incipient colour (Sakiyama and Stevens 1976) or the first occurrence of pink colouration (Kader et al. 1977). Bertin et al. (2002) demonstrated also that the sugar/acid ratio was better correlated with the acid content than with the sugar content in July, and equally well correlated with both components in September.

In summary, tomato quality and especially human health related characteristics of tomato fruits are influenced by several compounds and substances many of which develop during ripening stages. For example, there are references reporting that during ripening stage of tomato fruits, concentration of carotenoids particularly lycopene and β-carotene, phenol content, ascorbic acid, caffeic acid and total acidity increased. Development of those compounds and many others, occurring during the ripening stage are essential for the typical tomato nutritions and aroma. Appropriate post- harvest storage conditions can also give tomatoes a higher quality value.

5 Tomato Quality and Cropping Systems

In recent years, there has been growing interest among farmers, researchers, governmental agencies and environmental conservation groups in investigating and adopting alternative crop production practices that are less chemical-intensive, less dependent on nonrenewable fossil fuels and that function to conserve soil and water resources. This interest has resulted in part from studies documenting negative impacts of conventional agriculture on long-term profitability and resource stewardship, including declines in soil organic matter levels due to intensive tillage, surface water quality degradation due to reduced water infiltration rates and reduced soil tilth (National Research Council 1989). Over the last decades, alternative farming strategies have been increasingly investigated for opportunities to sustain and improve the soil resource base while meeting the needs and concerns of farmers (Drinkwater et al. 1995; Ghorbani et al. 2010; Mitchell et al. 1998).

Fundamental differences between organic and conventional production systems, particularly in soil fertility management, may affect the nutritive composition of plants, including secondary plant metabolites (Ghorbani et al. 2008b). Organic systems emphasize the accumulation of soil organic matter and fertility over times through the use of cover crops, manures, composts and rely on the activity of a diverse soil ecosystem to make N and other nutrients available to plants (Mitchell et al. 2007). Organic horticulture is generally accepted as friendly to the environment, good for crop quality and also for the consumer's health. Recent research data has shown that organic crops under organic farming practices contained more bioactive substances such as flavones, vitamin C, carotenoids; they also contain less pesticides residues, nitrates and nitrites (Hallmann and Rembiałkowska 2007). Consumers often regard organically produced food to be tastier and healthier than conventional products (Ekelund and Tjärnemo 2004).

Reviews studies comparing the nutritional quality of conventionally and organically produced vegetables demonstrate inconsistent differences with the exception of higher levels of ascorbic acid (vitamin C) and less nitrate in organic products (Bourn and Prescott 2002). There are references that compared the levels of secondary plant metabolites (e.g., antioxidants) in conventional and organically grown foods. Hakkinen and Torronen (2000) compared the phenolic content in three cultivars of strawberries grown organically and conventionally. They reported that only one cultivar grown under organic conditions showed higher levels of phenolic than inorganically grown counterpart, whereas the other two cultivars showed no significant differences in their phenolic contents. Hallmann and Rembiałkowska (2007) demonstrated that conventional tomatoes were richer in lycopene and organic acids. Heeb et al. (2005a) demonstrated that significantly higher scores were achieved for sweetness, acidity, flavour and acceptance for the tomatoes grown with the organic or the ammonium-dominated treatments compared with the tomatoes grown with the nitrate dominated nutrient solution. It is suggested that ammonium is an equivalent nitrogen source for tomato plants compared with nitrate and that, when tomato plants are supplied with reduced nitrogen forms such as ammonium or organic nitrogen, an improved tomato fruit taste can be observed. The nutritional quality of organically grown plants has been compared mainly in terms of macronutrients, vitamins and minerals. The mean total phenolic and ascorbic acid content of tomatoes grown organically was higher than the tomatoes grown using mineral fertilization. (Toor and Savage 2006; Toor et al. 2006a). Ghorbani et al. (2008a) reported that application of poultry manure in an ecological system showed lower disease incidence, as shown by 80% healthy tomato, compared with the other fertilizer.

Many studies around the world reported that organic plants contain more bioactive substances. Guil-Guerrero and Rebolloso-Fuentes (2009) showed that tomatoes grown on organic substrates contained significantly more Ca and vitamin C and less

Fe than did fruit grown on hydroponic media. Another study demonstrated that organic tomatoes contained more dry matter, total and reducing sugars, vitamin C, ß-carotene and flavonoids in comparison to the conventional ones (Hallmann and Rembiałkowska 2007). In a greenhouse experiment, organic fertilizers released nutrients more slowly than mineral fertilizers, resulting in decreased S and P concentrations in the leaves, which limited grown and yield in the organic N treatments. Analysis of tomato fruits and plants as well as taste-test gave no conclusive answer on the relationship between sugar or acid contents in the fruits, macronutrient content of plant leaves and fruits and perceived taste (Heeb et al. 2005a). Organic fertilizers release nutrients not as fast as mineral fertilizers and therefore, plants supplied with organic fertilizers often grow more slowly compared to plants fertilized with readily available mineral nutrients. This might reduce their water content leading to a higher concentration of plant compounds, e.g., sugars and acids (Hobson 1988; Guichard et al. 2001). In a tomato experiment using organic or mineral fertilizers with different ammonium-to-nitrate ratios, it was shown that the taste of organic or ammonium-fertilized tomatoes was better compared to the nitrate-fertilized ones (Heeb et al. 2005b). At moderate total N supply, high ammonium-to-nitrate ratios did not decrease yield or fruit quality (Heeb et al. 2005a, b). Different nitrogen forms in organic or mineral fertilizers affect yield, quality and taste of tomatoes (Heeb et al. 2005a, b). Plants can take up N either as ions (NH_4^+ or NO_3^-), or as organic N (Gagnon and Berrouard 1994; Sandoval-Villa et al. 2001). In organic tomato production, N is supplied as organic fertilizer, e.g., animal manure, composts or plant residues. This organic material is mineralized by microorganisms and small molecules of organic N (e.g., amino acids) and NH_4^+ are released. Finally, NH_4^+ can be nitrified to NO_3^- (Heeb et al. 2005a, b). In this study ammonium was a very effective source of nitrogen for tomato plants when applied in an NO_3^-: NH_4^+ ratio of 1:4 provided that the total nitrogen supply was lowers than 750 mg N plant^{-1} week^{-1}. Gao et al. (1996) observed that application of high NH_4^+ and low NO_3^- levels increased the reduced nitrogen forms in the plants and that this treatment resulted in improved fruit quality. In an organic production system for tomatoes, it was observed that the soil solution of the organic system contained higher NH_4^+ and chloride levels compared to systems using inorganic fertilizer (G redal 1998). Studies on the benefit of NH_4^+ for plant growth have led to contradictory results. The addition of low levels of NH_4^+ to a NO_3^- based system can have positive effects on growth (Gill and Reisenauer 1993) and on taste (Siddiqi et al. 2002). On the other hand, NH_4^+ nutrition, especially at high levels, can result in plant growth problems, generally referred to as NH_4^+ toxicity (Glass et al. 1997; Zhu et al. 2000). The occurrence of blossom-end-rot (BER) was one major problem that has been observed in tomato production when NH_4^+ was used as N source (Hao and Papadopoulos 2000; Hohjo 2001). These experiments suggested that plants may save energy by taking up reduced nitrogen. It is then possible that the energy saved may be used for increased production of secondary metabolites. This could result in an improved fruit quality and taste (Heeb et al. 2005b). There is a scarcity of data on the effect of the form of N on the production of secondary metabolites in plants (Brándt and Mølgaard 2001).

According to the 'C/N balance theory', when N is readily available, plants will primarily make compounds with high N content (e.g., protein for growth). When N availability is limited, metabolism changes more towards carbon-containing compounds such as starch, cellulose and non-N containing secondary metabolites such as phenolics and terpenoids (Haukioja et al. 1998). The relative differences in the release of nutrients from various fertilizers could lead to different C/N ratios in plants and this in turn could lead to a difference in the production of secondary metabolites (Brandt and Molgaard 2001). Compared to their conventionally-grown counterparts, organic products are lower in waste content, reserving higher nutrient density; richer in iron, magnesium, vitamin C and antioxidant; more balanced with essential amino acid. Organic produce has consistently been rated to have better flavor and texture than non-organic produce. Moreover, organic foods have enhanced nutritional quality; for example increased amounts of vitamin C in organic foods increase the effect of vitamin E, folic acid and iron in our bodies. Aggregation of farms by type (organic vs conventional) across two years resulted in no significant differences between organic and conventional farming systems for all tomato parameters measured, including quality (pH, soluble solids, acidity and colour), content of bioactive compounds with antioxidant activity (ß-carotene, lycopene, ascorbic acid and total phenolics), and antioxidant activity (Juroszek et al. 2009). Toor et al. (2006a) showed that the nutrient source plays a major role in determining the levels of titratable acidity and antioxidant components in tomato. Also, fertilizers sources can have a significant effect on the macronutrient concentration, taste and antioxidant components of tomatoes. They suggested that the titratable acidity of tomatoes can be significantly improved with the use of organic and fertilizers and may help to improve the taste of tomatoes. Researches should continue to explore the role of organic foods in promoting human health and safety and make use of new holistic research methods.

In organic systems using mulches are recommended. Mulch materials in tomato crops may have an indirect influence on fruit phytonutrients via their effect on weed control, reduction of nutrient losses, and improvement of the soil hydrothermal regimes, and light quality that is reflected to the plants. Similarly, covering materials for greenhouses generally block most of the UV radiation and may reduce or/and modify the spectral quality received by plants, affecting tomato health-components (see section on light). Protected cultivation and greenhouse technology which are largely spread around the world (greater than 450 000 ha, around 13% of the total tomato production, Dorais et al. 2001a) are the best alternative for using land and other resources more efficiently. Wang et al., (2008) suggested that either production of cover crops, especially sunn hemp, or the application of compost at high rates can improve winter fresh market tomato yields and quality and advance organic farming. Moreover, greenhouses provide a controlled environment that offers a great opportunity to improve the concentration of phytonutrients in tomato. Brandt et al. (2003) significantly higher lycopene content was observed in tomato harvested in glasshouse grown (83.0 $mg{\cdot}kg^{-1}$ f.w.) than in field- grown (59.2 $mg{\cdot}kg^{-1}$ f.w.), at different harvesting times.

In conclusion, based on the present data, production system can change the quality of tomato fruits. In addition to sweetness, taste, flavour and storability, contents of lycopene, organic acids, phenolic and ascorbic acids, secondary metabolites, vitamin c and E in tomato produced in organic farming and low input production systems in most cases were higher than tomato of conventional production systems. However, knowledge about the nutritive value and antioxidant status of organic tomato is still leaking.

Application of mushroom-bed residues as a mulch in an ecological tomato farm in Iran

6 Tomato Processing, Packaging and Storage

Although tomatoes are commonly consumed in fresh, over 80% of the tomato consumption comes from proceed products such as tomato juices (Gould 1992). There are various methods of processing, but those that preserve antioxidant capacity of the foods such as high pressure processing which can be achieved without heating are useful for preserving antioxidant capacity (Cheftel 1992; Farr 1990). Different processing forms of tomato including pulp, purée, sauce, juice, paste and peeled whole tomato (Hayes et al. 1998; Slimestad and Verheul 2005) which are important sources of carotenes, organic acids and phenolics for human (Giovanelli and Paradiso 2002; Loiudice et al. 1995; Scalbert and Williams 2000) could be done in many ways. The quality and the chemical composition of tomato may changes during processing. Consumers are demanding high quality and convenient products with natural flavour and taste and greatly appreciate the fresh appearance of minimally processed food (Oey et al. 2008).

The effects of tomato processing on lycopene, ascorbic acid and phenolics have been studied by several authors (Dewanto et al. 2002; Gahler et al. 2003; Re et al. 2002; Sahlin et al. 2004; Toor and Savage 2006; Toor et al. 2006a). In order to extend the shelf life of these products they are usually processed thermally using methods such as hot water immersion, however these treatments can cause a reduction in antioxidant capacity (Dewanto et al. 2002). Mikkelsen (2005) showed that packing commonly expose tomatoes to supplemental ethylene gas (a natural hormone produced by many types of fruit) in order to accelerate the ripening process. Patras et al. (2009) showed that redness and colour intensity of purée were better preserved by high pressure processing than conventional thermal treatment. Also, antioxidant activity, ascorbic acid and carotenoids after exposure to high pressure treatment (400–600 MPa) were well retained. From a nutritional prospective, high pressure processing is an excellent food processing technology which has the potential to retain compounds with health properties in foods. Therefore, high pressure processed foods could be solid at a premium over their thermally processed counterparts as they will have retained their fresh like properties (Patras et al. 2009). Thermal processing is the most common method for extending the shelf-life of tomato juices, by inactivating microorganisms and enzymes. However, heat treatment can reduce the sensory and nutritional qualities of juices (Braddock 1999). Therefore, consumers demands for healthy and nutritious food products with a fresh-like appearance has raised the awareness of the food industry for the development of milder preservation technologies to replace the existing pasteurization methods (Linnemann et al. 1998). High intensity pulsed electric fields (HIPEF) processing of liquid foods is being investigated to avoid the negative effects of heat pasteurization (Deliza et al. 2003). HIPEF treatment is efficient enough to destroy microorganisms in fruit juices at levels equivalent to heat pasteurization (Yeom et al. 2000). Odriozola-Serrano et al. (2008) showed that HIPEF processing could produce tomato juice with higher nutritional value than conventional thermal processing. Also, storage time shows a significant effect on the studied compounds. Lycopene, vitamin C and antioxidant capacity deplete with time irrespective of the treatment applied, whereas the initial content of total phenolic compounds is kept during storage. The bioavailability of the nutrient content of tomato products depends on the processing that they have undergone and on the duration and conditions of storage (Sánchez et al. 2006). A decrease of ascorbic acid quality during the storage of ripe fruits was established. As a result additional ripening during which a synthesis of ascorbic acid becomes and followed by storage at 1°C, its content was near this of fruits in red-ripe stage at the moments of harvesting (Brashlyanova and Pevicharova 2008). The content of pigment substances indicated a changeability which is associated with the decrease of lycopene content and the increase of ß-carotene one. During the additional ripening under refrigerated conditions the synthesis of ß-carotene was faster than the synthesis of lycopene in respect to tomatoes that had been ripened in the open air (Brashlyanova and Pevicharova 2008).

Ordóñez-Satos et al. (2008) concluded that the lycopene content of bottled tomato pulp remained stable during 180 days' storage; ß-carotene and total phenolics concentrations rose significantly, while the concentrations of malic, ascorbic and citric acids all underwent significant reductions that correlated well with an increase inHMF (5-Hydroxymethyl-2-furfural) concentration.

There are large genotypic variations in tomato quality attributes and it is possible to develop new cultivars which have good eating quality and maintain their firmness when fully ripe so that they can withstand the postharvest handling procedures. Hossain and Gottschalk (2009) resulted that significantly higher losses of colour, ascorbic acid, lycopene and total flavonoids were found for room environment than those of cool chamber. Tomatoes subjected to bruising usually have less “tomato-like” flavor and more off-flavors than those without physical damage. Ethylene treatment results in faster and more uniform ripening of green tomatoes by reducing their ‘green-life’. Since ethylene treatment reduces the time between harvest and consumption, it may have positive effects on flavor quality and vitamin C content relative to tomatoes picked green and ripened without ethylene application (Kader 1986).

Therefore, the processing method and storage conditions can reduce tomato quality characteristics such as ascorbic acid, pigment substances, lycopene, and total flavonoids. Using processing methods which retain tomato health related properties e.g. high pressure methods instead of thermal processing should be chosen carefully. However, it should be considered that postharvest losses in quality and quantity are very often related to immaturity at harvest, inadequate initial quality control, incidence and severity of physical damage, exposure to improper temperatures, and delays between harvest, processing and consumption. Shortening the time between harvest and consumption can minimize loss of mentioned nutritional characteristics in tomato.

Harvested organic tomato before storage

7 Conclusion

Based on the reviewed literatures in this paper, the final quality is not depending merely on genotype or breeded seeds. Tomato fruit quality, including appearance (colour, size, shape, freedom from defects and decay), firmness, flavor, and nutritional value is a product of interaction of genotype, environmental factors, agricultural practices, after-harvest processing and storage. Many environmental factors especially light, temperature, atmospheric carbon dioxide, air pollutant, chemical pesticides, water availability, salinity and soil conditions can greatly impact the nutritional quality of tomato fruits. Finding the best combinations of those factors to maximize nutritional quality, often affected quite differently by a particular set of conditions, will be a big challenge. The development of models of tomato nutritional quality may assist in defining the conditions required to maximize all of those specific health attributes. Although the ideal would be a single set of environmental conditions which promote high nutritional quality in all tomatoes, this may not be logistically possible. Having a high degree of control over the environmental factors which is being practical in greenhouses could enhance the quality of greenhouse-grown tomato fruit. However, the positive effects of some environmental conditions on nutritional quality are offset by negative effects on yield. This may mean that health-promoting tomatoes would be produced under unique growing conditions which do not necessarily gain the highest yields, and could then be marketed as a specific health promoting food.

It is necessary to know more about the effects of environmental conditions and production practices on quality characteristics, especially lycopene, pholic compounds and antioxidants contents in tomatoes. Cropping production systems such as organic or ecological farming that involve organic fertilizers such as compost, manure and farm yard, using minimum chemical pesticides, using renewable non-fossil inputs, applying mulches and cover crops all had positive effects on tomato fruit quality and human health related factors. It would be of great interest to have more data to help understanding more clearly how agronomic factors and techniques are liable to affect the canopy characteristics and interfere with the effects of light, temperature, and carbon dioxide which along with the genetic background and production practices, are the main determinants really responsible for the accumulation of these compounds during ripening and storage. Packing tomato for houses commonly expose tomatoes to supplemental ethylene gas (a natural hormone produced by many types of fruit) in order to accelerate the ripening process. Commercial tomatoes are frequently selected for disease and pest resistance or growing season restrictions that are best served by a particular hybrid. Also, cultural practices such as picking fruit before it is vine ripened also can have negative effects on taste and quality.

Therefore, increasing consumer demands for healthy and nutritious tomato products with a fresh-like appearance has raised the awareness of the food industry for the development of environmentally friendly agricultural practices and milder preservation technologies should be applied instead of conventional agricultural methods and existing high demand energy and pasteurization approaches. Although improved quantity and quality has long been a goal of breeding programs, little attention has been paid to tomato nutrition and even some scientists (e.g. Davis et al. 2004) believe in a decline in some aspects of nutritional quality of tomatoes in last decades. Therefore, the goal should be now to produce highly flavorful, nutritious tomatoes with healthy promoting compounds while maintaining the more grower-focused characteristics of high yield, pest and disease resistance, etc.

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