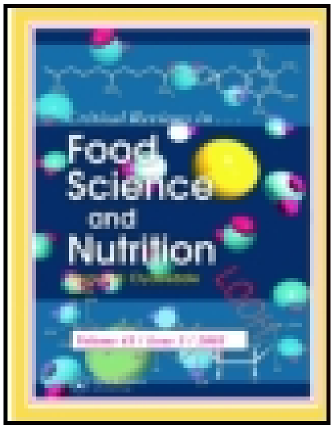

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GENOTYPIC VARIATION IN TOMATOES AFFECTING PROCESSING AND ANTIOXIDANT ATTRIBUTES

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Abstract

Tomatoes are widely consumed either raw or after processing and can provide a significant proportion of the total antioxidants in the diet associated with beneficial health properties. Over the last two or three decades an increasing interest for processing and antioxidant attributes in tomatoes has arisen. The screening of processing attributes of tomatoes is subject of a large number of articles; however, special interest has been addressed to the biochemical composition. The postharvest and industrial processing of tomato in tomato-based products includes several steps. Processing and antioxidant characteristics of the raw fruit are important considering the processing steps and final product. To respond to consumer and industrial complaints, breeders should know the range of genetic variability available in tomato resources, including local genotypes, for improving the mentioned attributes. Characterization and conservation of traditional and modern varieties is a major goal for their preservation and utilization. The bioactive contents have an impact on the processed destines so their stability must be contemplated while selecting the tomato fruits for processing. The endeavor of this review was to examine comprehensively the variation in processing and antioxidant attributes among tomatoes. Role of tomato peel in terms of bioactive contents and information on high pigment tomato mutants are also touched to some extent. Probably, patterns of variation identified/ discussed in this paper would give impetus for planning breeding strategies to develop and improve the new processing cultivars with good antioxidant status.

Keywords: Tomato fruit, processing attributes, physicochemical variations, bioactive constituents, antioxidants, fruit processing.

INTRODUCTION

Tomatoes and tomato-based products are consumed around the world and consistently associated with a lower risk of several types of cancer and to a lesser extent, to a lower incidence of coronary heart disease (Ilahy et al., 2011a; Pernice et al., 2010). All tomato-based products contain micronutrients, such as potassium, antioxidant vitamin C, vitamin E and folate (Pernice et al,. 2010). In addition to their sensorial appealing, tomatoes and therefore their tomato-based products, also contain valuable phytochemicals.

The postharvest and industrial processing of tomatoes into tomato-based products includes several steps such as sorting, grading, disinfecting, storage, and transport, size reduction, drying, heating, and pasteurizing. Characteristics of the raw fruit are important considering the processing steps and final product (Siddiqui et al., 2011; Siddiqui, 2012). Size is less important for processing purpose, but it is important for table purpose. The influence of fruit size has been often a consequence of the influence of fruit shape, and this can determine the consumer preference (Atta-Aly et al., 1999). Fruit weight also determines the shape of fruits; the varieties with the highest fruit weight were flattened in shape, while a rounded shape was predominant in small-fruited varieties (Rodríguez-Burruezo et al., 2005). Tomatoes with fewer locules (four or less than four) are desirable, particularly for fresh market. Tomato firmness is granted by the pericarp thickness; Thicker pulp generally enhances the firmness and ultimately the shelf life of the tomato (Batu, 2004). Tomato fruits with thicker pericarp would stand long distance transport and keep well. Firmness is a very important component of internal fruit quality, both in terms of commercialization and of the assessment of organoleptic properties (Toivonen and Brummell, 2008). The moisture content affects the juice recovery, and the alcohol insoluble solids can affect the viscosity of the juice. According to Zegbe et al. (2006), lower water content in tomato fruit could be prefer for the processing industry. pH below 4.5 is a desirable trait, because it halts the proliferation of microorganisms in the final product during industrial processing (Giordano et al., 2000).

On the other hand, the bioactive content of tomato cultivars is having an impact on the processed destines. The bioactive constituents and their stability must be contemplated while selecting the processing steps of tomato fruits (Siddiqui, 2012). Among the most labile bioactive constituents, the ascorbic acid can be mentioned. Tomato contains moderate amounts of ascorbic acid (20 mg/100 g) (Abushita et al., 2000), thus contributing to 40% of the recommended dietary allowance for ascorbic acid. Followed by the phenolic and flavonoids constituents and finally by the carotenoids presented in the fruit, and changes in these compounds would be reflected the antioxidant activity of the fruits.

Having observed the published research on tomatoes and their processing aspects it is revealed that there is wide variation in traditional and modern varieties in terms of processing and antioxidant attributes. However, studies on physical attributes are quite lesser than that on biochemical attributes. In this context, the aim of this review was to examine extensively the variation in processing and antioxidant attributes among tomatoes.

CARPOMETRIC ATTRIBUTES

Shape, size, and weight

Although phenotypic traits are classic and essential breeders' selection tools, they can be greatly affected by genetic and environmental factors. The shape (round and ovate), size (polar and equatorial diameter), and average weight of fruit are important quality attributes for nutritional and processing purposes to maintain the uniformity in handling and final product (Table 1). Fruit size is less important for processing purpose, but it is important for table purpose. The influence of fruit size has been often a consequence of the influence of fruit shape (Grandillo et al., 1999b; Terzopoulos and Bebeli, 2010). For instance, the varieties with the highest fruit weight were flattened in shape, while a rounded shape was predominant in small-fruited varieties (Rodriguez-Burruezo et al., 2005). Domesticated tomatoes show a wide range of morphological diversity, whereas wild tomatoes produce small, round fruit (Passam et al., 2007). According to Gastélum-Barrios et al. (2011), fruit size determines the consumer preference. The range of fruit weight and size (polar and equatorial diameters) varies among normal and high lycopene cultivars (Ilahy et al., 2011a; Tiwari and Upadhyay, 2011; Sekhar et al., 2009; Page et al., 2008). The cultivars also differ greatly in fruit shape, which may be spherical, oblate, elongated, or pear like. Small to medium sized fruits with lower TSS and higher acid contents are suitable for processing into juice (Cerne and Resnik, 1994). Tomato concentrate made from a large-fruited variety has a deep red color, with a pleasant texture, fire flavor, and higher sugars and acid co-efficient. Fruits of cherry tomato are generally round, similar to a cherry juicy and meaty berry, red when ripe, bigger than 1.5 cm in diameter (Silva and Giordano, 2000). It is advisable to maintain a range of 4-6 fruits per cluster to reduce the variation of average fruit weight. Number of fruits per truss also affects fruit shape and size. In most commercially grown tomato cultivars, fruit development takes about seven weeks, depending on temperature (Gillaspy et al., 1993). Over this period tomato, fruit diameter increases from few mm to 35–70 mm and fresh weight increases from 1.4 mg to 23–80 g (Andrews, 2003). Chaib et al. (2007)

observed a significant difference in fruit weight between the two groups from 35 days post anthesis (DPA) until the ripe stage. The first group included the parental lines and NIL-L9, and showed higher weight (100 g at 35 DPA and 140 g at the ripe stage) than the second group (50 g) containing NIL-B9 and lines carrying the five QTLs (Lx and Bx).

Parents of hybrids were also found to have an influence on fruit shape. Kurian et al. (2001) reported that the female parents involved in the cross, had round fruits (shape index 0.79 to 0.89) and male parents had ovate fruits (shape index 1.03 to 1.22). The hybrids produced fruits with round shape as indicated by index value less than one (0.86 to 0.92). They also reported a significant variation in individual fruit weight that ranges from 21.40 to 88.38 g in parent lines and 25.0- 70.97 g in hybrids. Rodriguez-Burruezo et al. (2005) evaluated 55 North American “heirloom” tomatoes from different origin and stated wide variation in individual fruit weight. Traka-Mavrona et al. (2002) also observed a high level of phenotypic diversity in three small-fruit sized Greek tomato landraces.

Number of Locules

Locules in tomato fruit play an important role in governing its quality (Table 1). Number of locules in the fruit is very important for the selection of varieties for processing (Chakraborty et al., 2007). Locule number is negatively associated with fruit firmness. Hence, tomatoes with the fewer locules (four or less than four) are desirable, particularly for fresh market. Pear shaped cultivars are known to have two locules whereas round fruited cultivars have a higher locules number (Chakraborty et al., 2007). Most of the world’s tomatoes, including processing tomatoes (cultivars used for canning, freezing, drying, etc.) are grown under non-limiting light conditions

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for most of the year. Under these conditions, multi-locular fruit can be easily grown (Barrett et al., 1998). The genotypes with large locular portion and with high concentration of acid and sugar have better sugar flavor than those with a smaller locular portion (Stevens et al., 1979). The lower number of locules is preferred as ascorbic acid and sugar content are markedly higher in locules than pericarp tissue (Dhaliwal et al., 1999). Different tomatoes have different locule numbers and a particular tomato material is inhomogeneous, the internal structure characteristics have a significant effect on the mechanical properties and damage of tomato fruits during mechanical harvesting (Li et al., 2011; Li et al., 2009, 2010).

Number of locule per fruit found to vary among different genotypes (Tiwari and Upadhyay, 2011; Mane et al., 2010; Sekhar et al., 2009; Kurian et al., 2001). Li et al. (2011) when studying the physical and mechanical properties of tomatoes stated that the locule number had a significant effect on height, diameter, arithmetic mean diameter, geometric mean diameter, sphericity and surface area, but it had no significant effect on volume, porosity, total mass and bulk density. Chaib et al. (2007) studied differences in locule number and the percentage of locule area in relation to the total area (%LO) of tomato fruit. They reported that, for locule number, two groups were detected, one corresponding to lines with many locules including Levovil, NIL-L4, and NIL-L9, and one corresponding to a mean of two locules for Lx and all the lines in Bgb (VilB, NIL-B4, NIL-B9, and Bx). For %LO, Levovil had the highest value, and NIL-L4, Lx, and VilB had the lowest means.

Pericarp Thickness

Pericarp thickness assumes prime importance among the parameters which conditions fruit firmness (Table 1). Thicker pulp generally enhances the firmness and ultimately the shelf life of the tomato (Chakraborty et al., 2007). Tomato fruits with thicker pericarp would stand long distance transport and keep well. Fruit firmness and the ratio of fruit wall to locular contents refer to fruit texture and increase in fruit pericarp. In the tomato, as in many but not all fleshy fruits, the mature ovary wall (the pericarp) is not highly differentiated, and a distinct exocarp, mesocarp, and endocarp are lacking. Pericarp includes the skin, peripheral pericarp, radial arms, and columella (Barrett et al., 1998). Firmness of fruit is associated with a decrease in thickness of fruits wall and inter-locular parts (Bhutani and Kalloo, 1991). Oval shaped varieties have a higher pericarp thickness than others (Thakur and Kaushal, 1995; Chakraborty et al., 2007). Pericarp thickness of the fruits depends on the parents of hybrids. Kurian et al. (2001) reported that the hybrids had increased pericarp thickness (4.46 to 6.29 mm) than the female parents. The mean pericarp thickness of the organically and hydroponically grown cherry tomato was 3.61 mm and 3.70 mm, respectively (Stertz et al., 2005). Garcia and Barrett (2006a) opined that the pericarp wall thickness does not necessarily increase with fruit weight; in some cultivars, small fruit may have quite thick walls.

Chaib et al. (2007) studied pericarp thickness of different tomato lines. The relative thickness of the pericarp, showed less variation and was distributed in three groups. There is a large variation of pericarp thickness in the same cultivar and maturity stage. For 6 of the 10 cultivars studied, the pericarp thickness decreased (7.9 to 20%) with maturity; therefore, there may be a genetic effect of pericarp thickness (Garcia and Barrett, 2006a). Chaib et al. (2007) and

Cheniclet et al. (2005) described very few differences in the pericarp pattern at anthesis, whereas marked variations are observed at the breaker stage.

Scar Size

Processors commonly believe that tomatoes with deep shoulders and large stem scars present more difficulty in peeling. However, Garcia and Barrette (2006) reported that cultivars having a small stem scar were easily peelable. Large size of scar can reduce the value of the fruit due to leakage of juice and/or enhancing pathogen (Elkind et al., 1990). Terzopoulos and Bebeli (2010) evaluated different Greece tomato landraces and recorded wide variation in scar size.

Fruit Firmness

The morphology of fruit and the permutation of the diverse tissues play a vital role in texture (Serrano-Megias and Lopez-Nicolas, 2006; Gonzalez-Cebrino et al., 2011). Texture is one of the critical components for the consumer's perception of tomato fruit quality (Causse et al., 2003; Serrano-Megias and Lopez-Nicolas, 2006). The degree of fruit firmness has been used as an indication of fruit quality and firmness may be the final index by which the consumers decide to purchase a given batch of tomatoes (Batu, 2004). According to Zapata et al. (2007), firmness is a very important component of internal fruit quality, both in terms of commercialization and of the assessment of organoleptic properties. Many traits are involved in fruit texture, mainly sensory attributes such as flesh firmness, mealiness, meltiness, juiciness, and crispness (Redgwell and Fischer, 2002; Szczesniak, 2002). Major changes in texture occur during fruit ripening, mainly associated with softening which considerably influences post-

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harvest performance, i.e. transportation, storage, shelf life, and pathogen resistance (Brummell and Harpster, 2001; Siddiqui and Dhua, 2010). The textural quality of tomatoes is influenced by flesh firmness. Changes in firmness were highly correlated with surface appearance characteristics of tomatoes that were related to color, shape and sense of feel for firmness at the time of purchasing (Batu, 2004).

Several researchers have shown that firmness (mechanical properties) of fruit or vegetables are cultivar dependent (Table 1; Allende et al., 2004; George et al., 2001) and are important factors determining differences in damage between cultivars (Rodriguez-Burruezo et al., 2005; Chaib et al., 2007; Ordones-Santos et al., 2009; Ordones-Santos et al., 2009; Gonzalez-Cebrino et al., 2011). Kacjan-Maršić et al. (2011) while assessing different processing and fresh tomato cultivars stated all the round fruits had a lower average firmness than the oval and elongated fruits. Varieties having higher fruit weight have lower firmness (Rodriguez- Burruezo et al., 2005). Varieties, maturity stage, cultivation practice, and environmental events (degree of sun exposure, drought, salinization, and water stress) are the important factors affecting tomato texture (Kacjan-Maršić et al., 2005; Kacjan-Maršić et al., 2011).

Juice Recovery (%)

Variation among different tomato cultivars in terms of juice and pulp contents was reported in literatures (Table 1; Aggarwal et al., 1995; Kumar and Singh, 1996; Mane et al., 2010; Gupta et al., 2011). Gupta et al. (2011) stated that juice and pulp contents of two tomato varieties differed significantly. Wide range of juice content in tomatoes was reported by Aggarwal et al. (1995) and Kumar and Singh (1996). Gowda (1994) and Madaiah et al. (1986)

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observed different varieties and reported the values for pulp contents 24.7 to 48.0 and 23 to 50 %, respectively, whereas the juice recovery from fruits of different genotypes ranged from 47.57 to 73.73% (Mane et al., 2010). Saimbhi et al. (2001) reported that cultivars with high locules number were juicier. The difference in juice percentage may be attributed to the variations in genetic background and moisture content of the different genotypes (Gupta et al., 2011).

Juice Viscosity

Yield and flow attributes of the finished products are of commercial importance. It is generally believed that properties related to consistency (apparent or absolute viscosity) and solid contents largely determine finished yield and flow ability (Mohr, 1987). Viscosity is an important quality parameter of tomato juice, and its loss is related to the degradation of pectic substances by endogenous enzymes such as pectin methylesterase and polygalacturonase. Thus, the levels of each enzyme among different tomato genotypes can explain the behavior of viscosity (Tangwongchai et al., 2000; Creiler et al., 2001; Plaza et al., 2003). Jarret et al. (1995) observed large differences in viscosity for the two crosses compared, and hp/og^c hp selections gave consistently higher measures of viscosity than their corresponding crimson or normal lines. Average raw product viscosity estimates were 64 and 42% higher than normal for og^c and hp lines, respectively, whereas crimson lines were not significantly different from normal. Hsu et al. (2008) reported the viscosity of fresh tomato juice (control) was 1875 MPas. The juice by conventionally thermal processing had a significantly lower viscosity (1624 MPas) than control and that by 300-MPa processing (1856 MPas).

Moisture contents/ total solids or dry matter

The large amount of water also makes the fruit perishable (Table 1). Ripe tomato contains about 90- 96% water and found to be influenced by cultivar and growing regions (Raffo et al., 2002; Guil-Guerrero and Rebolloso-Fuentes, 2009; Gupta et al., 2011). According to Zegbe-Domı´nguez et al. (2006), lower water content in tomato fruit could be prefer for the processing industry. The average dry matter (DM) or total solids (TS) content of tomato reported by Frusciante et al. (2007) is 5.5%. Kerkhofs et al. (2005) reported that DM content of fresh tomatoes ranged from 5.8 to 7.1% among three cultivars with an average of 6.4%. In addition, Turhan and Seniz (2009) and Majkowska et al. (2008) while studying with different tomato genotypes reported DM contents ranged from 3.3 to 7.0%. Peng et al. (2008) while studying with 3 different varieties for DM contents in the fractions (peel, pulp, and seeds) established that DM contents vary among varieties as well as in different sections such as peel (5.5- 5.8%), pulp (4.2- 4.6%) and seeds (6.2- 6.5%) within a fruit.

BIOCHEMICAL ATTRIBUTES

Total Soluble Solids

The Total soluble solid (TSS) is a refractometric index that indicates the proportion (%) of dissolved solids in a solution. It is the sum of sugars (sucrose and hexoses; 65%), acids (citrate and malate; 13%) and other minor components (phenols, amino acids, soluble pectins, ascorbic acid and minerals) in the tomato fruit pulp (Balibrea et al., 2006; Kader, 2008; Beckles, 2012). Similarly, Baxter et al. (2005) opined that of the total soluble metabolites measured, sugars account for 33%, organic acids for 13% and amino acids for 15% (Baxter et al., 2005). The soluble solid contents in ripe tomato fruit are a chief determinant of commercial value

(Luengwilai and Beckles, 2009). TSS influences the final yield, consistency, and overall quality of the finished product. Campos et al. (2006) have reported the minimum value of total soluble solid to be around 4.5%, which is considered low for industrial tomatoes. According to Cemeroglu et al. (2003) as TSS content in industrial tomatoes increases, it generally increases tomato paste efficiency and this value must be between 5 and 6.5% in industrial tomatoes (Yousef and Juvik, 2001; Baxter et al., 2005; Turhan and Seniz, 2009). Many studies demonstrated that TSS contents found to depend on the cultivar (Table 2). Martinez-Valverde et al. (2002), Moraru et al. (2004), Ruiz et al. (2005), Benal et al. (2005), Ordones-Santos et al., (2009) Mane et al. (2010) and Tigist et al. (2012) noted that average TSS contents range from 4.5 to 5.2^{0}Brix among different cultivars while in hp cultivars from 5.87 to 6.20^{0}Brix (Ilahy et al., 2011a). Gonzalez-Cebrino et al. (2011) while studying with different organically grown traditional and modern tomato varieties of Spain, reported variation in TSS contents (4.05-6.22^{0}Brix). Singh et al. (2010) reported that TSS contents of the peel of all cultivars were about 1.5 times higher than the pulp. TSS content in the pulp of red and yellow cultivars ranged from 5.0 to 9.2 and 4.9 to 6.8^{0}Brix, respectively. Among the red and yellow cultivars, TSS content in tomato peel ranged from 6.5 to 13.5 and 7.3 to 10.5^{0}Brix.

Several studies have identified alleles from wild tomato species that enhance total soluble solids contents in cultivated backgrounds. Eshed and Zamir (1994) reported that marker-assisted introgression of chromosomal segments from the wild species *Lycopersicon pennellii* into *L. esculentum* improved the TSS of cultivated varieties by as much as 16%. Tanksley et al. (1996) introgressed alleles from *L. pimpinellifolium* associated with high TSS contents into an elite processing cultivar. However, most of the introgressed alleles enhanced TSS; they were also associated with negative effects on other fruit characteristics and yield. Triano and St. Clair (1995) reported on the development of inbred backcrossed lines containing introgressions from *L. cheesmanii* with improved TSS and acceptable fruit size, pH, and color. Rodriguez-Burruezo et al. (2005) identified sources of variation among different 'Heirloom' and normal tomato genotypes.

The difference with respect to TSS of fruit might be due to varietal difference and growing region. Moraru et al. (2004) also indicated that TSS content is variety dependent and frequently correlates with greater tomato yield, but in general, varieties with high °Brix values tend to be agronomically less productive. However, genetic variability for TSS among cultivated tomato varieties is extremely limited (Yousef and Juvik, 2001).

Acidity

The acids are mostly malic and citric acids, organic acids comprise about 15% of the dry content of fresh tomatoes, and the malic to citric acid ratio is a varietal attribute and is known to be responsible for variations in the acidity of the different cultivars (Davies and Hobson, 1981). Giordano et al. (2000) and Garcia and Barret, (2006a) suggested a titratable acidity (TA) value greater than 0.35% for processing tomato. Davis and Hobson (1981) established that acidity content is considerably affected by cultivars. Gonzalez-Cebrino et al. (2011) reported total acidity of that conventionally grown tomatoes accordingly significantly influenced by cultivar. The levels of organic acids influence both fruit flavor and pH that are important factors in canned tomato products to control the growth of thermophilic microorganisms (Yousef and Juvik, 2001). The average acidity (as citric acid) of normal fresh tomato reported to be around 0.40%

(Ordones-Santos et al., 2009; Gomez et al., 2001). However, different range of acidity were also reported (Ruiz et al., 2005; Herna´ndez Sua´rez et al., 2008; Turhan and Seniz, 2009; Gonzalez-Cebrino et al., 2011). Ilahy et al. (2011a) pointed out titratable acidity (TA) contents in hp cultivars to vary from 0.35 to 0.38%. The range of 0.25 to 0.70% for different tomato genotypes from India was also reported by George et al. (2004), in which maximum value recorded for Cherry tomatoes (0.51 to 0.70%).

On the other hand, Adedeji et al. (2006) and Fanasca et al. (2006) did not observe the cultivar dependence of the total acidity of tomato among hydroponically grown tomatoes. Kerkhofs et al. (2005) also reported that acidity does not differ significantly among cultivars. They found an average titratable acidity of 0.6 mg citric acid/100 g DM among three cultivars. Similarly, Baldwin et al. (1991) did not find any significant variation between the two cultivars for organic acid content, with the exception of higher levels of fumaric acid in 'Sunny' tomatoes in the later stages of ripening. Malic and fumaric acid concentrations decreased significantly during the later stages of ripening while citric, oxalic, and succinic generally increased.

According to Mahakun et al. (1979), the genetic factor is the major acid content determinant in tomato fruits, with great variation occurring between genotypes. The effect of different factors on fruit acidity is complex and some studies favor the hypothesis that organic acids are produced in the fruit itself from stored carbohydrates (Sakiyama and Stevens, 1976), although some of these acids may be translocated from the leaves and roots to the fruits (Bertin et al., 2000).

TSS: Acid ratio

Because acids influence the perception of sweetness, another useful indicator of tomato taste is the TSS-to-titratable acid (TA) ratio (Hernandes-Suarez et al., 2008; Beckles, 2012). The ratio TSS to titratable acidity also gives a good indication of tomato ripeness (Gonzalez-Cebrino et al., 2011) and a measure of the equilibrium between sugars and acids (Grasselly et al., 2000). There are two primary acids in tomato, citric and malic: citric acid is half as acidic as malic, and higher citric levels give glucose a higher apparent sweetness index than fructose (Petro-Turza, 1987). A minimum TSS of 5 and a minimum TA of 0.4, respectively (TSS: TA of 12.5), is considered desirable to produce a good-tasting table tomato (Beckles, 2012). Rodriguez-Burruezo et al. (2005) reported that TSS: TA ratios in ‘Heirloom’ and normal tomato varieties ranged from 6-14, which indicate that they had an equilibrated taste (Grasselly et al., 2000). A wide range of variation in TSS: acid ratio was recorded by Gonzalez-Cebrino et al. (2011) among different organically grown Spanish tomatoes ranging from 13.93 to 18.68. Hernández Suárez et al. (2008) reported variation in TSS: Acid ratio among different tomato varieties that ranges from 9 to 9.7.

Sugars

The typical tomato fruit contains approximately 5–7.5% total sugar (TS), roughly 75% of which is reducing sugars (mainly glucose and fructose) with the remainder consisting of organic acids (citrate and malate) and minor amounts of minerals, lipids, pigments, vitamins, and volatiles (Davies and Hobson, 1981). The total sugar (TS) content and acidity are the most important characteristics of tomatoes taste (Rodica et al., 2008; Tadesse et al., 2012). The mean sugar concentration in tomatoes given in food composition tables varies between 3 and 3.5%

(Moreiras et al., 2005). The cultivated variety of tomato predominantly accumulates hexose sugars. Generally, the tomato fruit accumulates sugars in the form of sucrose or reducing sugars (glucose and fructose), depending on the environmental conditions and on the growth phase of the plant. In contrast, the wild relative, *Lycopersicon pennellii*, has small, green fruit that predominantly accumulates sucrose and have higher soluble solids content (Islam et al., 1996; Baxter et al., 2005). This variable (sugar) is known to be highly influenced by variety, method of cultivation, and dates and places of production, such that it is plausible to find values outside the range (Hernándes Suárez et al., 2008).

As reported by several authors (Gonzalez-Cebrino et al., 2011; Gupta et al., 2011; Gomez et al.,2009; Kamis et al., 2004) the concentration of total sugar, reducing sugar and non-reducing sugar reported to vary significantly as a function of cultivars (Table 2). Gonzalez-Cebrino et al. (2011) studied different tomato cultivars for their fructose and glucose contents. They pointed out the range 1.29 g/100 g fw (CIDA-59-A) to 2.27 g/100 g fw (CIDA-62) for fructose and from 1.35 g/100 g fw (CIDA-59-A) to 2.29 g/100 g fw (CIDA-62) for glucose, and the ratios of glucose to fructose were between 0.9 and 1. Loiuidice et al. (1995), Osvald et al. (2001) and Hernández Suárez et al. (2008) reported sugars value for tomato cultivars to be 1.2% (fructose) and 1.4% (glucose). The mean sugar concentration in tomatoes given in food composition tables varies between 3 and 3.5% (Moreiras et al., 2005). Baldwin et al. (1991) studied two varieties for sugar contents and reported that ‘Solar Set’ tomatoes had significantly higher levels of both glucose and fructose than ‘Sunny’. It was recorded that glucose and fructose both increased noticeably during ripening (Raffo et al., 2002). Turhan and Seniz (2009), Melkamu et al. (2008) and Jongen (2002) reported the total sugar contents of fruit ranged from 1.67- 4.70% belonging to different genotypes of different locations. In the study of Yen et al. (1997), high pigmenting (*hp*) fruit demonstrated a significant accumulation of sucrose as compared to normal tomatoes. Generally, the altered (increased) photosynthetic activity has an impact on carbohydrate metabolism and therefore ultimately increased sugar content in high pigment tomatoes (Peters et al., 1992; Yen et al., 1997). Gupta et al. (2011) reported that non-reducing sugar varies between varieties SEL-7 (2.60%) and ARTH-3 (3.82%) on dry weight basis.

Alcohol Insoluble Solids

Determination of alcohol insoluble solids (AIS) is an excellent indication of maturity and texture in some horticultural products (Table 2). In tomatoes, alcohol-insoluble solids consist of protein (8%), pectic substances (7%), hemicellulose (4%), and cellulose (6%) dry matter (Davies and Hobson, 1981). It determines the viscosity of fruit juice and thick consistency of processed products (Dhaliwal et al., 1999). It was noted that AIS is a small fraction of the total solid content of tomato juice, yet it accounts for a significant variation in juice viscosity (Barrett et al., 1998). AIS contents of fruits vary among varieties and according to fruit shape; for example, oval fruits of Punjab Chhuhara contained a higher percentage of AIS than that of round fruited variety Punjab Kesri (Upasana and Bains, 1988). Martinez-Valverde et al. (2002) and Ordones-Santos et al. (2009) pointed out variation in AIS contents among different cultivars. However, the AIS contents were not significantly influenced by either cultivar or growing methods (Ordones-Santos et al., 2009).

pH

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Many studies have centered on pH, which is also a key element in tomato selection (Hong and Tsou, 1998; Table 2). Among the chemical parameters considered for the processing tomato quality, pH is important because of its influence on the thermal processing conditions applied in the tomato industry for producing safe products (Garcia and Barret, 2006a). According to Giordano et al. (2000), pH below 4.5 is a desirable trait, because it halts the proliferation of microorganisms in the final product during industrial processing. Thus, pH values as low as possible (up to the point that it does not adversely affect the taste) should be bred into tomato cultivars for industrial use (Tigist et al., 2012). Tomato pH is dependent on several factors, such as cultural practices, growing location, seasonal and varietal variations (Garcia and Barret, 2006a; Favati et al., 2009).

The varietal influence of pH of tomato also reported by Moraru et al. (2004), Benal et al. (2005), Ordones-Santos et al. (2009), Turhan and Seniz (2009), Mane et al. (2010), Gonzalez-Cebrino et al. (2011) and Tigist et al. (2012). However, Kerkhofs et al. (2005) reported that pH does not differ significantly among cultivars. They found an average pH of 4.38 among three cultivars. The 18 genotypes of tomatoes analyzed by Frusciante et al. (2007) showed that their pH value ranged from 4.13 (Motelle) to 4.60 (1512). The majority of genotypes showed a pH value below 4.5 that is considered an important quality requirement for fresh tomato fruit (Nisen et al., 1990). In case of hp cultivars the pH reported to be 4.69- 4.88 (Ilahy et al., 2011).

BIOACTIVE CONTENTS

Ascorbic Acid:

Ascorbic acid (AsA) is taken as an index of quality of fresh produce (Table 3). Tomato contains moderate amounts of ascorbic acid (20 mg/100 g) (Gould, 1992), thus contributing to 40% of the recommended dietary allowance for ascorbic acid. Gould (1992), in his recommendations for breeding varieties for processing, suggested the need for developing varieties, which have ascorbic acid in excess of 20 mg/100 g. Mean AsA contents of cherry tomatoes during ripening was reported to be 12 mg/100 g FW (Raffo et al., 2002). The variation in ascorbic acid (AsA) content in tomatoes depends mainly on the agronomic conditions and the varietal differences (Singh et al., 2010; Chakraborty et al., 2007). Temperature and light intensity also have a profound influence on ascorbic acid content, the lower the temperature more will be the AsA level (Chakraborty et al., 2007).

Within the species *S. lycopersicum* L., AsA content differs from variety to variety as observed by several authors (Spagna et al., 2005; Adalid et al., 2007; Zapata et al., 2007; Odriozola-Serrano et al., 2008; Herna´ndez Sua´rez et al., 2008; Favati et al., 2009; Adalid et al.., 2010; Gonzalez-Cebrino et al., 2011; Tigist et al., 2012). AsA contents of tomatoes found to vary according to color as described by Singh et al. (2010) who found that it ranged from 23.21- 40.44 and 24.38- 33.87 mg/ 100g in red and yellow cultivars, respectively. Among the three fractions (peel, pulp, and seeds) of tomato, skin contained the highest levels of ascorbic acid, which ranged from 7.52 to 15.8 mg/100 g (FW) (Peng et al., 2008). Toor and Savage (2005) showed that the mean ascorbic acid content in the skin of tomato cultivars (15.7-18.6 mg/100 g of FW) was significantly higher in relation to the pulp and seeds. As regards to *hp* tomatoes, the AsA content reported to vary from 10 to 18 (Ilahy et al., 2011a) and 25- 35 mg/ 100g FW (Ilahy et al., 2011b) among different cultivars (Table 3). This variability in ascorbic acid may also result from a number of factors such as maturity stage, the conditions during production and after harvesting (Zapata et al., 2007; Odriozola-Serrano et al., 2008; Favati et al., 2009; Gonzalez-Cebrino et al., 2011). While studying with three different varieties, Kaur et al. (2002) and Toor et al. (2006) reported that ascorbic acid content varies from 153 to195 and 165 to 252 mg/ 100 g DW, respectively. George et al. (2004) observed AsA content ranged from 8.4 to 32.4 mg/ 100 g in tomato pulp. Substantial amounts of ascorbic acid were also detected in peels (9.0–56.0 mg/ 100 g DW and 104–462 mg/100 g DW).

Carotenoids

Total carotenoid content is influenced by the variety and ripeness of the tomato (Martínez-Valverde et al., 2002). Among all characters, carotenoids content accounts for the major variability explained by the genotype (Frusciante et al., 2007). According to Sahlin et al. (2004) the carotenoids and the antioxidant content of tomato mostly depends on cultivars, stage of maturity, environmental factors, and growing conditions. The major carotenoids that accumulate in ripe red tomato fruits are lycopene (~ 90%), β-carotene (5–10%), and lutein (1–5%) with trace amounts (< 1%) of other carotenoids (Ronen et al., 1999). Recently, Kotíková et al. (2009) determined the carotenoids (lycopene, β-carotene, and lutein) of 11 varieties of tomato at the red ripe stage. They stated that in total carotenoid content lycopene abundance was on average 70%, β-carotene 26%, and lutein 4%. Burns et al. (2003) recorded that content of total carotenoids in tomatoes averaged 90 mg/ 100g, where lycopene represented 52 mg/ 100g, β-carotene 5.6 mg/ 100 g and lutein 9.4 mg/ 100g on dry weight basis. Lycopene and other carotenoids are found mostly in the outer pericarp with tomato skin containing 12 mg lycopene/100 g skin (wet basis) while whole mature tomato contains only 3.4 mg lycopene/100 g FW (Al- Wandawi et al., 1985).

Lycopene

Tomato lycopene content that is responsible for the red color of tomatoes varies considerably, reflecting the influence of variety (generally genetic factors), maturity, agronomic and environmental conditions during growing (Abushita et al., 2000; Shi and Le Maguer, 2000; Martinez-Valverde et al., 2002; Dumas et al., 2003; George et al., 2004; Kaur et al., 2006; Garcia and Barret, 2006b; Favati et al., 2009). Variety is an important factor affecting both the composition and content of plant pigments (Guil-Guerrero and Rebolloso-Fuentes, 2009; Aherne et al., 2009; Mane et al., 2010; Adalid et al., 2010; Gonzalez-Cebrino et al., 2011).

There is an extensive literature on the lycopene content of fresh tomatoes, revealing a wide variety of concentrations (Table 3). Abushita et al. (2000), Gómez et al. (2001), Dumas et al. (2003), Lenucci et al. (2006), Kaur et al. (2006) and Frusciante et al. (2007) found levels of 4.3 to 18.1 mg/ 100 g fw in tomatoes grown in the open air. Adalid et al. (2010) observed wide variation in lycopene content among tomato accessions of different origin. The lycopene content of tomatoes varied considerably among cultivars, stages of maturity and growing conditions (Sahlin et al., 2004; Odriozola-Serrano et al., 2008). Harvest maturity, soil fertilization, irrigation, light intensity, and day/night temperatures could also affect lycopene formation in tomatoes (Heinonen et al., 1989).

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A wide range of lycopene content in tomato juice varying according to cultivars and growing locations, is also reported in the literature 7.83 mg/ 100g in commercial U.S. tomato juice (Nguyen and Schwartz, 1998), 8.2–11.0 mg/ 100g in tomato juice sold in Hungary (Lugasi et al., 2003), 61.6 mg/kg in commercial Brazilian tomato juice (Tavares and Rodriguez-Amaya, 1994), and 12.2 mg/ 100g in juice prepared from hydroponically grown Laura cultivar tomatoes (Arias et al., 2000). Variations of around 4-fold in lycopene concentrations is reported (Dumas et al., 2003) in tomatoes from Southern Italy, and up to 3-fold variations in tomatoes grown in Hungary (Abushita et al., 1997).

Some of color mutants such as high pigment (*hp*), dark green (*dg*) and crimson (*ogc*) have been found to improve the color of normal or local cultivars. The lycopene contents of red ripe fruits of high lycopene cultivars ranged from about 18- 25 (Ilahy et al., 2011a) and 12- 24 mg/ 100g FW (Ilahy et al., 2011b). The variations in lycopene content between high lycopene and normal tomatoes are mainly due to genotypic factors (Ilahy et al., 2011b). The dark green (*dg*) gene increases the density of chloroplasts and chromoplasts and old gold crimson (og^c) is a defective fruit-specific beta-cyclase. Combining these genes leads to the accumulation of trans-lycopene (Rubio-Diaz et al., 2010). An investigation carried out by Jarret et al. (1995) revealed that genotypes containing *hp* and og^c genes crossed with some normal cultivars significantly improved the yield pattern and several attributes of fruit quality including color. In accordance with previous reports (Ronen et al., 2000), the ripe fruit from the og^c mutant contained comparatively higher levels of the carotenoid (3-fold) than ordinary tomatoes. The considerable lycopene accumulation in high-lycopene tomato genotypes can be, in fact, due to the reduced cycling rate of this molecule to synthesize carotenes and/or to an enhanced enzymatic activity of

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phytoene synthase-I that causes a massive production of lycopene precursors in ripening tomato fruits (Fraser et al., 2009).

The waste during tomato processing is obtained in the form of seeds and skin residues, which could provide a useful source of lycopene (Elbadrawy and Sello, 2012). In tomatoes, lycopene biosynthesis increase dramatically during the ripening process, as chloroplast undergoes transformation to chromoplast. Globulous chromoplast containing mainly β- carotene is found in the jelly part of the pericarp while chromoplast in the outer part of the pericarp contains voluminous sheets of lycopene (Choudhari and Ananthanarayan, 2007). The levels of lycopene recorded to be differed significantly between peel and pulp as well as among different cultivars. In fact, tomato skins can contain up to 5 times more lycopene than the pulp (Sharma and Le Maguer, 1996). Singh et al. (2010) observed that lycopene contents of pulp ranged from 2.75- 4.55 mg/ 100g and 0.76- 1.23 mg/ 100g in fruits belonging to red and yellow colored varieties, respectively. The colored cultivars had 3-6 times more lycopene contents than yellow cultivars. They also stated that peel contained about 3- 5 folds higher lycopene in relation to pulp having a range of 9.78- 26.75 and 1.47- 5.28 mg/ 100g in red and yellow cultivars, respectively (Singh et al., 2010). Sharma and Le Maguer (1996) reported the occurrence of lycopene in different fractions of tomato fruit such as tomato skin, the water insoluble fraction, and the fibrous fraction including the fiber and soluble solids. Their results indicated that 72–92% lycopene was associated with the water-insoluble fraction and the skin. Tomato extracts and especially skin extracts contain high amounts of lycopene (Sharma and Le Maguer, 1996). George et al. (2004) reported significant variation in the pulp and peel fractions of examining genotypes. A variation of 1–4 folds (fw) and 1–2 folds (dw) was seen in the pulp. The extent of variation was 4.8–14.1 mg/100 g in peels and 2.0–6.9 mg/100 g in pulp on fw.

Carotene

The second most important carotenoid is β-carotene, which represents about 3- 7% of the total carotenoid content (Singh et al., 2010). β- carotene is of special interest due to its being the main provitamin-A, and unusual antioxidant activity from β-carotene has been associated with reduced risk of lung cancer (Sies, 1991). Several workers (Abushita et al., 2000; Dumas et al., 2003; Raffo et al., 2006; Frusciante et al., 2007; Adalid et al., 2010; Gupta et al., 2011) have revealed variation in this content as a function of genotype (Table 3).

According to Bugianesi et al. (2004), the lycopene content of tomatoes is approximately more than ten-fold higher than that of β- carotene. Depending on the type of tomato tested, differences between lycopene and β-carotene content ranged from 4- to 14-fold (Irish) and from 3- to 19-fold (Spanish). Guil-Guerrero and Rebolloso-Fuentes (2009) and Aherne et al. (2009) reported that the cherry (Irish) variety had the greatest amount of β-carotene (0.4 to 7.3 mg/ 100g DW) when compared with other tomato varieties. Thus, varietal factors can affect (to a considerable extent) the overall biosynthesis of carotenoids, particularly β- carotene formation via cyclization of lycopene (Abushita et al., 1997). Several environmental factors exert an influence on carotene content than on lycopene in tomato fruits (Potaczek and Michalik, 1998). Winter grown tomatoes are found to have higher mean β- carotene content than summer-grown tomatoes (Chakraborty et al., 2007).

Ilahy et al. (2011a) and Ilahy et al. (2011b) reported total carotenoids of red ripe fruits of high lycopene (*hp*) cultivars ranged from 19- 28 mg β- carotene equiv / 100g FW and 0.80- 1.94 mg/ 100g FW, respectively. Variation in the mean concentration of β- carotene in different tomato species has been observed by Elizalde-González and Hernández-Ogarcía (2007) in which the content was *Lycopersicum periforme* Dun (Guajillo tomato; 403 μg/ 100mg) > *Lycopersicum cerasiforme* (Cherry tomato; 254 μg/ 100mg) > *Lycopersicum esculentum* (Saladet tomato; 6 μg/ 100mg) ~ *Lycopersicum esculentum* Mill (Beef tomato; 6 μg/ 100mg). In the face of the reported interference of genotypes, the influence of environmental factors (temperature, light, growing season and location), as well as the agricultural techniques, may also be responsible for the variation in carotenoid accumulation (Dumas et al., 2003; Raffo et al., 2006).

Total Phenols

Phenolic compounds are important secondary metabolites in plants and the antioxidative activities of total phenolics in several plant extracts have been recently reported, suggesting possible protective roles of total phenolics in reducing risk of cardiovascular diseases in humans (Liu et al., 2010). Therefore, they are presently being viewed as star nutrients particularly in tomato (Kaur and Kapoor, 2008). The main representative phenolic compounds of normal-sized tomatoes are chlorogenic acid and the flavonoid quercetin, followed by naringenin and rutin (Sakakibara et al., 2003; Mart´ınez-Valverde et al., 2002). Tomato polyphenols, mainly phenolic acids, are present in free soluble form and in insoluble form when they are bound to the fiber (Frusciante et al., 2007). Several workers also observed the significant variation in phenolic contents of tomato among varieties (Table 3). George et al. (2004) studied different varieties and found that free phenolic content ranged from 9.20 to 22.0 mg/100 g (fw) in pulp. Peels had significantly higher phenolic contents than the pulp. The total phenolic contents of fruits belonging to high pigment (*hp*) cultivars were higher than ordinary tomatoes (Ilahy et al., 2011a & b). This comprehensive overproduction of phytonutrients is associated with increased plastid biogenesis and therefore overproduction of other plastid-accumulating metabolites may be expected in these high pigment mutants (Kolotilin et al., 2007; Azari et al., 2010). The average total phenol contents in tomato were 200 mg GAE/ 100 g on dry weight basis (Kahkonen et al., 1999). Toor and Savage (2005), who reported that the total polyphenolic content (mg GAE/100 g) of skin and seeds of tomatoes were, respectively, 29.1 and 22.0, compared to 12.7 mg/100 g in the pulp. Singh et al. (2010) studied different varieties and reported that in red and yellow cultivars phenolic contents ranged from 21.46-57.60 and 22.5- 47.36 mg GAE/ 100 g, respectively whereas, in case of peel the values ranged from 48.66-123.56 and 57.13- 135 mg GAE/ 100 g, respectively pointing out that peel contained 3-4 times more phenols than the pulp. Helmja et al. (2007) studied skin extract of different solanaceous vegetables including tomato and reported that the total phenolic content of the tomato skin extract was 0.6 g/L. Peng et al. (2008) reported that the amount of phenols except chlorogenic acid was found to be higher in the skin of tomatoes compared to the pulp and seeds. The content of chlorogenic acid varies from 1.08 to 3.69 mg/100 g FW (Peng et al., 2008) and 1.4 to 3.2 mg/ 100 g FW (Martinez-Valverde et al., 2002). Although genetic control is the primary factor in determining phenols in fruits and vegetables (Ilahy et al., 2011a), their level may be affected by environmental conditions, such as light, temperature and growing season (Dumas et al., 2003; Slimestad and Verheul, 2009), mode of fertilization (Macheix et al., 1990) and analytical methodology (George et al., 2011).

Total Flavonoids

The tomato fruit, as well as being a good source of carotenoids, has also been shown to accumulate phenols, especially flavonoids, mainly in the peel (Muir et al., 2001). Rutin (quercetin-3-rhamnosylglucoside) and naringenin chalcone are representative flavonoids of tomato, respectively conjugated and nonconjugated (Martinez-Valverde et al., 2002; Bovy et al., 2007; Frusciante et al., 2007; Vallverdú-Queralt et al., 2012) and flavonols such as myricetin are found in tomato and its products (Shen et al., 2007). Flavonoids are health-protecting components in the human diet because of their capacity to activate endogenous antioxidant defense systems and signaling pathways (Meiers et al., 2001; Williams et al., 2004). Schindler et al. (2005) reported that the natural amount of rutin in mature tomatoes varied from 2.78 to 53.4 ppm and that of naringenin from 0.29 to 12.2 ppm. Several factors seem to affect the flavonoid contents in tomatoes including environmental factors. Frusciante et al. (2007), while studying with different lines of tomato reported that flavonoids showed a significant variation among all lines (Table 3). Recent studies demonstrated that the fruits of high lycopene (*hp*) tomatoes concentrated higher total flavonoid contents in relation to ordinary ones (Ilahy et al., 2011a & b). Variations can be ascribed to the high-lycopene traits mainly due to genotypic differences (Ilahy et al., 2011b). In fact, it has been reported that in high-pigment mutants the increase in carotenoid content, was accompanied by a dramatic rise in plastid biogenesis and in the synthesis of other compounds such as flavonoids and vitamin C (Cookson et al., 2003; Bino et al., 2005; Kolotilin et al., 2007; Ilahy et al., 2011b). Nevertheless, this discrepancy could be due to environmental factors as well (George et al., 2004).

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Calvenzani et al. (2010) and Torres et al. (2005) reported the highest concentrations of all flavonoids in *hp-1* peel at turning stage and a dramatic reduction of naringenin chalcone at the red ripe stage. Yen et al. (1997) demonstrated the differences in flavonoid contents of fruits obtained from normal (Hp/Hp) and nearly isogenic mutant (hp/hp) tomatoes (cv Ailsa Craig) pointing out quercetin accumulation was elevated over 13-fold from 2.95 mg/ 100g fw in normal tomatoes to 40.59 mg/ 100g fw in hp fruits. In high pigmented genotypes (*hp*-2) flavonoid levels recorded up to 3.5 fold, lycopene content was twofold higher and β-carotene levels accumulated up to ten-fold compared to wild type fruits (Davuluri et al., 2005). In greenhouse-grown tomatoes, induction and accumulation of flavonoids in the skin is lower than in field-grown tomatoes due to a decrease in the UV radiations received (Toor et al., 2006). Stewart et al. (2000) reported that field-grown tomatoes from Spain and South Africa contained 4–5 times more flavonoids than greenhouse grown Scottish and English tomatoes. The accumulation of flavonoids in peel observed to be higher than pulp. Stewart et al. (2000) reported that the majority of the flavonols in tomatoes are present in the skin. In addition, Bovy et al. (2007) recently opined that in tomato fruit, flavonoids accumulate mainly in the peel, whereas in the flesh, which comprises 95% of the total fruit weight, only traces of flavonoids can be found. Helmja et al. (2007) reported that total flavonoid contents of the tomato skin extract were 240 mg/100 g DW.

Total antioxidant activity

Evaluation of antioxidant potential is becoming increasingly pertinent in the field of sustenance as it provides useful information with regard to health promoting and functional quality of raw material without the analysis of each antioxidant compound (Koley et al., 2012; Scalfi et al., 2000). Eberhardt et al. (2000) and Odriozola-Serrano et al. (2008) indicated that most of the antioxidant capacity comes from the natural combination of different phytochemicals. The parameter accounts for the presence of efficient oxygen radical scavengers, such as carotenoids, ascorbic acid and phenolic compounds and their synergistic and/or antagonistic effects. Genetics, maturation stage, and cultivar of tomato have been reported to influence their antioxidant composition (Kaur et al., 2002; Raffo et al., 2002; Toor et al., 2006). The environmental conditions (solar radiation and temperature) during the fruit development and ripening have also been reported to influence the antioxidant components of tomato with the largest effect in the final few weeks of ripening (Chakraborty et al., 2007).

Odriozola-Serrano et al. (2008) reported the radical (DPPH) scavenging capacity of the six cultivars ranged from 9.8% to 26.3% of DPPH inhibition. Bola tomatoes showed the significantly highest antioxidant capacity, whereas no significant differences were observed among tomatoes cvs. Rambo, Cencara, and Pitenza. Mansour et al. (2009) evaluated eleven tomato cultivars and stated that all cultivars showed an evident DPPH radical scavenging effect ranging from 55- 80%, wherein cvs. Aledo and Money Maker had the strongest antiradical action.

Total antioxidant activity (TAA) variation in relation to varieties has been reported by several authors (Toor et al., 2006; Odriozola-Serrano et al., 2008; Gonzalez-Cebrino et al., 2011, Ilahy et al., 2011a; Ilahy et al., 2011b). In general, TAA found to vary between 80 to 200 µmol TEAC/ 100 g fw (Odriozola-Serrano et al., 2008). Toor et al. (2006) reported that antioxidant activity in tomatoes varies from 81–207 µM TEAC/100 g on a fresh weight basis. Gonzalez-Cebrino et al. (2011) reported that traditional varieties, when compared with the commercial cultivar 'Baghera', show a higher TAA and sugar content; 'Baghera' also exhibits low level of TAA and vitamin C. The values of TAA ranged from 22.65 to 43.58 mg TEAC/100 g FW. TAA, as evaluated by FRAP, ranged from 0.64 to 2.3 mM FRAP among different genotypes. Significantly high FRAP values were observed in the variety 818 cherry (2.3 mM FRAP) and the lowest in variety FA-574 (George et al., 2004). Scalfi et al. (2000) have also reported significantly high antioxidant activity in small corbarini tomatoes. Toor and Savage (2005) also reported significant variations in antioxidant potential of different fractions (peel, pulp, and seed) of three tomato varieties. Varying degrees of antioxidant capacities in different tomato cultivars may be due to differences in reaction kinetics and steady state antioxidant potentials of various reductive substrates in the genotypes (Ozgen et al., 2008; Olaniyi et al., 2010). The antioxidant capacity of tomatoes depends on a large number of phytochemical compounds and the interactions that occur between them (Odriozola-Serrano et al., 2008; Gonzalez-Cebrino et al., 2011).

Ilahy et al. (2011b) assessed hydrophilic and lipophilic antioxidant activity assays of different high lycopene and ordinary tomato cultivars. HAA values ranged from 405.8µM Trolox/100 g fw in cv Donald to 572.1µM Trolox/100 g fw in cv HLY 18. A variation between 1.2- and 1.4-fold was found in the HAA of high-lycopene tomato cvs compared to the ordinary cv Donald. The LAA values ranged from 133.5µM Trolox/100 g fw in cv Donald to 540.1µM Trolox/100 g fw in cv Lyco 2. HLY 13, HLY 18, and Kalvert cvs. A variation between 2.7- and 4.0-fold was found in LAA of high-lycopene tomato cvs compared to cv Donald. The difference between high lycopene and ordinary tomatoes could be attributed to high levels of lycopene and phenolic compounds (Elbadrawy and Sello, 2012).

CONCLUSIONS AND FUTURE RESEARCH

The variation in physicochemical and nutritional attributes among tomatoes has been attributed to numerous causes, among the most relevant parameters this review found the influence of fruit size, shape, firmness, pericarp thickness, moisture content, juice recovery and its viscosity, sugar: acidity ratio, among others. On the other hand, the bioactive contents of tomato cultivars have an impact on the processed destines, mainly by lycopene and phenolic constituents. The bioactive constituents and their stability must be contemplated while selecting the processing steps of tomato fruits. Moreover, higher amount of lycopene and other bioactive contents is also particularly important in tomatoes subjected to industrial processing to compensate for the loss of antioxidant activity due to chemical, physical as biological factors. A special attention to these constituents must be paid considering future research on designing new cultivars of tomato fruit.

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Table Legends

Table 1: Variation in carpometric attributes of tomatoes

Table 2: Variation in biochemical attributes of tomatoes

Table 3: Variation in bioactive compounds of tomatoes

Table 1

Attribute(s)	Country	Range	Reference(s)
Weight	Tunisia	70.0- 94.0 g	Ilahy et al. (2011)
	India	32.24- 93.70 g	Tiwari and Upadhyay (2011)
	Slovenia	71.0- 105.0 g (Proc) 133.0- 204.0 g (Fresh)	Kacjan-Maršić et al. (2011)
	India	21.02- 42.79	Mane et al. (2010)
	India	38.86- 67.14 g	Sekhar et al. (2009)
	France	20.4- 106.9 g	Page et al. (2008)
	USA	115.4- 334.1 g	Perkin Veazie et al. (2006)
	New Zealand	53.0- 102.0 g	Toor et al. (2006)
	Spain	4.2- 265.1 g	Rodriguez-Burruezo et al. (2005)
	India	21.40- 88.38 & 25.0- 70.97 g	Kurian et al. (2001)
Equatorial diameter	India	3.30- 7.30 cm	Tiwari and Upadhyay (2011)
	China	6.82- 7.53 cm	Li et al. (2011)
Polar diameter	China	5.75- 6.47 cm	Li et al. (2011)
Fruit shape index	India	1.03- 1.22, 0.79- 0.89 & 0.86- 0.92	Kurian et al. (2001)
Number of Locules	India	3.40- 5.33	Tiwari and Upadhyay (2011)
	India	2.24- 4.48	Mane et al. (2010)
	India	2.70- 4.0	Sekhar et al. (2009)
Pericarp thickness	India	4.67- 5.99 mm	Mane et al. (2010)
	India	5.5- 7.0 mm	Sekhar et al. (2009)
Fruit firmness	Spain, USA, West Indies	2- 3 Kg	Ordones-Santos et al. (2009), Fleisher et al. (2006) and Mohammed et al. (1999)
	Spain	1.08- 6.47 N	Gonzalez-Cebrino et al. (2011)
	India	0.62- 0.67 Kg	Gupta et al. (2011)
	France	74.62- 53.60 N	Page et al. (2008)
	Spain	3.21- 13.92 N	Rodriguez- Burruezo et al. (2005)
	India	4.0- 8.40 lb	Gowda et al. (1994)
Juice (%)	India	22.11- 30.86	Gupta et al. (2011)
	India	47.57	Mane et al. (2010)
	India	45.83.3	Kumar and Singh (1996)
	India	53.6- 83.3	Aggarwal et al. (1995)
	India	24.7- 48	Gowda (1994)
Moisture contents (%)	India	90-96	Thakur and Kaushal (1995)
	Italy		Raffo et al. (2002)

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	Spain	92.6- 96	Guerrero and Rebolloso-Fuentes (2009)
	India	92.27- 94.45	Gupta et al. (2011)
Dry matter or total solids (%)	West Indies	6.0- 7.5	Mohammed et al. (1999)
	Spain		Ordones-Santos et al. (2009)
	Italy	4.0- 9.2	Frusciante et al. (2007)
	New Zealand	5.80- 7.1	Kerkhofs et al. (2005)
	Poland	3.30- 7.0	Majkowska et al. (2008)
	Turkey		Turhan and Seniz (2009)

Table 2

Attributes		Country	Range	Reference(s)
TSS⁰Brix		South Africa	4.23- 5.22 (fresh) 4.11- 4.18 (Proc)	Tigist et al. (2012)
		Tunisia	5.87- 6.20	Ilahy et al. (2011a)
		India	5.10- 5.50	Gupta et al. (2011)
		Spain	4.05- 6.22	Gonzalez-Cebrino et al. (2011)
		India	4.87- 5.82	Mane et al. (2010)
		India	3.80- 5.0	Sekhar et al. (2009)
		France	5.5- 8.9	Page et al. (2008)
		Spain	4.30- 5.0	Herna´ndez Sua´rez et al. (2008)
		USA	4.30- 5.20	Perkins-Veazie et al. (2006)
		New Zealand	3.90- 6.30	Toor et al. (2006)
		Spain	3.92-10.14	Rodriguez-Burruezo et al. (2005)
		India	5.0- 7.0	George et al. (2004)
		Italy	5.03- 6.07	Raffo et al. (2002)
Acidity (%)		Spain	0.35- 0.38	Ilahy et al. (2011a)
		India	0.50- 0.54	Gupta et al. (2011)
		Spain	0.24 to 0.35	Gonzalez-Cebrino et al. (2011), Ordones-Santos et al. (2009), Ruiz et al. (2005)
		India	0.19- 0.36	Mane et al. (2010)
		Turkey	0.22- 0.40	Turhan and Seniz (2009)
		Spain	0.47- 0.54	Herna´ndez Sua´rez et al. (2008)
		India	0.25- 0.70	George et al. (2004)
Sugar (%)	Total	Italy	25- 28 (DW)	Loiuidice et al. (1995)
		India		Thakur and Kaushal (1995)
		India		Gupta et al. (2011)
		Turkey	1.67- 4.70	Turhan and Seniz (2009)
		Ethiopia		Melkamu et al. (2008)
		Netherlands		Jongen (2002)
		Turkey	2.30- 2.85	Cemeroglu et al. (2003)
		India	2.5- 4.5	Kalloo and Bhutani (1993)
	Reducing	India	22-24 (DW)	Gupta et al. (2011), Thakur and Kaushal (1995)
		Nigeria	1.2- 1.6	Kamis et al., 2004,
Alcohol Insoluble Solids (% DW)		India	44.1- 50.4 (P) 29.2- 53.8 (P) 27.0- 56.1 (Hy)	Garg and Cheema (2011)
		Spain	24.4- 36.6	Ordones-Santos et al. (2009) Martinez-Valverde et al. (2002)
pH		Spain	4.69- 4.88	Ilahy et al. (2011a)

Spain	4.15- 4.34	Gonzalez-Cebrino et al. (2011)
India	3.92- 4.51	Mane et al. (2010)
Spain		Ordones-Santos et al. (2009)
India		Benal et al. (2005)
USA		Moraru et al. (2004)
Turkey	3.78-5.25	Turhan and Seniz (2009)
Spain	4.12- 4.19	Herna´ndez Sua´rez et al. (2008)
Italy	4.13- 460	Frusciante et al. (2007)

Table 3

Attributes	**Country**	**Range**	**Reference(s)**
Ascorbic acid (mg/ 100g)	South Africa	9.29- 15.08	Tigist et al. (2012)
	Tunisia	10- 18 25- 35	Ilahy et al. (2011a & b)
	India	27.82- 31.33	Gupta et al. (2011)
	Spain	23.36- 45.92	Gonzalez-Cebrino et al. (2011)
	India	19.32- 35.34	Mane et al. (2010)
	Spain	3.0 - 31.0	Adalid et al. (2010)
	Spain	16.4- 26.3	Guil-Guerrero and Rebolloso-Fuentes (2009)
	Spain	13.0- 15.0	Marcos et al. (2005)
	Spain	12.7- 41.1	Rodriguez-Burruezo et al. (2005)
	Hungary	21.0- 48.0	Abushita et al. (1997)
	Hungary	17.0- 22.0	Abushita et al. (2000)
	New Zealand	165- 252 (dw)	Toor et al. (2006)
	India	153- 195 (dw)	Kaur et al. (2002)
Lycopene (mg/ 100g)	Spain	2.54- 6.22	Gonzalez-Cebrino et al. (2011)
	Tunisia	18.0- 25 12.0- 24	Ilahy et al. (2011a & b)
	India	3.23- 4.03	Gupta et al. (2011)
	India	2.43- 9.74	Mane et al. (2010)
	Spain France Italy India Italy	4.3- 18.1	Gómez et al. (2001), Dumas et al. (2003), Lenucci et al. (2006), Kaur et al. (2006), Frusciante et al. (2007)
	Spain	0.04- 27.0	Adalid et al. (2010)
	Italy	5.50- 8.0 (fresh) 8.40- 17.3 (Proc)	Pernice et al. (2010)
	India Hungary New Zealand Ireland Spain	1.1- 6.5	Benal et al. (2005), Helyes and Lugasi (2006), Toor et al. (2006), Aherne et al. (2009), Ordones-Santos et al. (2009)
	USA	5.0- 6.0	Arias et al. (2000)
	Italy	17.5- 25.3	Lenucci et al. (2006)
	Croatia	1.82- 11.19	Markovic´ et al. (2006)
	Italy	11.12- 14.83 15.91- 17.73	Spagna et al. (2005)
	Spain	2.8- 35 (DW)	Guerrero and Rebolloso-Fuentes (2009)
β-carotene	India	5.40- 6.78	Gupta et al. (2011)

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(mg/ 100g)	Tunisia	19- 28 0.80- 1.94	Ilahy et al. (2011a & b)
	Spain	0.08- 1.31	Adalid et al. (2010)
	Spain	0.4- 7.3 (DW)	Guil-Guerrero and Rebolloso-Fuentes (2009)
	Ireland		Aherne et al. (2009)
	Italy	0.28- 1.0	Frusciante et al. (2007)
	Italy	8.35- 15.12	Raffo et al. (2006)
	Italy	3.40- 15.0	Dumas et al. (2003)
	Hungary	2.35- 6.15	Abushita et al. (2000)
	India	4.80- 5.30	Kumari (1998)
Total phenol (mg/ 100g)	Tunisia	24.0- 31.0 10.5- 39.4	Ilahy et al. (2011a & b)
	Spain	18.7- 33.6	Odriozola-Serrano et al. (2008)
	Spain	19.7- 21.1	Hernández et al. (2007)
	Italy	2.04- 3.75	Frusciante et al. (2007)
	New Zealand	169- 579 (DW)	Toor et al. (2006)
	India	9.20- 22.0	George et al. (2004)
	Italy	2.25- 25.84	Giovanelli et al. (1999)
Total flavonoids (mg/ 100g)	Tunisia	21.0- 27.0 10.5- 51.1	Ilahy et al. (2011a & b)
	France	0.18- 5.33	Peng et al. (2008)
	Italy	2.13- 5.18	Frusciante et al. (2007)