IOSR Journal of Biotechnology and Biochemistry (IOSR-JBB)
ISSN: 2455-264X, Volume 11, Issue 1 Series 1 (Jan. – Feb. 2025), PP 39-47
www.iosrjournals.org

Phytochemical Composition, Antioxidant Potential, and Health-Promoting Properties of Tomato (*Solanum lycopersicum* L.): A Comprehensive Evaluation of Cultivar Variability and Processing Effects

Brajesh Kumar Chaturvedi[1], Yogesh Singh[2], Manoj Pandey[2], Devesh Kumar[3*]
[1]*Department of Horticulture, RBS College, Agra,*
[2]*Department of Agricultural chemistry and Soil Science, RBS College, Agra,*
[3*]*Department of Botany, RBS College, Agra,*
Affiliated to Dr. Bhimrao Ambedkar University, Agra, Uttar Pradesh, India
Corresponding Author E-mail: drdeveshjadon@gmail.com

Abstract
Tomato (Solanum lycopersicum L.) is globally recognized not only as a staple vegetable but also as a potent functional food due to its rich phytochemical profile. This review synthesizes the current understanding of the antioxidant properties, health-promoting benefits, and biochemical diversity among tomato cultivars. Particular attention is given to the effects of post-harvest processing and storage on the stability and bioavailability of key compounds, especially lycopene, vitamin C, flavonoids, and phenolic acids. The implications of these properties in the prevention and management of chronic diseases, such as cardiovascular diseases, cancers, and metabolic disorders, are also discussed. Recognising how varietal and processing influences tomato phytochemistry can help guide breeding programs, dietary recommendations, and food industry innovations.
Keywords*: Tomato (Solanum lycopersicum L.), Lycopene, Flavonoids, carotenoids.*

Date of Submission: 10-02-2025 Date of Acceptance: 25-02-2025

I. Introduction

Tomato (*Solanum lycopersicum* L.) stands out as one of the most economically important and extensively cultivated horticultural crops across the globe. Its wide acceptance is attributed not only to its culinary adaptability in diverse food preparations but also to its exceptional nutritional profile and health-promoting properties. Tomatoes are consumed fresh or processed into various products such as sauces, juices, pastes, and purees, making them a staple in many diets worldwide.

One of the most distinctive features of the tomato is its bright red coloration (Figure: 1). Brilliant colouration of tomato is primarily due to the presence of lycopene—a carotenoid pigment known for its potent antioxidant capacity. Lycopene is considered one of the most effective quenchers of singlet oxygen and free radicals, which play key roles in oxidative stress and the development of chronic diseases (Rao & Rao, 2007). Alongside lycopene, tomatoes are a rich source of other bioactive compounds including β-carotene, lutein, vitamin C, vitamin E, phenolic acids, and flavonoids. These phytochemicals synergistically contribute to the antioxidant potential of tomatoes, enhancing their functional value.

Figure: 1 Fresh tomato with vibrant colours

Beyond their antioxidant activity, these compounds have been implicated in a range of health benefits, such as reducing the risk of cardiovascular diseases, certain cancers, and inflammatory conditions. The increasing body of scientific evidence linking tomato consumption with improved human health has driven research interest in understanding the phytochemical composition, antioxidant mechanisms, and factors influencing the nutritional quality of tomatoes. Particular focus has been given to the variation among different cultivars and the impact of agricultural practices and processing methods on the bioavailability and stability of these beneficial compounds. Given their rich nutritional profile and abundance of bioactive compounds, tomatoes are increasingly being recognized not just as a common food item, but as a valuable functional food with potential health benefits. Their regular consumption has been associated with a reduced risk of various lifestyle-related diseases, such as heart disease, certain cancers, and metabolic disorders. As a result, there is growing scientific interest in exploring the diversity of phytochemicals present in tomatoes, particularly those with antioxidant activity, to better understand their role in promoting health and preventing disease. This has positioned tomatoes as an important subject of study in modern nutrition and medical research, where the focus is on identifying natural dietary sources that support overall well-being and chronic disease prevention.

II. Phytochemical Composition of Tomato

2.1 Lycopene in Tomato (*Solanum lycopersicum* L.)

Lycopene is a naturally occurring pigment and the most prominent carotenoid found in ripe tomatoes, contributing to their characteristic red colour. Unlike some other carotenoids such as β-carotene, lycopene does not possess provitamin A activity, meaning it cannot be converted into vitamin A in the human body. However, it exhibits remarkable biological activity due to its strong antioxidant properties. Structurally, lycopene is a linear, unsaturated hydrocarbon composed of 11 conjugated and 2 non-conjugated double bonds (Figure:1), which play a central role in its ability to neutralize reactive oxygen species (ROS), particularly singlet oxygen—an especially reactive and damaging form of oxygen (Rao & Agarwal, 1999).

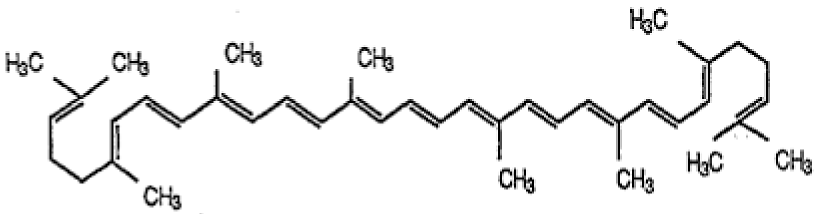

Figure: 2 Chemical structure of lycopene

Lycopene has garnered significant attention for its potential health benefits, especially in reducing oxidative stress, which is implicated in the pathogenesis of various chronic diseases, including cardiovascular diseases, certain types of cancer, and neurodegenerative disorders. Among all dietary carotenoids, lycopene is considered one of the most efficient antioxidants due to its superior ability to quench singlet oxygen—estimated to be twice as effective as β-carotene and ten times more effective than α-tocopherol (Di Mascio *et al.,* 1989).

In nature, lycopene predominantly occurs in the all-trans configuration, which is thermodynamically stable. However, when tomatoes are subjected to heat during cooking or processing, a portion of the all-trans lycopene isomerizes into cis-isomers. These cis-isomers are more soluble in bile acid micelles, making them easier to absorb in the human gastrointestinal tract. Consequently, the bioavailability of lycopene increases significantly following the thermal processing of tomatoes, as seen in products like tomato paste, sauce, or juice (Shi & Le Maguer, 2000). This transformation enhances the functional properties of processed tomato products, making them a more efficient dietary source of bioavailable lycopene than raw tomatoes.

Additionally, the presence of dietary fats during tomato consumption further improves lycopene absorption, since it is a lipophilic compound that requires fat for efficient intestinal uptake (Gartner, Stahl, & Sies, 1997). These factors underline the importance of food matrix, processing methods, and dietary context in determining the health benefits of lycopene from tomatoes.

2.2 β-Carotene in Tomato (*Solanum lycopersicum* L.)

β-Carotene is one of the key carotenoids present in tomatoes and plays a vital role in human health as a provitamin A compound. Upon ingestion, β-carotene is metabolized into retinol (vitamin A), a nutrient essential for maintaining normal vision, immune defense, reproductive health, and epithelial tissue integrity. This conversion is particularly important in populations at risk of vitamin A deficiency (Saini & Keum, 2018).

A defining feature of β-carotene is its long chain of conjugated double bonds (alternating single and double bonds), comprising 11 conjugated double bonds in a linear sequence (Figure: 2). The molecular structure of β-carotene includes a linear carbon backbone with a series of conjugated double bonds (polyene chain) and two identical β-ionone rings at each end. These cyclic end groups resemble the structure of retinol (Vitamin A) and are essential for enzymatic cleavage to produce two molecules of Vitamin A in the human body via the action of β-carotene 15,15'-monooxygenase. β-Carotene (MW 536.888 g/mol) is a fat-soluble, yellow-orange plant pigment with a highly conjugated structure and terminal β-ionone rings. Its structure underlies both its vibrant colour and its role as a vitamin A precursor and antioxidant.

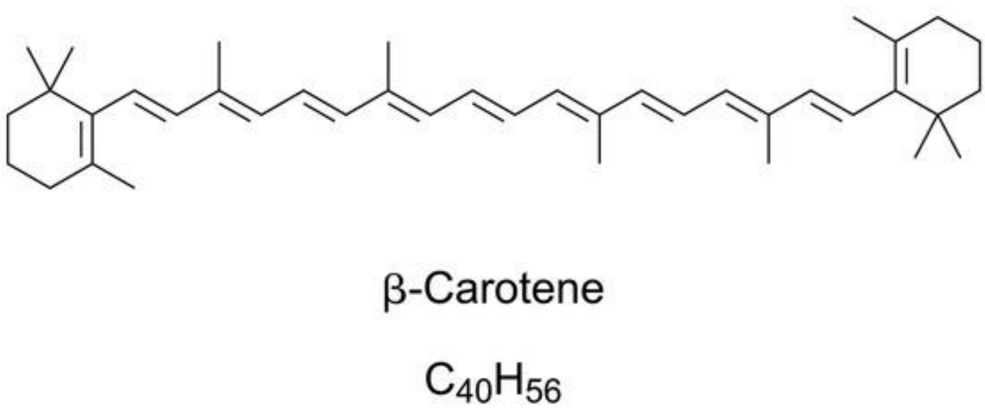

Figure: 3 Chemical structure of Beta-carotene

In addition to its role as a vitamin A precursor, β-carotene exhibits potent antioxidant activity. As a lipophilic molecule, it efficiently integrates into lipid membranes, where it helps scavenge reactive oxygen species such as singlet oxygen and peroxyl radicals. This action helps reduce oxidative damage to cellular lipids, proteins, and DNA—mechanisms that are central to the pathogenesis of many chronic conditions, including cardiovascular disease and cancer (Liu & Liang, 2010; Saini & Keum, 2018).

Epidemiological studies and meta-analyses have shown promising associations between dietary β-carotene intake and reduced mortality risk. For instance, a 2013 meta-analysis suggested that higher consumption of β-carotene from food sources was linked to a significant reduction in all-cause mortality, with an estimated 37% lower risk compared to lower intake levels (Liu & Liang, 2010). However, it is important to distinguish between natural dietary intake and supplementation. Several clinical trials have found that high-dose β-carotene supplements, particularly in smokers, may not provide the same benefits and could even increase the risk of certain diseases, indicating that the source and dose of β-carotene are critical factors in determining its health effects (Tanvetyanon & Bepler, 2008).

In tomatoes, β-carotene contributes not only to the orange-red hue but also to their nutritional value. Although its concentration is lower than that of lycopene, breeding efforts and postharvest treatments have been explored to enhance β-carotene content in specific cultivars to improve the functional food value of tomatoes (Cebolla-Cornejo *et al.,* 2011).

2.3 Lutein & Zeaxanthin

Lutein and zeaxanthin are oxygenated carotenoids belonging to the xanthophyll class. Unlike β-carotene, these pigments do not serve as precursors to vitamin A. However, they perform crucial and distinct roles in maintaining eye health. Both lutein and zeaxanthin are selectively accumulated in the macula lutea, the central region of the retina responsible for high-resolution vision. Here, they act as natural filters of high-energy blue light, helping to reduce the amount of light-induced oxidative damage. By absorbing blue light, they minimize the formation of reactive oxygen species (ROS), thereby offering photoprotective support to delicate retinal cells (Krinsky *et al.,* 2005; Ma *et al.,* 2024).

In addition to their light-filtering properties, these carotenoids possess strong antioxidant potential. Both in vitro and in vivo studies have shown that lutein and zeaxanthin are capable of directly scavenging free radicals and preventing lipid peroxidation within the eye. Their presence helps maintain the structural and functional integrity of ocular tissues by reducing oxidative stress, which is a major contributing factor to age-related eye conditions such as macular degeneration and cataracts (Stringham & Hammond, 2005; Schmid & Wolf-Smith, 2024).

2.4 Phenolic Compounds in Tomato (*Solanum lycopersicum* L.)

Tomatoes are a significant dietary source of phenolic compounds, which are secondary plant metabolites known for their strong antioxidant, anti-inflammatory, and antimicrobial activities. Phenolic compounds enhance the total antioxidant capacity of tomatoes by donating hydrogen atoms or electrons to neutralize free radicals. Their activity is often synergistic with carotenoids like lycopene and β-carotene. However, their bioavailability is influenced by processing methods—peeling, heating, or homogenization may alter their stability and absorption (Martinez-Valverde *et al.,* 2002; Vallverdu-Queralt *et al.,* 2011). These compounds are integral to the plant's defense system and also contribute to the health-promoting properties of tomato-based foods in human diets.

2.4.1. Phenolic Acids

Among the phenolic constituents, hydroxycinnamic acids such as chlorogenic acid, caffeic acid, and ferulic acid are most prevalent in tomatoes. These compounds are typically found in bound or esterified forms, primarily in the skin and outer tissue layers of the fruit.

Chlorogenic acid, a conjugate of caffeic and quinic acid, has been shown to inhibit lipid peroxidation and reduce oxidative stress in biological systems (Clifford, 2000).

Caffeic acid exhibits both antioxidant and anti-inflammatory effects, playing a role in reducing the risk of chronic diseases such as cancer and cardiovascular disorders (Sanchez-Moreno *et al.,* 2006).

Ferulic acid acts as a powerful free radical scavenger and has been studied for its role in skin protection and neuroprotection (Zhao & Moghadasian, 2010).

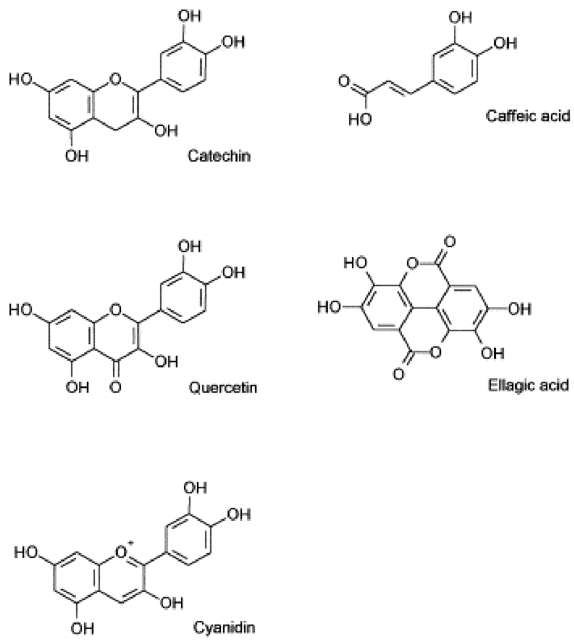

Figure: 4 Phenolic Compounds in Tomato

2.4.2. Flavonoids

Tomatoes also contain a variety of flavonoids, with quercetin and kaempferol being the most notable. These flavonols are primarily concentrated in the skin of the tomato fruit and can be influenced by cultivar type, ripening stage, and environmental conditions.

Quercetin is known for its vasodilatory, anti-carcinogenic, and immune-modulating effects. It contributes to cellular protection by neutralizing reactive oxygen and nitrogen species (Li *et al.,* 2016).

Kaempferol has been linked to anti-inflammatory, anti-obesity, and anti-diabetic properties, making it a compound of growing interest in nutraceutical research (Calderon-Montano *et al.,* 2011).

The phenolic profile of tomatoes varies significantly between cultivars, with cherry tomatoes and some landraces showing higher levels of total phenolics. Moreover, processing techniques, such as making tomato paste or juice, can concentrate phenolics due to water removal or release them from the cellular matrix (Pinela *et al.,* 2012). Despite some losses during thermal processing, the bioavailability of bound phenolics may increase, enhancing their nutritional impact. Phenolic acids and flavonoids in tomatoes play a pivotal role in the plant's antioxidant system and significantly contribute to human health. Their presence complements other phytochemicals in tomatoes, offering protection against oxidative stress and chronic diseases.

2.5 Vitamins and Minerals in Tomato (*Solanum lycopersicum* L.)

Tomatoes are nutritionally rich fruits, valued not only for their phytonutrient content but also for being a notable source of essential vitamins and minerals. Among these, vitamin C, vitamin E, and potassium are particularly significant due to their roles in maintaining cellular homeostasis, antioxidant defense, and physiological functions in humans. These nutrients, combined with tomato phytochemicals, provide additional antioxidant protection, promote cardiovascular and immune health, and strengthen the fruit's role in chronic disease prevention.

2.5.1 Vitamin C (Ascorbic Acid)

Vitamin C is a water-soluble antioxidant abundantly found in fresh tomatoes. It plays a pivotal role in neutralizing reactive oxygen species (ROS), regenerating other antioxidants (like vitamin E), and supporting collagen synthesis, immune function, and iron absorption (Carr & Maggini, 2017). In tomatoes, ascorbic acid content varies by cultivar, ripeness, and environmental factors but generally contributes significantly to the daily recommended intake when consumed raw.

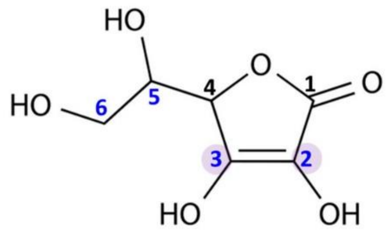

Figure: 5 Chemical structure of Ascorbic Acid

Vitamin C is a six-carbon compound structurally related to glucose. It contains a lactone ring (a cyclic ester) known as γ-lactone. It has four hydroxyl (–OH) groups, two of which are on adjacent carbon atoms, contributing to its strong antioxidant properties. The enediol structure in the ring (two –OH groups on adjacent carbons) makes it readily donate electrons, allowing it to neutralize free radicals.

Furthermore, vitamin C levels may decrease with processing or prolonged storage, but eating fresh or minimally processed tomatoes is still an effective strategy for antioxidant protection and immune support (Willcox *et al.,* 2003).

2.5.2 Vitamin E (Tocopherols and Tocotrienols)

Vitamin E, mainly in the form of α-tocopherol, is a lipid-soluble antioxidant present in the tomato's lipid fractions. It helps protect cell membranes from oxidative damage by scavenging lipid peroxyl radicals and preventing lipid peroxidation chain reactions (Traber & Atkinson, 2007). In tomatoes, vitamin E content is relatively modest but synergizes with other antioxidants like lycopene and β-carotene to enhance the fruit's overall oxidative defense profile.

Dietary intake of vitamin E from tomatoes may contribute to reduced risk of cardiovascular disease and certain neurodegenerative conditions, particularly when part of a diet rich in various antioxidant-rich foods (Brigelius-Flohe & Traber, 1999).

2.5.3 Potassium

Tomatoes are an excellent source of potassium, an essential mineral involved in electrolyte balance, muscle contraction, nerve impulse transmission, and blood pressure regulation. Potassium intake is inversely associated with the risk of hypertension, stroke, and cardiovascular disease (Whelton *et al.,* 1997).

A medium-sized tomato provides approximately 5–10% of the recommended daily intake of potassium, making it a valuable component of heart-healthy diets. Moreover, potassium also supports intracellular enzyme activity and fluid balance, critical for metabolic functions and cellular integrity (Boeing *et al.,* 2012).

III. Antioxidant Potential of Tomato

The antioxidant potential of tomato (*Solanum lycopersicum* L.) is attributed to the synergistic action of various bioactive compounds, including carotenoids (especially lycopene and β-carotene), phenolic acids, flavonoids, and vitamins such as C and E. These compounds work in concert to neutralize reactive oxygen species (ROS), thereby mitigating oxidative stress and cellular damage. The antioxidant activity of tomato has been extensively validated through in vitro assays like DPPH (2,2-diphenyl-1-picrylhydrazyl), FRAP (Ferric Reducing Antioxidant Power), and ABTS (2,2′-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid), which have consistently demonstrated the strong radical-scavenging capacity of tomato extracts (George *et al.,* 2004). Among these phytochemicals, lycopene stands out due to its highly conjugated polyene structure with 11 conjugated double bonds, which enables it to effectively quench singlet oxygen and stabilize free radicals, making it one of the most potent dietary antioxidants identified to date.

Experimental studies have further substantiated the antioxidant efficacy of tomato through both in vitro and in vivo approaches. In vitro analyses have shown that extracts derived from different parts of the tomato fruit—such as peel, pulp, and juice—are capable of inhibiting lipid peroxidation, reducing ROS generation, and protecting against DNA and protein oxidation. These effects are enhanced when the extracts retain a diverse mix of hydrophilic and lipophilic antioxidants, highlighting the importance of whole-food consumption over isolated compounds. In vivo, dietary intake of tomato and tomato-based products has been associated with improved systemic antioxidant status. For example, Riso et al. (2006) reported that regular consumption of tomato juice for two weeks resulted in significantly elevated plasma levels of lycopene and β-carotene, alongside a measurable decrease in oxidative biomarkers, including 8-hydroxy-2′-deoxyguanosine and malondialdehyde (MDA), which are indicators of DNA and lipid oxidation, respectively. These findings underscore the role of tomatoes as functional foods capable of enhancing endogenous antioxidant defenses and reducing oxidative damage linked to chronic diseases.

IV. Health-Promoting Properties

4.1 Cardiovascular Health

Lycopene-rich diets have been widely studied for their protective role in cardiovascular health. Lycopene, a potent lipophilic antioxidant abundant in tomatoes, contributes significantly to the reduction of oxidative stress, which plays a central role in the development of atherosclerosis. By neutralizing reactive oxygen species, lycopene prevents the oxidation of low-density lipoprotein (LDL) cholesterol—a key step in plaque formation within arterial walls. Clinical and epidemiological studies have demonstrated that individuals with higher dietary intake or plasma levels of lycopene tend to exhibit lower levels of oxidized LDL, a recognized biomarker of cardiovascular risk (Arab & Steck, 2000). Moreover, regular consumption of tomato and its products has been associated with favourable changes in lipid profiles, including decreased total cholesterol and LDL levels, and in some cases, increased high-density lipoprotein (HDL) levels. Additionally, lycopene is thought to exert vasodilatory effects by modulating endothelial function and reducing blood pressure. This antihypertensive property is believed to result from improved nitric oxide bioavailability and decreased angiotensin-converting enzyme (ACE) activity. Overall, the cumulative evidence supports the cardioprotective potential of lycopene-rich foods like tomatoes as part of a heart-healthy diet.

4.2 Anticancer Effects

Tomato consumption has been consistently linked to a reduced risk of various cancers, particularly prostate, lung, and gastric cancers. This protective effect is largely attributed to lycopene, the principal carotenoid in tomatoes, along with other antioxidants such as β-carotene, vitamin C, and flavonoids. These bioactive compounds act through multiple mechanisms to counteract carcinogenesis. Lycopene, for instance, exerts potent antioxidant activity that helps neutralize free radicals, thereby preventing DNA damage—a critical initiating event in cancer development. Beyond its antioxidant role, lycopene has been shown to regulate key cellular processes involved in tumour suppression. It promotes apoptosis (programmed cell death) in malignant cells, inhibits uncontrolled cell proliferation, and interferes with growth factor signalling pathways that drive tumour progression. Furthermore, lycopene and other tomato-derived compounds can enhance immune surveillance and modulate inflammatory responses, both of which are important in controlling tumour growth and metastasis.

Epidemiological studies support these findings; higher intake of tomato products has been inversely associated with the risk of prostate cancer in particular, as well as other epithelial-origin cancers. Thus, regular consumption of tomatoes may serve as an effective dietary strategy for cancer prevention.

4.3 Anti-Inflammatory and Anti-Diabetic Effects

Tomato and its bioactive constituents have demonstrated notable anti-inflammatory and anti-diabetic effects, making them valuable in managing chronic metabolic disorders. The anti-inflammatory activity of tomato extracts is largely attributed to their rich content of flavonoids, carotenoids, and vitamins, which collectively modulate inflammatory signalling pathways. In particular, tomato consumption has been shown to reduce levels of pro-inflammatory cytokines such as tumour necrosis factor-alpha (TNF-α), interleukin-6 (IL-6), and C-reactive protein (CRP). These effects are believed to result from the antioxidant action of tomato phytochemicals, which suppress oxidative stress-induced activation of nuclear factor-kappa B (NF-κB), a key transcription factor regulating inflammation (Basu & Imrhan, 2007).

In the context of diabetes, tomato bioactives help improve insulin sensitivity and glucose metabolism. Flavonoids such as quercetin and kaempferol may enhance insulin signalling pathways and inhibit enzymes like α-glucosidase, which delays carbohydrate digestion and glucose absorption. Additionally, the reduction in oxidative stress contributes to the preservation of pancreatic β-cell function and attenuation of insulin resistance. Human and animal studies have demonstrated that regular intake of tomato or tomato juice can lead to modest reductions in fasting blood glucose levels and improvements in insulin response. Together, these findings underscore the potential role of tomato-based foods as complementary dietary interventions for inflammatory conditions and type 2 diabetes management.

4.4 Neuroprotection

Lycopene, a key carotenoid found abundantly in tomatoes, has shown promising neuroprotective properties in both preclinical and clinical studies. Neurodegenerative diseases such as Alzheimer’s and Parkinson’s are often associated with heightened oxidative stress, inflammation, and mitochondrial dysfunction in neural tissues. Due to its strong antioxidant capacity, lycopene can cross the blood-brain barrier and directly scavenge reactive oxygen species (ROS) in the brain, thereby mitigating oxidative damage to neurons and glial cells (Hadley *et al.,* 2003). This protective action helps preserve neuronal structure and function, which is essential in slowing cognitive decline and neurodegeneration.

In addition to its antioxidant activity, lycopene also exhibits anti-inflammatory effects within the central nervous system. It can downregulate pro-inflammatory cytokines and inhibit microglial activation, processes that are often implicated in the progression of neurodegenerative disorders. Furthermore, studies have reported that lycopene supplementation may enhance mitochondrial efficiency and reduce apoptotic signalling in neural cells, contributing further to neuroprotection. While more human studies are needed, current evidence suggests that regular consumption of lycopene-rich foods like tomatoes may offer a non-pharmacological strategy to support brain health and protect against age-related cognitive disorders.

V. Cultivar Variability in Phytochemical Content of Tomato

Tomato (*Solanum lycopersicum* L.) cultivars exhibit substantial variability in their phytochemical content, which is primarily influenced by genetic makeup and modulated by environmental and agronomic factors. Among the diverse tomato types, cherry tomatoes are particularly notable for their elevated levels of lycopene, total phenolics, and flavonoids compared to larger-fruited cultivars. This higher concentration of bioactive compounds is attributed to the dense cellular structure and increased skin-to-pulp ratio in smaller fruits, where many phytochemicals are localized (Toor & Savage, 2005).

Genotypic differences play important role in determining the antioxidant capacity of tomato cultivars. For instance, variations in gene expression related to carotenoid biosynthesis pathways can lead to substantial differences in lycopene and β-carotene content among different varieties. These genetic traits are also influenced by external factors such as soil composition, temperature, sunlight exposure, irrigation practices, and the stage of fruit ripeness at harvest. Studies have shown that fruits harvested at full ripeness generally exhibit higher antioxidant levels due to the culmination of biosynthetic activity (Dumas *et al.,* 2003).

In response to increasing demand for nutritionally superior crops, plant breeding programs have focused on developing biofortified tomato lines with enhanced levels of health-promoting compounds. Through both conventional and molecular breeding techniques, cultivars with elevated concentrations of lycopene, lutein, and flavonoids have been successfully created. These efforts aim not only to improve the nutritional profile of tomatoes but also to contribute to public health by reducing the risk of chronic diseases through diet (Rosati *et al.,* 2000).

VI. Effect of Processing on Antioxidant Properties of Tomato

Processing methods significantly influence the antioxidant profile of tomatoes, altering the concentration, stability, and bioavailability of their bioactive compounds. The impact varies depending on the type of processing, temperature, duration, and storage conditions.

6.1 Thermal Processing

Heat treatment through boiling, steaming, or canning can enhance the bioavailability of certain antioxidants, particularly lycopene. Lycopene naturally exists in the all-trans form in fresh tomatoes, which is less efficiently absorbed in the human body. Thermal processing induces isomerization of all-trans lycopene to cis-isomers, which are more soluble in bile acid micelles and thus more readily absorbed (Gartner *et al.,* 1997). This increase in bioavailability often compensates for the partial loss of other heat-sensitive nutrients. However, thermal processing can lead to degradation of heat-labile compounds such as vitamin C and some phenolic acids. These losses depend on the intensity and duration of heat exposure, making mild cooking methods preferable for preserving overall antioxidant content.

6.2 Drying and Storage

Drying tomatoes concentrates phytochemicals by reducing water content, often resulting in higher per gram concentrations of antioxidants such as carotenoids and flavonoids. However, the antioxidant potential can diminish over time due to oxidative degradation, particularly when storage conditions are not optimal. Factors such as exposure to light, oxygen, and high temperatures accelerate the breakdown of sensitive compounds like vitamin C and phenolics. Packaging materials that limit oxygen exposure and light penetration, along with storage at low temperatures, are essential for preserving antioxidant activity during shelf life (Dewanto *et al.,* 2002).

6.3 Industrial Products

Commercially processed tomato products—such as sauce, paste, juice, and ketchup—retain a significant proportion of their antioxidant activity. Interestingly, some studies report that these processed products may exert greater biological effects than fresh tomatoes, particularly in terms of reducing oxidative stress biomarkers in vivo. This enhanced activity is largely due to improved lycopene bioavailability in cis-isomer form and the concentration of tomato solids during processing. Moreover, industrial products are often consumed in cooked or heated forms, which helps release bound antioxidants from the plant matrix, further contributing to their functional efficacy (Rao & Agarwal, 1998).

VII. Conclusion

Tomato (*Solanum lycopersicum* L.) stands out as a nutritionally rich and health-promoting food, widely recognized for its diverse array of bioactive compounds. The presence of potent antioxidants such as lycopene, vitamin C, flavonoids, and phenolic acids underlies its functional role in mitigating oxidative stress and preventing chronic diseases. Scientific evidence consistently supports the contribution of tomato consumption to cardiovascular health, cancer prevention, neuroprotection, and anti-inflammatory responses, reinforcing its status as a functional food.

However, the nutritional quality and antioxidant capacity of tomatoes are significantly influenced by genetic variability among cultivars and by post-harvest processing techniques. Cherry and biofortified tomato varieties often exhibit higher phytochemical concentrations, while processing methods such as cooking and canning can enhance lycopene bioavailability but may compromise heat-sensitive nutrients like vitamin C. Thus, strategic selection of cultivars and application of optimized processing conditions are crucial for retaining or enhancing health benefits.

Integrating tomatoes and tomato-based products into daily diets offers a practical and accessible approach to improving public health. To fully realize this potential, further interdisciplinary research involving breeding, food technology, and clinical nutrition is needed to enhance the stability, efficacy, and accessibility of tomato-derived health benefits in various dietary contexts.

References

[1]. Arab, L., & Steck, S. (2000). Lycopene and cardiovascular disease. *The American Journal of Clinical Nutrition, 71*(6), 1691S-1695S.
[2]. Basu, A., & Imrhan, V. (2007). Tomatoes versus lycopene in oxidative stress and carcinogenesis: conclusions from clinical trials. *European Journal of Clinical Nutrition, 61*(3), 295–303.
[3]. Boeing, H., Bechthold, A., Bub, A., Ellinger, S., Haller, D., Kroke, A., & Watzl, B. (2012). Critical review: vegetables and fruit in the prevention of chronic diseases. European Journal of Nutrition, 51(6), 637–663.
[4]. Brigelius-Flohe, R., & Traber, M. G. (1999). Vitamin E: function and metabolism. The FASEB Journal, 13(10), 1145–1155. https://doi.org/10.1096/fasebj.13.10.1145
[5]. Calderon-Montaño, J. M., Burgos-Moron, E., Perez-Guerrero, C., & Lopez-Lazaro, M. (2011). A review on the dietary flavonoid kaempferol. Mini-Reviews in Medicinal Chemistry, 11(4), 298–344.
[6]. Carr, A. C., & Maggini, S. (2017). Vitamin C and immune function. Nutrients, 9(11), 1211. https://doi.org/10.3390/nu9111211

[7]. Cebolla-Cornejo, J., Rosello, S., & Nuez, F. (2011). Nutritional composition of tomatoes. Improving the Health-Promoting Properties of Fruit and Vegetable Products, 171–219.
[8]. Clifford, M. N. (2000). Chlorogenic acids and other cinnamates – nature, occurrence and dietary burden. Journal of the Science of Food and Agriculture, 80(7), 1033–1043.
[9]. Dewanto, V., Wu, X., Adom, K. K., & Liu, R. H. (2002). Thermal processing enhances the nutritional value of tomatoes by increasing total antioxidant activity. *Journal of Agricultural and Food Chemistry, 50*(10), 3010–3014.
[10]. Di Mascio, P., Kaiser, S., & Sies, H. (1989). Lycopene as the most efficient biological carotenoid singlet oxygen quencher. Archives of Biochemistry and Biophysics, 274(2), 532–538.
[11]. Dumas, Y., Dadomo, M., Di Lucca, G., & Grolier, P. (2003). Effects of environmental factors and agricultural techniques on antioxidant content of tomatoes. *Journal of the Science of Food and Agriculture, 83*(5), 369–382.
[12]. Gartner, C., Stahl, W., & Sies, H. (1997). Lycopene is more bioavailable from tomato paste than from fresh tomatoes. *The American Journal of Clinical Nutrition, 66*(1), 116–122.
[13]. George, B., Kaur, C., Khurdiya, D. S., & Kapoor, H. C. (2004). Antioxidants in tomato (Lycopersium esculentum) as a function of genotype. *Food Chemistry, 84*(1), 45–51.
[14]. Giovannucci, E. (2002). A review of epidemiologic studies of tomatoes, lycopene, and prostate cancer. *Experimental Biology and Medicine, 227*(10), 852–859.
[15]. Hadley, C. W., Clinton, S. K., & Schwartz, S. J. (2003). The consumption of processed tomato products enhances plasma lycopene concentrations in association with a reduced lipoprotein sensitivity to oxidative damage. *The Journal of Nutrition, 133*(3), 727–732.
[16]. Krinsky, N. I., & Johnson, E. J. (2005). Carotenoid actions and their relation to health and disease. *Molecular Aspects of Medicine, 26*(6), 459–516.
[17]. Liu, C., & Liang, J. (2010). The role of β-carotene in human health. Journal of Food Composition and Analysis, 23(6), 559–566.
[18]. Martínez-Valverde, I., Periago, M. J., Provan, G., & Chesson, A. (2002). Phenolic compounds, lycopene and antioxidant activity in commercial varieties of tomato (*Lycopersicon esculentum*). *Journal of the Science of Food and Agriculture, 82*(3), 323–330.
[19]. Li, Y., Yao, J., Han, C., Yang, J., Chaudhry, M. T., Wang, S., ... & Yin, Y. (2016). Quercetin, inflammation and immunity. Nutrients, 8(3), 167.
[20]. Martínez-Valverde, I., Periago, M. J., Provan, G., & Chesson, A. (2002). Phenolic compounds, lycopene and antioxidant activity in commercial varieties of tomato (*Lycopersicum esculentum*). Journal of the Science of Food and Agriculture, 82(3), 323–330.
[21]. Pinela, J., Barros, L., Carvalho, A. M., & Ferreira, I. C. F. R. (2012). Nutritional composition and antioxidant activity of four tomato (*Lycopersicon esculentum* L.) farmer's varieties in Northeastern Portugal homegardens. Food Chemistry, 134(4), 2633–2640.
[22]. Rao, A. V., & Agarwal, S. (1998). Bioavailability and in vivo antioxidant properties of lycopene from tomato products and their possible role in the prevention of cancer. *Nutrition and Cancer, 31*(3), 199–203.
[23]. Rao, A. V., & Agarwal, S. (1999). Role of antioxidant lycopene in cancer and heart disease. *Journal of the American College of Nutrition, 18*(5), 563–569.
[24]. Rao, A. V., & Rao, L. G. (2007). Carotenoids and human health. *Pharmacological Research, 55*(3), 207–216.
[25]. Riso, P., Visioli, F., Grande, S., Guarnieri, S., Gardana, C., Simonetti, P., & Porrini, M. (2006). Tomato consumption does not affect markers of oxidative stress in healthy men. *The Journal of Nutrition, 136*(10), 2593–2597.
[26]. Rosati, C., Aquilani, R., Dharmapuri, S., Pallara, P., Marusic, C., Tavazza, R., ... & Giuliano, G. (2000). Metabolic engineering of beta-carotene and lycopene content in tomato fruit. *Plant Journal, 24*(3), 413–419.
[27]. Saini, R. K., & Keum, Y. S. (2018). Carotenoid extraction, chemistry, and stability: A review of the advancements in methods and understanding. Food Research International, 111, 12–27.
[28]. Sanchez-Moreno, C., Cano, M. P., de Ancos, B., & Plaza, L. (2006). Nutritional and functional properties of tomato. In Tomato plant culture: in the field, greenhouse, and home garden (pp. 295–312). CRC Press.
[29]. Schmid, L., & Wolf-Smith, K. (2024). An overview on the effects of some carotenoids on health: lutein and zeaxanthin. Current Nutrition Reports, 13(4), 828–844.
[30]. Shi, J., & Le Maguer, M. (2000). Lycopene in tomatoes: chemical and physical properties affected by food processing. *Critical Reviews in Biotechnology, 20*(4), 293–334.
[31]. Tanvetyanon, T., & Bepler, G. (2008). Beta-carotene in multivitamins and the possible risk of lung cancer among smokers versus former smokers: A meta-analysis and evaluation of national brands. Cancer, 113(1), 150–157.
[32]. Toor, R. K., & Savage, G. P. (2005). Antioxidant activity in different fractions of tomatoes. *Food Research International, 38*(5), 487–494.
[33]. Traber, M. G., & Atkinson, J. (2007). Vitamin E, antioxidant and nothing more. Free Radical Biology and Medicine, 43(1), 4–15.
[34]. Vallverdu-Queralt, A., Medina-Remon, A., Casals-Ribes, I., Andres-Lacueva, C., & Lamuela-Raventós, R. M. (2011). Changes in phenolic profile and antioxidant activity during production of tomato sauces and ketchup. Journal of Agricultural and Food Chemistry, 59(17), 9296–9304.
[35]. Whelton, P. K., He, J., Cutler, J. A., Brancati, F. L., Appel, L. J., Follmann, D., & Klag, M. J. (1997). Effects of oral potassium on blood pressure. JAMA, 277(20), 1624–1632.
[36]. Willcox, J. K., Catignani, G. L., & Lazarus, S. (2003). Tomatoes and cardiovascular health. *Critical Reviews in Food Science and Nutrition, 43*(1), 1–18.
[37]. Zhao, Z., & Moghadasian, M. H. (2010). Chemistry, natural sources, dietary intake and pharmacokinetic properties of ferulic acid: A review. Food Chemistry, 109(4), 691–702.