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Tomato Components and Quality Parameters. A Review

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ABSTRACT

Tomatoes (Solanum lycopersicum L.) are some of the most important vegetable foods worldwide. They are the second largest grown vegetable in both terms of production and consumption. Demand for tomatoes has been increasing recently due to their high content of nutritionally- acclaimed carotenoids, fibers, vitamins, and minerals, hence it has been the subject of numerous studies both in the laboratory and under field conditions. The quality of a tomato is determined by internal and external attributes, internal such as texture, sweetness, acidity, aroma, flavor, and nutritional value, and external which are appearance factors such as color, shape, size, and firmness. This review aims to investigate the chemical composition of tomato fruits and how they influence their quality. The findings of chemical composition (minor and major) components that were reported by many researchers are reviewed in this article. Also, this review focuses on the effect of tomato variety on the chemical composition of this fruit, and how these components are varied during the ripening process. In addition, chemical, physical and sensory quality factors were discussed in this review.

Keywords: Tomatoes, components, quality, sensory attributes.

INTRODUCTION

Tomato (Solanum lycopersicum L.) belongs to the family Solanaceae. It is one of the most popular horticultural crops worldwide being second only to potatoes (Siddiq et al., 2018). It is consumed either fresh or processed in such forms as tomato juice, soup, paste, puree, ketchup, sauce, and salsa (Shatta et al., 2017). Tomato fruits are some of the most important nutritious vegetable crops consumed by man, several studies show its nutritional content as a rich source of the potent antioxidant lycopene, β-carotene, vitamin C, pro-vitamin A, folate and minerals such as potassium and secondary metabolites including flavonoids, phytosterols, and polyphenols. Some of these nutrients are maintained after processing, thus providing important components for human health (Vallverdú-Queralt et al., 2011, El-Dengawy et al., 2016). Tomato plants are cultivated in

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almost all home gardens and also in the field for their adaptability to a wide range of soils. It is also produced in temperate, subtropical, and tropical areas around the world (Mohammed et al., 2017).

Factors that influence tomato quality can be divided into two groups: appearance factors (color, shape, and freedom of defects) and internal attributes such as texture, sweetness, acidity, aroma, flavor, shelf life, and nutritional value (Hewett, 2006). The quality of tomato fruits and their acceptance by consumers as assessed by sensory evaluation correlates highly with its chemical analysis. Fruit composition and their desirability are affected by many factors such as growth media, fertilizers, and salinity sources (Kowalczyk et al., 2011).

There is a large number of tomato cultivars with a wide range of morphological and sensorial characteristics which determine their use. The particular quality and nutritional traits of tomatoes were mostly differentiated by the type of cultivar, the date, of harvest, and other agronomic practices (Pinela et al., 2012, Kowalczyk et al., 2011).

In this review, an overview is provided of the findings recently reported on the biochemical composition of these fruits and how this is influenced by both genetic and external factors.

Methodology

Official scientific books and internet browsing from different databases were used to recognize and download review and research articles linked to the terms (components of tomato, antioxidants and vitamins content of tomato, effect of ripening process on minor components of tomato, effect of genetic and environmental factors on tomato quality, proximate composition of tomato, tomato color, sensory attributes). Research papers that were linked to the key terms (chemical, physical, and quality factors of tomatoes and their products, biochemistry of minor components of tomato, and their effect on quality) were collected as a priority for this scientific review. Reference lists of identified studies were also searched to find additional articles and reviews.

Chemical Composition of Tomatoes and Their Products

Minor Components: The chemical composition of the minor components of tomatoes and their products, influence the organoleptic attributes of color, taste, and texture (including firmness and paste viscosity). Following is a discussion of each of these components.

Carotenoids:

Carotenoids are 40-carbon isoprenoid derivatives, so the basic structure of carotenoids is a chain of eight isoprenoid units and their lipid-soluble pigments with colors ranging from yellow to orange to red, the hydrocarbon carotenoids are known as carotenes e.g. lycopene and β-carotene, while oxygenated derivatives of these hydrocarbons are known as xanthophylls e.g. lutein. Carotenoid profiles differ based on the genetics, maturity, cultivation techniques, and growing conditions of tomato plants (Chen, 2018, Lucini et al., 2012). Figure (1).

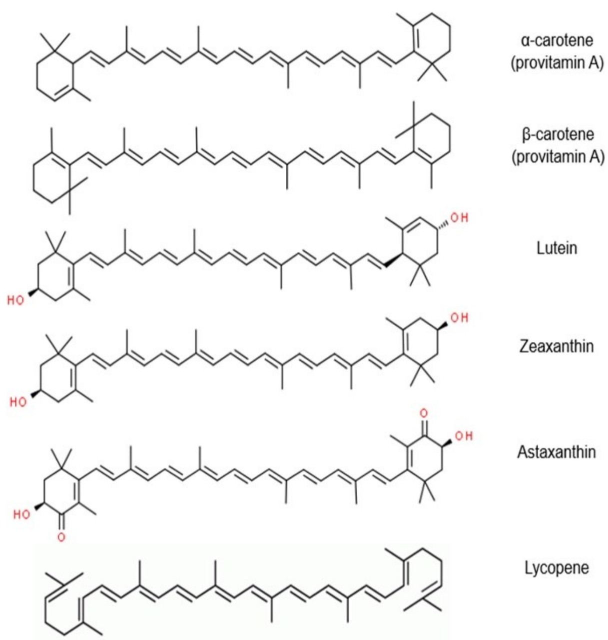


Figure (1): Structure of commonly known carotenoids.

Lycopene:

A beneficial component in tomato fruit that recently has gained great public attention is the carotenoid lycopene. It is the red pigment and a major carotenoid in tomato (Lycopersicon esculentum, Mill.) fruits. It is a potent natural antioxidant and the focus of many tomato genetics and breeding programs. Lycopene is a precursor to the production of α-carotene and β-carotene. The antioxidant capacity of lycopene is at least twice that of β-carotene (Hyman et al., 2004). The chemical structure of lycopene, C40H56, contains 11 conjugated and two non-conjugated double bonds, thus providing plants, such as tomatoes their distinctive red color, it was found to be a more efficient antioxidant (singlet oxygen quencher) than β-carotene, α-carotene, and α-tocopherol (Alda et al., 2009, Arballo et al., 2021).

Mevalonic acid, believed to be a precursor, is converted step by step by a loss of hydrogen in each step, to produce lycopene. Dehydrogenation is most likely involved in each step. Thus, lycopene exists as small globules, which are suspended in the tomato pulp throughout the fruit. Lycopene appears as solid microcrystals and thus the light reflected from them gives the tomato its typical bright red color (Shi et al., 2000).

Martínez-Valverde et al. (2002) reported that the concentrations of lycopene and the various phenolic compounds as well as the antioxidant activity were significantly influenced by the tomato variety, the lycopene content ranged from 18.6 to 64.98 mg/kg among nine varieties. Mohammed et al. (2017) found that lycopene content in three different tomato varieties in Nigeria ranged from 6.88 to 7.83 mg/100g. García-Valverde et al. (2013) found that the total lycopene content ranged from 0.39 mg/kg to 141.32 mg/kg of fresh weight of three different varieties during the ripening stages. Cherry tomatoes ranked the highest in lycopene content. On a dry weight basis, Roma tomatoes contained the highest lycopene concentration, while the vine tomatoes ranked the lowest in lycopene content (Toma et al., 2008). Hyman et al. (2004) reported that lycopene content ranged from 0 to 246 µg/g fresh weight across 24 tomato genotypes. Helyes et al. (2003) found that the lycopene content of five well-known commercial processing tomato varieties harvested in Hungary ranged between 60.8 and 171.0 mg /kg. Alda et al. (2009) found that the lycopene content of samples of fresh tomatoes was approximately 12 mg/100g. The total carotenoids in fresh tomato juice were 6.74 mg/100g and after being processed tomato paste increased to 34.31 mg/100g (Kamil et al., 2011).

The synthesis of lycopene pigment and its accumulation during the ripening of tomatoes is responsible for its red color. Helyes and Pék, (2006) reported that lycopene changed significantly and increased sharply during maturation and accumulated mainly in the deep red stage. Therefore, the content of lycopene has been suggested as a good indicator of the ripening level. Lycopene concentration varies during the ripening process, initially, it is present in the locules at the breaker stage, and then its concentration rises during the ripening process (Martí et al., 2016). Heinonen et al. (1989) reported that the lycopene concentration in tomatoes was higher in summer and lower in winter, and fruits picked green and ripened in storage are considerably lower in lycopene than vine-ripened fruits, and tomatoes fruits grown outdoors during summer are higher in lycopene than fruits are grown in the greenhouse either in winter or summer.

β - carotene:

Another important carotenoid is β-carotene which possesses both antioxidant capacity and provitamin A activity, Physiologically, β-carotene had a similar chemical structure (C40H56) to that of Vitamin A, could change to be vitamin A in the human body, which was considered to be the safest and most effective vitamin A. is commonly known as a radical scavenger and a physical scavenger of singlet oxygen and is believed to play an important role in the inhibition of the initial stages of lipid peroxidation. β-Carotene the second main colored carotenoid present in tomatoes is responsible for orangey colors (Martí et al., 2016, Hasan et al., 2019).

García-Valverde et al. (2013) stated that the content of β-carotene in tomatoes is significantly affected not only by the degree of maturity but also by the variety and growing location, they found that the β-carotene content ranged from 0.76 to 5.44 mg/kg fresh weight of three different varieties during ripening stages. Hyman et al.

(2004) reported that β-carotene content ranged from less than 1 to 12 µg/g across 24 tomato genotypes of tomatoes. Ahamad et al. (2007) determined the β-carotene content in different fresh vegetables, they found that β-carotene content in fresh tomatoes is 1610 µg/100g. Hasan et al. (2019) found that the amount of β-carotene in tomato samples collected from local farms in El-Beida City-Libya ranged from 31.53 - 72 .6 ppm on a wet weight basis.

The biosynthesis of carotenoids starts with carotenoid precursors, isopentenyl diphosphate (IPP) and dimethylallyl diphosphate (DMAPP), and converts to a C20 terpenoid geranylgeranyl diphosphate (GGPP). Then, 15-cis-phytoene is condensed from two GGPPs. 15-cis-phytoene is converted to tetra-cis-lycopene via two desaturations and one isomerization reaction by three enzymes. Afterward, an isomerase converts tetra-cis-lycopene to all-trans-lycopene. Later, all-trans-lycopene is cyclized through two routes and branched to form δ-carotene or β-carotene, and ultimately results in lutein or neoxanthin (Chen, 2018) as shown in figure (2).

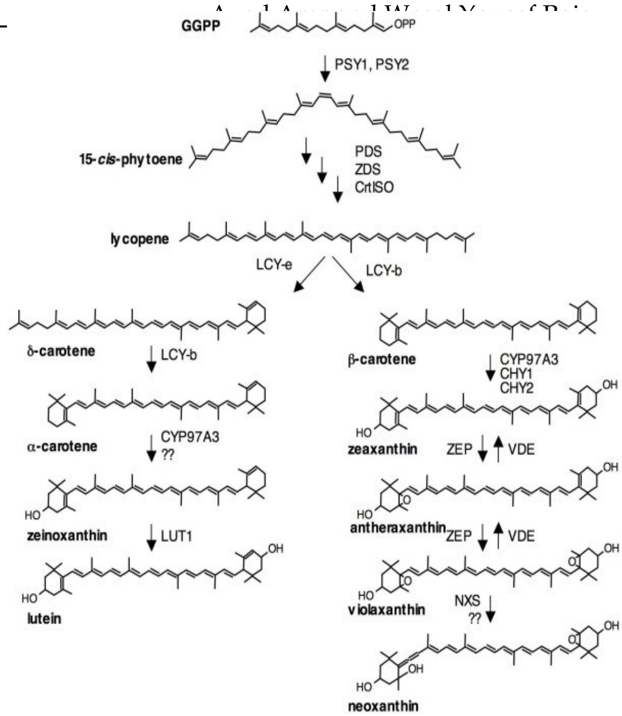


Figure (2): Carotenoid biosynthetic pathway.

The content of lycopene and β-carotene from the different references are summarized in the below table (1).

Table (1): Lycopene and β-carotene Contents from Different References

Fruit or Fruit Part	Lycopene / β-caroten	Content	Reference
Nine varieties of fresh tomatoes	Lycopene	18.6 to 64.98 mg/kg	Martínez-Valverde et al. (2002)
Three different tomato verities in Nigeria	Lycopene	68.8 to 78. 3 mg/kg	Mohammed et al. (2017)
Three different varieties during ripening stage	Lycopene	0.39 to 141.32 mg/kg	García-Valverde et al. (2013)
	β-carotene	0.76 to 5.44 mg/kg	
Twenty-four tomato genotypes	Lycopene	0 to 246 µg/g	Hyman et al. (2004)

	β-carotene	< 1 to 12 µg/g	
Five processing tomato varieties in Hungary	Lycopene	60.8 and 171.0 mg /kg	Helyes et al. (2003)
Fresh tomatoes	Lycopene	120 mg/kg	Alda et al. (2009)
Fresh tomato juice	Total carotenoids	67. 4 mg/kg	(Kamil et al., 2011)
Fresh tomatoes	β-carotene	16100 µg/kg	Ahamad et al. (2007)
Fresh tomatoes in El-Beida City- Libya	β-carotene	31.53 - 72 .6 mg/kg	Hasan et al. (2019)

Vitamin C:

Chemically, vitamin C is a dibasic acid with an enediol group on C2 and C3 of a heterocyclic lactone ring with the empirical formula of C6H8O6, figure (3) (Paciolla et al., 2019).

The vitamin C (L-ascorbic acid) content of fresh tomatoes depends on the variety and the cultivation conditions (Abushita et al., 1996). The antioxidant content of tomatoes depends mainly on both genetic and environmental factors as well as the ripening stage. Ascorbic acid (vitamin C) might increase with ripening due to enhanced respiration. This maintains firmness and lengthens the shelf-life of the fruit. Statistically significant differences were found among cultivars, while no clear trend was observed during ripening in the different cultivars studied, Vitamin C levels ranged from 2.79 mg/kg fresh weight (FW) to 297.62 mg/kg fresh weight of three different varieties during ripening stages (García-Valverde et al.,2013). L-Ascorbic acid was among the components in tomatoes highly sensitive to thermal degradation, its content is around 14.6 mg per 100 g of fresh red tomato depending on the cultivar and growing conditions (Abushita et al., 2000). Valsikova et al. (2017) found that vitamin C ranged from 6.74 - 21.51 mg/100g in nine varieties of differently ripened tomatoes. Mohammed et al. (2017) found that vitamin C in three different tomato varieties in Nigeria ranged from 3.73 to 4.59 mg/100g. The blending method had a significant effect on vitamin C content, Xu et al. (2018) reported that Waring blending of fresh whole tomatoes gave the lowest vitamin C content of tomato concentrate, which was attributed to the oxidation of the product by vigorous blending, they reported that the highest vitamin content was obtained by high temperature with shear blending method. Igile et al. (2016) found that vitamin C in raw tomato juice was 157.25 mg/ 100g. El-Dengawy et al. (2016) reported that vitamin C content in fresh tomato juice was 15.6 mg/100g.

Strong biochemical and genetic evidence has demonstrated that plant tissues synthesize Ascorbic acid primarily via the L-galactose Wheeler Smirnoff pathway which is considered the primary route pathway, although other pathways may be operating, involving either L-gulonic intermediates, or Myo-inositol, or L-galactonic intermediates (D-galacturonic acid) (Mellidou et al., 2008, Di Matteo et al., 2010), below figure (4) shows these pathways

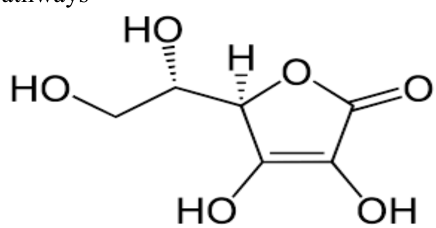


Figure (3): L- ascorbic acid structure.

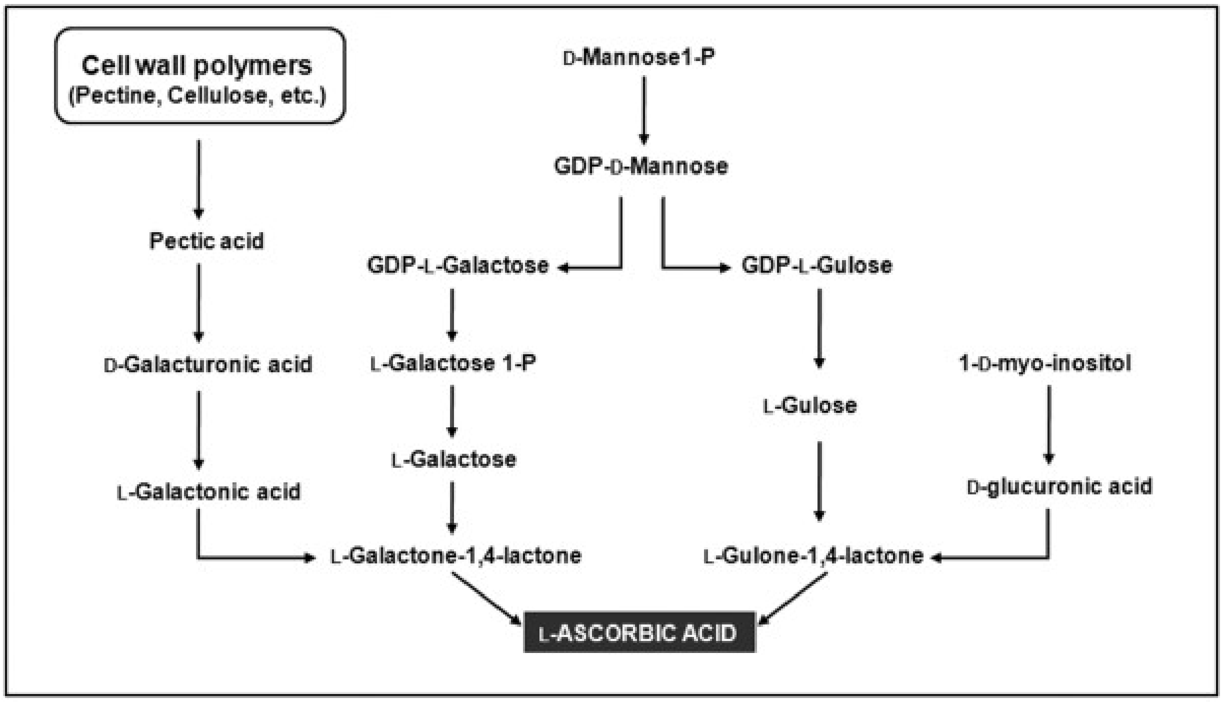


Figure (4): Alternative pathways for l-Ascorbic acid biosynthesis in plants. From left to right: d-galacturonate pathway, L-galactose pathway, l-gulose pathway, and myo-inositol pathway (Di Matteo *et al.*, 2010).

B- Vitamins:

Vitamins are nutrients essential in our diet. Eight of the water-soluble vitamins are known as Vitamin B-complex group. Thiamine (B1), riboflavin (B2), niacin (B3), pantothenic acid (B5), pyridoxine (B6), biotin (B7), folic acid (B9) and, cyanocobalamin (B12) constitute Vitamin B complex. B vitamins function as coenzymes helping the body obtain energy from food. Also, these are important for the nervous system, good vision, red blood cell formation, and, healthy skin. Tomato fruits are moderately rich in vitamins and their content of B vitamins needs to be improved (Kavitha et al., 2015, Mozumder et al., 2019)

In a study by Kavitha et al. (2015) eight genotypes and a wild species of tomato were profiled for 'B' vitamins at three different stages of fruit maturity, green, breake,r and, ripe stage. They found that at the ripe stage the niacin (B3) ranged from 0.00 to 0.350 mg/kg, pantothenic acid (B5) ranged from 0.373 to 2.522 mg/kg, pyridoxine (B6) ranged from 0.010 to 0.252, riboflavin (B2) ranged from 0.041 to 0.621 mg /kg, thiamin (B1) ranged from 0.02 to 0.830 and biotin (B7) ranged from 0.195 to 0.564 mg/ kg, they stated that the content of most of the vitamins increased with the ripening of the fruit.

Mozumdern et al. (2019) estimated the vitamin B complex in eleven selected vegetables of Bangladesh, they found that the content of thiamin (B1) in ripe tomato was 0.14 mg/100 g of edible portion, niacin (B3) in green tomato was 0.16 while in ripe tomato was 0.05 mg/ 100 g of edible portion.

Vitamins content in tomatoes is summarized from different references in below table (2)

Table (2): Vitamin Content of Tomatoes from Different References.

Fruit or Fruit Part	Vitamin	Range	Reference
Ripe tomatoes		0.279 to 29.7 mg/100g	García-Valverde *et al*. (2013)
Fresh ripe red tomato		14.6 mg/100 g	Abushita *et al*. (2000)
Ripe tomatoes		6.74 - 21.51 mg/100g	Valsikova *et al*. (2017)
Ripe tomatoes	Vitamin C	3.73 to 4.59 mg/100g	Mohammed *et al*. (2017)
Tomato juice		157.25 mg/ 100g	Igile *et al*. (2016)
Tomato juice		15.6 mg/100g	El-Dengawy *et al*. (2016)
Fresh tomato		10.86–85.00 mg/100g	Ali *et al*. (2021)
Eighteen different tomato genotypes		8.0-16.3 mg/100g	Frusciante *et al*. (2007)
Eight genotypes and a wild species at three different stages of fruit maturity	B1	0.02 to 0.830 mg/kg	
	B2	0.041 to 0.621 mg/kg	
	B3	0.00 to 0.350 mg/kg	
	B5	0.373 to 2.522 mg/kg	Kavitha *et al*. (2015)
	B6	0.010 to 0.252 mg/kg	
	B7	0.195 to 0.564 mg/kg	
Ripe tomato in Bangladesh	B1	0.14 mg/100 g	Mozumdern *et al*. (2019)
	B3	0.05 mg/100 g	
	B1	0.04–0.98 mg/100 g	
	B2	0.02–0.81 mg/100 g	
	B3	9.68 mg/100 g	
	B5	4.52–5.34 mg/100 g	Ali *et al*. (2021)

Fresh tomato	B6	1.29–1.72 mg/100 g	
	B7	68.97 µg/100g	
	B9	13.00–15.00 mg/100 g	
Eighteen different tomato genotypes	Vitamin E	0.17-0.62 mg/100g	Frusciante *et al*. (2007)
Fresh tomato		14.02–16.13 µg/100g	Ali *et al*. (2021)
Fresh tomato	Vitamin A	833 IU/100 g	Canene-Adams et al. (2005)
Fresh tomato		267.33–833.00 IU/100 g	Ali *et al*. (2021)

MSG:

Monosodium glutamate (MSG) is the sodium salt of the nonessential amino acid glutamic acid used as a flavor enhancer worldwide. MSG is found naturally in many protein-containing foods including Parmesan cheese, milk, meat, fish, and in a number of different vegetables (tomatoes, potatoes, mushrooms, etc.) and fruits such as grapes. It is one of the most widely used food additives in commercial foods (Kumar et al., 2020). Of all the taste classes, the most recent to attract attention is meatiness, meaty taste has come to be associated with two particular compounds, inosine monophosphate, IMP, and monosodium glutamate, MSG. both of these substances were first identified as the active components in popular food ingredients used to enhance the flavour of traditional Japanese dishes. Umami is a Japanese word used to identify the particular taste of these two compounds and others related to them. The use of tomatoes to bring out the flavor of meat and Parmesan as a garnish for minestrone soup can be justified by containing 260, and 1200 mg/100g of MSG respectively (Coultate, 2002).

Glutamate itself is regarded as one of the most important components in proteins. It is a key component in enhancing the flavor of foods when it is in their free form not when it is bound with others. Free glutamate is liberated in protein hydrolysis throughout fermentation, aging, ripening, and heat cooking process. The characteristic tastes of many natural foods are reproduced by mixing amino acids, umami taste substances, and salts in appropriate ratios. Both MSG and glutamate are the monosodium salts of glutamic acid. However, the totally dissociated form of L (+)-glutamic acid merely exhibits the umami effect. The MSG compound contains + separate sodium cations Na and glutamate − anions in zwitter ionic form, OOC-CH + −7 (NH)-(CH) -COO (Wijayasekara et al., 2017, Yamaguchi et al., 1998) figure (5).

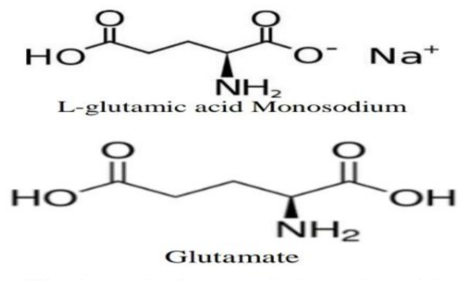


Figure (5): Ionic forms of glutamic acid (Wijayasekara et al., 2017).

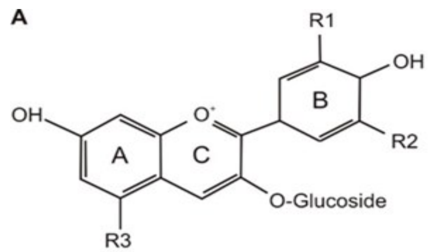
Wijayasekara et al. (2017) stated that it had been found that, an increase in sugars free amino acids and organic acids such as tomato contribute to the increase in flavor during the ripening of vegetables. For example, an increase in their natural contents of free amino acids is related to flavor maturation in ripening tomatoes. In fresh tomato juice, Glutamic acid comprises up to 45% of the total weight of free amino acids, and aspartic acid is the second highest. Free amino acids, Sugars, organic acids, and salts are the main components backing to tomato taste. Ninomiya et al. (1998) also reported measured free glutamic acid, which presents naturally in different foods including tomatoes which include 246 mg/100g. The mean concentration of glutamic acid in the flesh was 1.26 g/kg and that in the pulp 4.56 g/kg. The mean concentration of 5'-adenosine monophosphate (AMP) in the flesh was 80 mg/kg and in pulp, it was 295 mg/kg. Those are the contributing umami flavor compounds in tomatoes (Oruna-Concha et al., 2007).

Anthocyanins:

Anthocyanins are an important class of flavonoids that represent a large group of plant secondary metabolites. Anthocyanins are glycosylated polyphenolic compounds with a range of colors varying from orange, red, and purple to blue in flowers, seeds, fruits, and vegetative tissues. Anthocyanins are the glycosylated derivatives of the anthocyanidin molecules, whose chemical structure is based on a C15 skeleton formed by two polyhydroxylated or polymethoxylated aromatic rings (A and B) linked by a C3 benzene ring (C) (Figure 6). Glucose, galactose, arabinose, rutinose, rhamnose, and xylose are the sugars most commonly attached, as mono-, di- or tri-saccharides, to the 3-position on the C ring or the 5- or 7-position on the A ring. The sugar moieties can be further acylated with aliphatic and aromatic acids. Several anthocyanidins can be synthesized, differing in the substituent groups on the structural rings, but six of them represent 90% of the total, namely pelargonidin, cyanidin, delphinidin, peonidin, petunidin, and malvidin. Glucose represents the main glycosylating agent, and the 3-O-glucose derivatives are the most common anthocyanins found in nature (Figure 6).

The anthocyanin biosynthetic pathway has been well-studied in Solanaceous vegetables and summarized by (figure 7). (Gonzali et al., 2020, Liu et al., 2018).

The fruits of tomatoes (Solanum lycopersicum L.) are rich in several carotenoid pigments, such as lycopene and phytoene, but contain only small quantities of other flavonoids. Since tomato is the second most consumed vegetable in the human diet, their importance as a vehicle for nutrients and bioactive compounds is clear. Anthocyanins are known for their health-protecting function in our daily diet, for they are found to activate endogenous antioxidant defenses and suppress inflammatory mediators. Therefore, strategies such as genetic engineering and breeding programs have been recently carried out to increase the tomato content of anthocyanins.



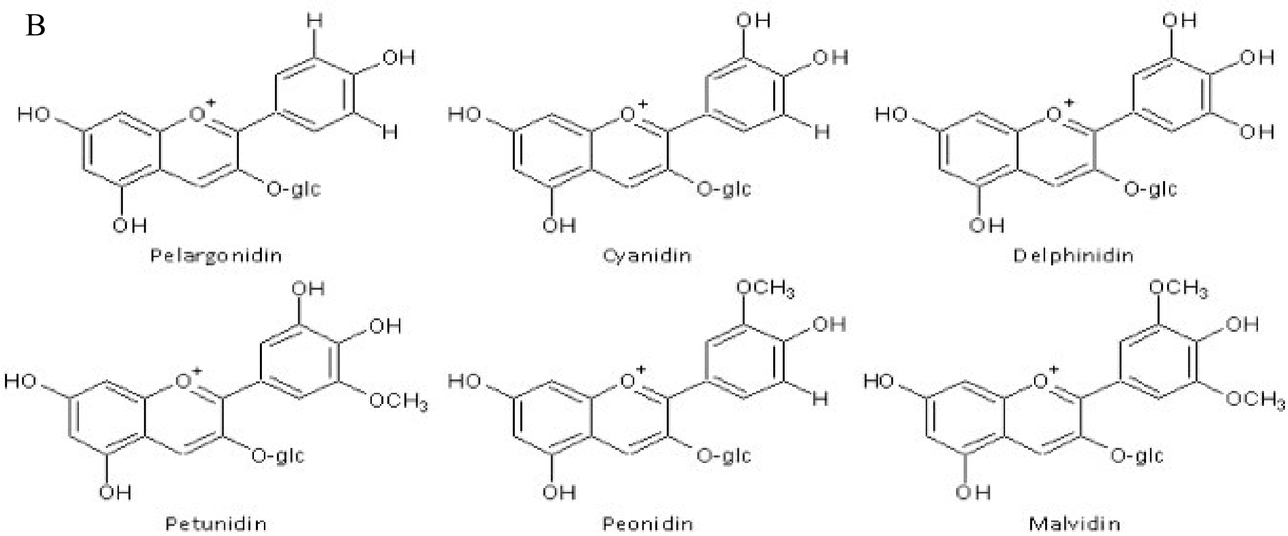


Figure (6): General chemical structure of anthocyanidins (A) and the most common Anthocyanins (B)..

Such strategies have resulted in success, leading to the production of new anthocyanin- rich fruit varieties, some of which are already marketed. These varieties produce purple fruits with a high nutraceutical value, combining the health benefits of the anthocyanins with the other classical tomato phytochemicals, particularly carotenoids (Gonzali et al., 2009, Cappellini et al., 2021).

Gonzali et al. (2020) reported that the concentration of anthocyanins varied according to fruit size and light exposition and could reach considerable values (more than 1 mg g-1 dry wieght). The purple tomato lines produced by genetic engineering are being characterized by a uniform phenotype with high anthocyanin concentrations in both peel and flesh.

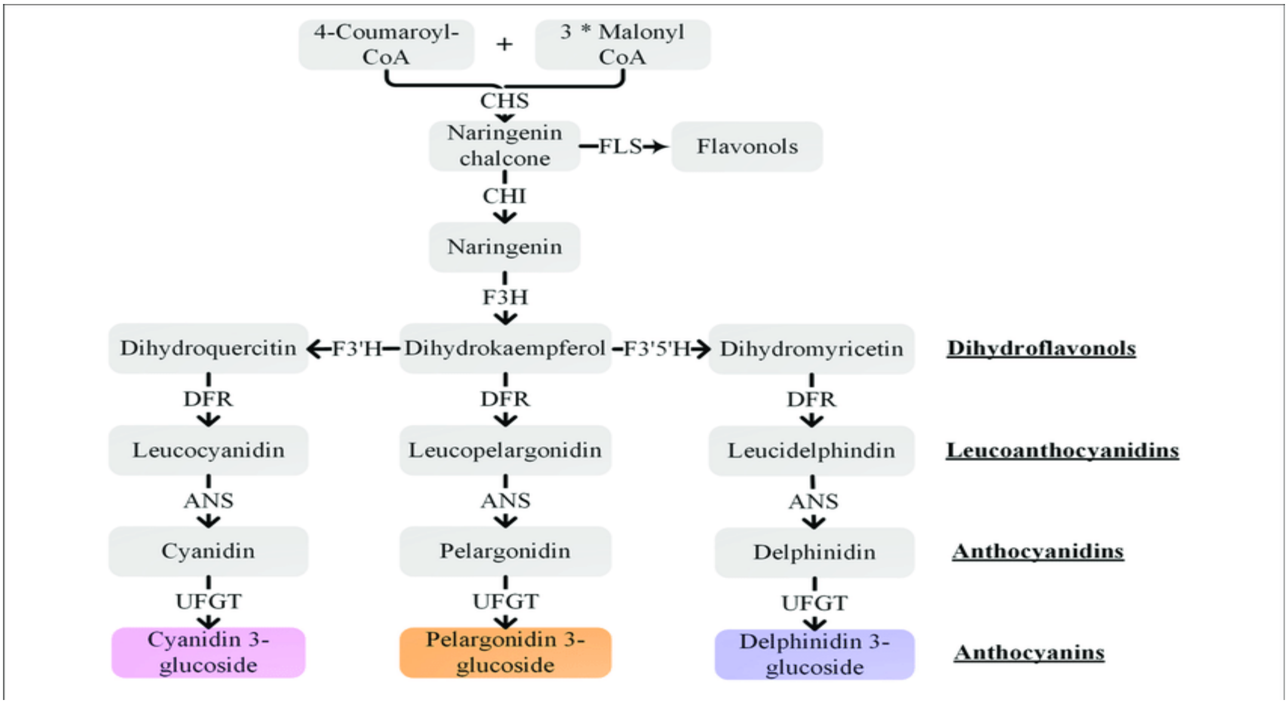


Figure (7): Schematic representation of the anthocyanin biosynthetic pathway. CHS, chalcone synthase; CHI, chalcone isomerase; F3H, flavanone 3-hydroxylase; F3′H, flavonoid 3′ -hydroxylase; F3′5 ′H, flavonoid 3′ ,5′ -hydroxylase; DFR, dihydroflavonol 4-reductase; ANS, anthocyanidin synthase; UFGT, flavonoid 3-O-glucosyltransferase; FLS, flavonol synthase. The “*” means multiplication (Liu *et al.*, 2018).

Major Components (Proximate Composition)

Vegetables constitute a major source of vitamins, crude fiber, protein, antioxidants, and minerals even though their protein content is usually low. Some of the key proximate factors such as moisture, acidity, crude fiber, and protein, differ with cultivars, and cultural and postharvest handling practices. Moisture is of importance in food processing as a number of biochemical reactions, stability, and physiological changes in food depend very much on it (Mohammed et al., 2017).

Pinela et al. (2012) studied the proximate composition in four different tomato varieties in Portugal; they found that moisture ranged from 90.6 to 93.7 g/100 g, ash ranged from 0.54 to 0.74 g/100 g, protein ranged from 0.40 to 0.61 g/100g, fat ranged from 0.03 to 0.17g/100 g, carbohydrate range from 5.14 to 7.99 g/ 100 g, total sugar ranged from 3.91 to 6.62 g/100 g.

Kaaya et al. (2001) determined the nutrient composition of five major varieties of tomato grown in Uganda, they found that moisture ranged from 94.7 to 95.45 %, ash ranged from 0.44 to 0.665 %, protein ranged from 0.73 to 1.195 %, fat ranged from 0.075 to 0.135 %, carbohydrate range from 2.535 to 2.96 %, fiber ranged from 0.5 to 0.67 total sugar ranged from 0.2 to 0.31 %.

El-Dengawy et al. (2016) found that Egyptian tomatoes contain moisture 95 %, protein 0.78 %, fat 0.49 %, fiber 1.13 %, ash 0.90 %, carbohydrate 1.70 %, and total soluble solid (T.S.S) 5 %. Mohammed et al. (2017) determined the nutrient composition of three different varieties of tomato grown in Nigeria, they found that moisture ranged from 84.15 to 90.75 %, ash ranged from 0.14 to 0.18 %, protein ranged from 2.26 to 2.6 %, fiber ranged from 1.12 to 1.25%

The proximate composition of tomato and tomato juice from the different references is summarized in the below table (3)

Table (3): The Proximate Composition of Tomato and Tomato Juice from Different References

Content %	Four Portuguese tomato varieties Pinela et al. (2012)	Five Ugandan tomato varieties Kaaya et al. (2001)	Three Nigerian tomato varieties Mohammed et al. (2017)	Raw Egyptian tomato juice (El-Dengawy et al., 2016)
Moisture	90.63 - 93.70	94.7 – 95.45	84.15 – 90.75	95
Protein	0.40 - 0.61	0.73 – 1.195	2.26-2.6	0.78
Fat	0.03 - 0.17	0.075 – 0.135	——	0.49
Fiber	——	0.500 – 0.67	1.12-1.25	1.13
Ash	0.54 – 0.74	0.440 – 0.665	0.14-0.18	0.9
Carbohydrate	5.14 – 7.99	2.535 – 2.96	——	1.7
Total sugar	3.91 - 6.62	0.200 – 0.310	——	——

Quality Factors of Tomatoes and their products:

The quality attributes of tomatoes and their products of concern to the tomato industry include physical, chemical, and sensory factors, noting that even the physical factors are influenced by one chemical component or the other.

Physical Quality Factors:

The most important physical quality factors include color and tomato texture and juice viscosity.

Color:

The color and appearance of the products are the first quality attribute to stimulate us to purchase. Tomatoes are known for their vibrant red color, which indicates maturity and therefore the level of the desired flavor in addition to the relative content of lycopene as a beneficial antioxidant (Barrett et al., 2008).

Color is the major quality component of processing tomatoes, and breeders have focused on increasing this factor in processing tomatoes over the past several years, most tomato varieties are red in color due to the presence of the carotenoid, lycopene (Wilkerson, 2012) although some other colors e.g. violet, are being bred and marketed (Colanero et al., 2020). Vieira et al. (2020) conducted a study on color determination in different processing tomato cultivars using three different methods. The values for luminosity L*, chrome a*, and chrome b* varied significantly between cultivars, regardless of the color determination method. They found that the luminosity of the fruits through the colorimetric method varied from 33.4 to 37.2, values of chrome a* from the fruits (more reddish) ranged from 23.0 to 26.3, while the chrome b* values (more yellowish) of the fruit determined by colorimeter ranged between 19.0 and 25.6, they reported that the intensity of the red component (chrome a*) by both of colorimetric and digitals image methods (Cielab and Hunterlab) was higher than the yellow component (chrome b*), due to the fact that the fruits were in its ripe and red stage. The cultivar, the plantation zone, and the growing season are important factors that affect the concentration and pigmentation in tomatoes for processing, temperature is the most important environmental factor in the post-harvest life of tomato fruits because of its influence on the rate of biological processes, including the development of red color and softening of tomato fruits. Color development depends on a number of factors including temperature, maturity stage, and storage duration (Tadesse et al., 2015, Vieira et al., 2020).

Tomato Fruit Texture (Hardness):

Textural parameters of fruits and vegetables are perceived with the sense of touch, either when the product is picked up by hand or placed in the mouth and chewed. According to Bourne (1982), the textural properties of a food are the "group of physical characteristics that arise from the structural elements of the food and sensed by the feeling of touch. They are related to the deformation, disintegration, and flow of the food under a force, and are measured objectively by functions of mass, time, and distance. The texture of fruits and vegetables is derived from their turgor pressure, and the composition of individual plant cell walls, and the middle lamella "glue" that holds individual cells together. Tomatoes are an example of a fruit vegetable that is composed approximately of 93–95% water and 5–7% total solids comprised of roughly 80–90% soluble and 10–20% insoluble solids. The greatest contributor to the texture of tomato products is the insoluble solids, which are derived from cell walls (Barrett et al.,2010).

Most plant primary cell walls, those of tomato are principally composed of three classes of polysaccharides: cellulose, hemicelluloses (the most abundant of which in tomato cell walls is xyloglucan), and pectins. In tomato, and in many other fleshy fruits, some of the most pronounced ripening-associated changes occur in the pectic polysaccharides and these changes have therefore received the most sustained attention. Pectins are the most structurally complex plant cell wall polysaccharides and they play an important role in cell-to-cell adhesion. Three major classes of pectins have been identified: homogalacturonan (HG), which is composed of a backbone of 1,4-linked α-Dgalacturonosyluronic acid residues; rhamnogalacturonan 1 (RG-I), comprising interspersed α-Dgalacturonosyl residues and rhamnosyl residues, with sidechains of galactosyl and arabinosyl residues; and rhamnogalacturonan II (RG-II), have a 1,4-linked a-D-galacturonic acid backbone with side chains that are extremely complex in sugar, it is generally exists as an RG-II borate diester dimer. supposedly linking HG-connected pectin in the wall and structural data indicate that these three classes of pectin (HG, RG-I, and RG-II) are interconnected by covalent linkages via their backbones. During ripening a degradation of pectic polymers occurs as a result of the action of several pectin metabolizing enzymes such as endo-polygalacturonase (referred to here as PG, and which is distinct from an exo-acting polygalacturonase), which hydrolyzes HG, pectin methylesterase (PME) and galactanase (β-Gase) (Steele et al., 1997, Wang et al., 2018)

Factors that affect the textural properties of processing tomatoes may be categorized as either production-related or tissue-specific factors. Production-related factors include (1) cultivar or variety, (2) maturity at harvest and degree of ripeness, (3) cultural practices, including use and type of fertilizer, application of certain hormones, amount of water and degree of sun exposure, and (4) environmental stresses on the tomato plant prior to harvesting, such as drought, salinization, water, chilling, and freezing stresses. Tissue-specific or structure-related factors that affect the textural properties of tomatoes include the following: (1) chemical composition of the cell wall, (2) activity of softening-related enzymes such as polygalacturonase, pectin methyl esterase, and various hyrolases; (3) turgor pressure, (4) cell shape and size distribution, (5) the amount and distribution of intercellular spaces and (6) the proportion and arrangement of specialized tissues such as vascular, epidermal, and locular tissues (Bourne, 1982). The textural properties of processing tomatoes may be measured using both sensory and objective tests, the latter may be either destructive or nondestructive in nature. The destructive methods used for the evaluation of horticultural crop texture are classified into methods by force measuring such as puncture, extrusion, and crushing, and methods by the distance measuring such as Deformation, Acoustic spectrometer, and multiple measuring (Texture Profile Analysis). While non-destructive methods such as mechanical techniques, ultrasound techniques, and optical techniques (Barrett et al., 1998, Chen et al., 2013).

Juice and Paste Viscosity:

Gross viscosity is an important quality attribute of tomato products, such as juice, concentrates, ketchup, and other sauces. The factors which contribute to gross viscosity are divided into varietal and horticultural factors, compositional factors, and processing factors (Heutink, 1986). The viscosity of tomato products is expressed in different factors such as juice apparent viscosity, serum viscosity, and pulp content, pectin is known to be one of the most significant compounds defining tomato juice viscosity. According to the amount and type of pectins present in the tomato product, different viscosities can be achieved (Cadavid, 2014)

Tomato juice is considered a non-Newtonian fluid since its resistance to shear force is not linearly related to the rate of shear force applied to it. Viscosity is used to measure non-Newtonian fluids and it quantifies the resistance applied by a fluid product to the relative motion of its components (Cadavid, 2014). One of the main quality attributes of tomato concentrate products is their viscosity. The apparent viscosity of tomato concentrate is influenced by various factors: tomato variety and maturity, water-insoluble and soluble content, particle size distribution, and particle shape and processing variables (Sa´nchez et al.,2002).

Tomato paste is produced either by the cold break or by the hot break process. In a hot break process, the chopped tomatoes are immediately preheated to a temperature of at least 85 °C, this temperature inactivates the pectolytic enzymes polygalacturonas (PG) and pectin methylesterase (PME) present in the tomatoes which results in a highly viscous paste. While in the cold break process the chopped tomatoes are preheated to a temperature of around 60 °C, in this case, the pectolytic enzymes retain a large part of their activity (Sa´nchez et al., 2002) with the result of lower viscosity paste (or ketchup) due to action of the enzymes which hydrolyze the pectin substances. To improve the viscosity of ketchup processors usually add thickening agents like starch to improve the viscosity of their products. Paste with higher viscosity results from the hot break process even though some loss in flavor, whereas cold break results in a less viscous but more flavorful paste (Koh et al., 2012, Fito et al. 1983). In this respect, Barbana et al. (2012) stated that the apparent viscosity of tomato purées prepared from hot break extracted juice by evaporation was much higher than that made by centrifuging out the insoluble solids, concentrating the serum, and then reconstituting, whereas Tanglertpaibul et al. (1987b) found that apparent viscosity of tomato concentrates made by evaporation of hot break extracted tomato juice was lower than that obtained either by evaporating or by reverse osmosis concentration of the serum.

Tomato product's viscosity is usually determined by the Ostwald glass capillary viscometer which is an inexpensive, precise, and easy-to-perform technique. This technique starts by separating the serum from the paste, followed by the introduction of a specific serum volume into the viscometer where the temperature is equilibrated and then the sample is pulled through the capillary arm and the flow time is measured (Barrett et al., 1998)

Cadavid (2014) stated various techniques to assess the viscosity such as Rotational viscometers, Ultrasonic, Vibrating Viscometers, Tube viscometers, Magnetic Resonance Viscometry, and Piston Viscometer. The most practical method for measuring tomato products' viscosity is the Bostwick viscometer (Zhang et al., 2014).

Chemical Quality Factors

Acidity:

Titratable acidity (TA) not only influences the flavor of the fresh fruit and derivative products (concentrated pulp, tomato purée, ketchup, and juices), it is also related to energy saving during processing, thus affecting the thermal treatment timing during sterilization (Vieira et al.,2020). As the longer the titratable acidity (TA) is, the shorter will be the time and the better will be for the industry. The ratio of sugar to acid is the major contributor to the taste of tomato products, it is responsible for the sweetness, sourness, bitterness, and tartness, which are the major components defining consumers' acceptability of the product (Cadavid, 2014).

Anthon et al. (2011) stated that tomato pH increased upon ripening from the green to pink to the red stage and continued to increase as the red ripe fruit remained on the vine. Titratable acidity was at its maximum at the beginning of the ripening process then decreased as the fruit reached the ripe stage and continued to decrease with over-maturity.

Vieira et al. (2020) reported that the total acidity of 12 different tomatoes for processing cultivars varied from 3.38 to 4.61 g acid /100 g (as citric acid). Kaaya et al. (2001) determined the acidity of five major varieties of tomatoes grown in Uganda, they found that it ranged from 0.08 to 0.365 % as citric acid. While the pH ranged from 4.505 to 4.785. Igile et al. (2016) found the titratable acidity of raw tomato juice was 0.26 % and its pH was 4.59.

Citric acid is the most abundant acid in tomatoes and the largest contributor to the total TA. The decrease in TA with maturity and over-maturity is generally assumed to be due to a loss of citric acid, although direct measurements of changes in citric acid concentrations with maturity have not been reported. Malic and glutamic acids are also significant contributors to the TA. Malic acid is typically present at only one-tenth the level of citric acid, although the ratio of malic to citric can vary considerably between different tomato cultivars. Glutamic acid levels have been shown to increase 10-fold as the fruit ripens from the green to the red stage. Further changes in glutamic acid with over-maturity and changes in malic acid levels with maturity and over-maturity have not been reported. Glutamic acid is also an important contributor to tomato flavor (Anthon et al., 2011)

In fruit juices, titration is carried out with an alkaline solution until reaching a pH of 8.1 (Wills et al., 1990). One of the most common techniques used to analyze sugars and organic acids in tomato and tomato products is high-performance liquid chromatography (HPLC) which provides a good separation of these compounds and can be used to quantify them (Cadavid, 2014).

Total Soluble Solids (0Brix):

The tomato fruit quality is determined by at least two variables: fruit type and total solid soluble, the total soluble solids (oBrix) are determined using a refractometric index that indicates the percentage of soluble in a solution. The solutes consist of a mixture of several chemicals which predominate sugars (65%), acids (13%), and other compounds (mainly amino acids, ascorbate, minerals, pectins, and phenols) (Portugal et al., 2015). Flavor results from the complex interaction of taste and aroma. Sugars, acids, phenols, and minerals are the main constituents of tomato taste and flavor with sugars, quantitatively, making the largest contribution (Beckles, 2012).

The major contributors to the soluble solids content in tomato products are glucose and fructose. Soluble solids content depends on the tomato cultivar and the ripening stage in which the tomatoes are collected. Early harvested tomatoes usually contain higher soluble solids than later harvested tomatoes and this is consequent with the amount of glucose and fructose that usually declines over time (Cadavid, 2014). Between the first and last harvests soluble solids declined by between 4% and 7% which positively correlated with the measured declines in glucose and fructose (Anthon et al., 2011). Kaaya et al. (2001) determined the total soluble solids (TSS) of five major varieties of tomatoes grown in Uganda, they found that they ranged from 4.1 to 5.065. El-Dengawy et al. (2016) found that the total soluble solids of raw tomato juice are 5, whereas after processing increased to 9. While Kamil et al. (2011) found the TSS in fresh tomato juice is 4.07.

Soluble solids are also yielded indicators for tomato processors since higher °Brix means that less fruit amount is required to obtain a certain quantity of final product, and less time in the evaporation process is required to take water out of the tomato juice during the concentration process (Cadavid, 2014).

Sensory Quality of Tomatoes and their Products:

The sensory qualities of tomatoes constitute a crucial factor in assessing product quality because they influence the sensory acceptance and purchasing choice of consumers, thus affecting the economic interests of farmers, suppliers, and retailers (Li et al., 2021). Tomato fruit quality for fresh consumption is determined by a set of attributes that describe external (size, color, firmness) and internal (flavor, aroma, texture) properties. Sensory analysis is an efficient way of describing these properties and has to be compared to consumer preferences (Causse et al., 2003). Kowalczyk et al. (2011) reported that the good quality of tomato fruits and their acceptance by consumers are highly correlated with the sensory assessment and the results of chemical analysis, fruit composition, and their desirability. The same authors reported that sensory quality attributes are affected by a number of factors such as growth media, fertilizers, and salinity sources. Tomatoes harvested in July had a higher sugar content and received a higher sensory evaluation note than those harvested in September, also they reported that the skin firmness and sweet taste significantly correlated with the content of organic acids and soluble solids, whereas the sugar content in fruits positively correlated with the overall evaluation of tomato fruits.

The quality of the tomato for the fresh market is determined by appearance, firmness, and flavor; whereas the quality of the processing tomato is determined mainly its by soluble solid content, color, pH, and firmness. The color is the most attractive quality trait as it reflects the degree of ripeness which correlates highly with consumer acceptance through the high scoring of appearance, sugar content, acidity, pH, texture, flavor, and juiciness (Araujo et al., 2014) whether for processing or table use.

Pagliarini et al. (2001) reported the common sensory vocabulary to describe the tomatoes, appearance including (round, extended, watery, jelly-like), aroma vocabulary including (grassy, fruity, hay), taste vocabulary including (sweet, salty, acid, bitter), flavor vocabulary (Astringent, grassy and fruity) while texture vocabulary including (crispy, firm, thick-skinned, juicy and mealy).

Good external quality includes uniform size, shape, and color, with firm flesh. A good taste results from a pleasing combination of both texture and flavor. The texture is related to wall thickness and firmness which is influenced by the amounts of pectin and pectin methyl esterase whereas flavor is determined by the balance of sugar, free acids, and numerous volatile organic compounds, which are present in only trace amounts (Butt et al., 2004)

Conclusions

Tomato is one of the most important nutritious vegetable crops, several studies show it as a rich source of the potent antioxidant lycopene, β-carotene, vitamin C, and pro-vitamin A, which are influenced by the tomato variety, the ripening process, season, and the location and conditions of growing. The chemical composition of tomatoes depends mainly on both genetic and environmental factors as well as the ripening stage. Tomato naturally contains monosodium glutamate, which is identified as an active component that enhances the flavor. The good quality of tomato fruits is highly correlated with the sensory assessment and the results of chemical analysis, fruit composition, and desirability.

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مكونات البندوره وعناصر جودتها

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ملخص

تعتبر البندورة (Solanum lycopersicum L.) مكونًا غذائيًا مهمًا على مستوى العالم، ومن حيث الإنتاج والاستهلاك فإنها تشكل ثاني أكثر الخضروات زراعة، ازداد الطلب على البندورة مؤخرًا بسبب القيمة الغذائية المرتبطة بالكاروتينات والألياف والفيتامينات والمعادن التي تحتوي عليها مما جعلها موضوعًا رئيسيًا للدراسات على مستوى المختبرات والظروف الحقلية.

يتم تحديد جودة البندورة من خلال الخصائص الداخلية والخارجية، الداخلية مثل الملمس، والحلاوة، والحموضة، والرائحة، والنكهة، والقيمة الغذائية، والعوامل الخارجية المظهرية كاللون، والشكل، والحجم، والثباتية للتخزين.

تهدف هذه المراجعة إلى التعريف بالتركيب الكيماوي لهذه الثمار من حيث تأثره بالعوامل الوراثية والخارجية وارتباطه بجودة الثمار.

في هذه الورقة تم مراجعة المكونات الكيماوية (الثانوي والرئيسي) التي تم ذكرها من قبل العديد من الباحثين وكيفية تطورها أثناء النضج، كما تم مناقشة عوامل الجودة الكيمياوية والفيزيائية والحسية لثمرة البندورة ومنتجاتها.

الكلمات الدالة: بندورة (طماطم)، مكونات، الجودة، الصفات الحسية.