# Nutritional Composition in Tomatoes

Subjects: Nutrition & Dietetics
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Tomatoes are consumed worldwide as fresh vegetables because of their high contents of essential nutrients and antioxidant-rich phytochemicals. Tomatoes contain minerals, vitamins, proteins, essential amino acids (leucine, threonine, valine, histidine, lysine, arginine), monounsaturated fatty acids (linoleic and linolenic acids), carotenoids (lycopene and β-carotenoids) and phytoster-ols (β-sitosterol, campesterol and stigmasterol). Lycopene is the main dietary carotenoid in tomato and tomato-based food products and lycopene consumption by humans has been reported to protect against cancer, cardiovascular diseases, cognitive function and osteoporosis. Among the phenolic compounds present in tomato, quercetin, kaempferol, naringenin, caffeic acid and lutein are the most common. Many of these compounds have antioxidant activities and are effective in protecting the human body against various oxidative stress-related diseases. Dietary tomatoes in-crease the body's level of antioxidants, trapping reactive oxygen species and reducing oxidative damage to important biomolecules such as membrane lipids, enzymatic proteins and DNA, thereby ameliorating oxidative stress.

Keywords: nutrients ; tomatoes ; phytochemicals ; antioxidants

## 1. Introduction

Tomatoes (*Solanum lycopersicum* L.), which are frequently included in the Mediterranean diet and are widely consumed as vegetables, play an important role in nutrition because of their well-established health benefits [1]. Tomatoes are used in many processed food products such as sauces, salads, soups, and pastes [2]. Common nutrients reported to be present in tomatoes are vitamins, minerals, fiber, protein, essential amino acids, monounsaturated fatty acids, carotenoids and phytosterols [3][4][5][6]. These nutrients perform various body functions including constipation prevention, reduction in high blood pressure, stimulation of blood circulation, maintenance of lipid profile and body fluids, detoxification of body toxins and maintaining bone structure as well as strength [7][8]. Tomatoes are also an excellent source of nutrients and bioactive compounds, commonly known as secondary metabolites, the concentrations of which are correlated with the prevention of human chronic degenerative diseases, such as cardiovascular disease (CVD), cancer, and neurodegenerative diseases [9][10][11]. Due to the high concentrations of different natural antioxidant chemicals, such as carotenoids (β-carotenoids and lycopene), ascorbic acid (vitamin C), tocopherol (vitamin E) and bioactive phenolic compounds (quercetin, kaempferol, naringenin and lutein, as well as caffeic, ferulic and chlorogenic acids), tomatoes can help ameliorate many diseases, especially chronic diseases [12][13]. These compounds play beneficial roles in inhibiting reactive oxygen species (ROS) by scavenging free radicals, inhibiting cellular proliferation and damage, inhibiting apoptosis as well as metal chelation, modulation of enzymatic activities, cytokine expression and signal transduction pathways [14]. The main carotenoid in tomato is lycopene, which is responsible for its red color. The pharmacological activities of lycopene and other phenolic compounds include anticancer, anti-inflammatory, antidiabetic, anti-allergenic, anti-atherogenic, antithrombotic, antimicrobial, antioxidant, vasodilator and cardioprotective effects [15][16][17][18]. In addition to having good nutritive value and health promoting activities, the polyphenolic compounds and carotenoids also contribute to sensory activities including maintaining good aroma, taste, and texture [19]. Tomato is an important dietary source of both soluble and insoluble dietary fibers, namely cellulose, hemicelluloses and pectins [20]. In general, these fibers are resistant to intestinal digestion in the large intestine and are believed to ameliorate bowel disorders, cancer, diabetes, CVDs, and obesity [21][22]. Important proximate composition parameters for tomatoes include sugar content, pH, energy, acidity and reducing sugar contents [4]. The proximate compositions help in the characterization and identification of tomato nutrients. The combination of vitamins, minerals, amino acids, and fats all together contribute to making tomato part of a balanced diet. Phytosterols, which are involved in the prevention of colon cancer and heart disease, are present in tomatoes in lower amounts than that found in other fruits and vegetables [23]. Among the phytosterols, β-sitosterol, campesterol and stigmasterol are the main ones [5]. The antioxidant compounds predominately present in tomato consist of several different types of carotenoids, vitamin C, vitamin E, and phenolic compounds that confer their antioxidant activities by neutralizing reactive oxygen species (ROS) and protecting the cell membrane against lipid peroxidation [24][25].

Nutritional composition of tomato varies based on the tomato cultivar, extraction procedures, analysis methods and environmental conditions. During the processing of tomato products, up to 30% of their original weight are turned into waste, which may still contain some nutritive values [26]. For example, the seeds and the peel are the main waste product of tomato, which are rich in protein, dietary fibers, bioactive compounds and lycopene [27]. The by-products are used as food additives especially in the meat industries [28]. Nevertheless, although the waste products of tomato are a rich source of nutrients, proper research should be undertaken before their consumption. In spite of having health benefits, tomatoes demonstrate some undesired effects on the body when consumed in large amounts or in abnormal body conditions. The adverse effects of tomato intake are associated with renal problems, allergies, arthritis, heartburn, and migraine.

## 2. Nutritional Composition of Tomato

### 2.1. Proximate Composition

Proximate analysis is one of the first approaches for food characterization, particularly for the identification of nutrients in any food products. Generally, water, ash, protein, lipid, carbohydrate, sugar and reducing sugar contents, as well as pH, energy and acidity are the key proximate compositions of a food sample [29]. For instance, ash content is an important step in the analysis of nutritional element contents in food products. Ash refers to the inorganic residue (mineral content) that remains after the complete oxidation of organic matter and removal of water by heating (ashing) of a food sample in a furnace [30][31]. Next, moisture content (total solids) is important because it affects the chemical and physical aspects of food, which determine its freshness and storage stability [32][33]. Protein, lipids, and carbohydrates are principal components of foods and are the main elements in proximate composition analysis.

Proteins, which are macromolecules present in food, are important for cellular structure and biological functions. Protein analysis is crucial for nutritional labeling, as well as in describing the biological activities and functional properties of food products [33][34][35]. Lipids are another group of macromolecules that are generally insoluble in water but are soluble in organic solvents. In fact, precise and accurate analysis of lipid content in food is mandatory for the standard of quality and nutritional labeling and is important in ensuring manufacturing specification [36].

Carbohydrate analysis is also important as a major (more than 70%) energy source. Carbohydrate analysis yields nutritional information, standard of identity, water holding capacity, flavors, desirable textures, and stability of food products [37][38]. In addition, pH analysis of food samples is essential for food processing and storage. Dietary fiber is another important component of proximate analysis because it ensures a variety of health benefits, including protection against heart disease, colon cancer and diabetes [39]. In a more recent study based on previously published original research articles, an average tomato consists of ash 8.75%, water 94.17 (g/100 g), moisture 91.18 (g/100 g), total protein 17.71 (g/100 g), lipid 4.96 (g/100 g), carbohydrates 5.96 (g/100 g), total sugar 50.60 (g/100 g), pH 3.83, energy 34.67 kcal/100 g, acidity 0.48%, reducing sugar 35.84%, fructose 2.88%, glucose 2.45%, sucrose 0.02% and total fiber 11.44 (g/100 g) (Table 1).

**Table 1.** Proximate composition of tomato.

| Parameters | Values | Range | References |
| --- | --- | --- | --- |

| | | | |
|---|---|---|---|
| Energy (kcal/100 g) | 34.67 ± 18.74 | 18.00–75.00 | |
| Ash (%) | 8.75 ± 1.69 | 5.90–10.60 | |
| Moisture (g/100 g) | 91.18 ± 6.83 | 68.03–96.17 | |
| Total protein (g/100 g) | 17.71 ± 5.40 | 10.50–25.03 | |
| Lipid (g/100 g) | 4.96 ± 1.19 | 3.62–5.39 | |
| Carbohydrates (g/100 g) | 5.96 ± 1.37 | 3.92–8.00 | |
| Total sugar (g/100 g) | 50.60 ± 3.69 | 47.00–56.45 | [40][41][42][43][44][45][46][47][48][49][50][51][52] |
| pH | 3.83 ± 0.21 | 3.61–4.08 | |
| Acidity (%) | 0.48 ± 0.07 | 0.39–0.55 | |
| Reducing sugar (%) | 35.84 ± 4.57 | 30.03–41.21 | |
| Fructose (%) | 2.88 ± 0.49 | 1.15–3.42 | |
| Glucose (%) | 2.45 ± 0.48 | 1.74–3.18 | |
| Sucrose (%) | 0.02 ± 0.05 | 0.01–0.02 | |
| Total fiber (g/100 g) | 11.44 ± 9.31 | 1.32–19.36 | |

Values are expressed as mean ± standard deviation.

## 2.2. Mineral Content

Minerals are naturally occurring inorganic solid substances. They are essential for a variety of bodily functions, including the regulation of metabolic pathways, formation of vital organs, maintenance of bodily physiological functions, regulation of pH balance, fluid balance, blood pressure, nerve transmission, muscle contraction and energy production [53][54][55][56]. Some minerals, such as calcium (Ca), potassium (K), sodium (Na), phosphorus (P), magnesium (Mg), sulfur (S) and chlorine (Cl), are highly essential (average daily intake ˃ 50 mg) and are therefore known as major elements. Others include iron (Fe), iodine (I), zinc (Zn), fluorine (F), copper (Cu), selenium (Se), manganese (Mn), cobalt (Co), chromium (Cr), nickel (Ni), molybdenum (Mo) and selenium (Se), which are required in comparatively smaller amounts (< 50 mg/day) and are known as trace elements. Other elements, such as aluminum (Al), arsenic (As), boron (B), barium (Ba), bismuth (Bi), bromine (Br), lead (Pb), cadmium (Cd), cesium (Cs), germanium (Ge), lithium (Li), mercury (Hg), rubidium (Rb), silicon (Si), antimony (Sb), tin (Sn), samarium (Sm), strontium (Sr), tungsten (W), titanium (Ti) and thallium (Tl), which are needed in even smaller amounts, (1 µg/day) are known as ultratrace elements [57][58][59]. Pb, As, Hg, Cd, Cu, Cr, Ni, Zn and Mn are heavy metals that are toxic if present in low concentrations because they tend to accumulate in living cells [59][60].

From a nutritional perspective, tomato is a good source of minerals and other elements [44]. In this review, 23 types of minerals and their amounts present in tomato are compiled, including the major elements (calcium, potassium, sodium, phosphorus, magnesium, sulfur, chlorine) and trace elements (iron, iodine, zinc, fluorine, cupper, manganese, cobalt, chromium, nickel, aluminum, arsenic, boron, lead, cadmium, nitrate, chlorine, selenium, silicon) (Table 2).

**Table 2.** Mineral contents in tomato.

| Elements | Units | Concentrations | Range | References |
|---|---|---|---|---|
| Sodium (Na) | mg/100 g | 70.38 ± 12.20 | 56.90–80.65 | |
| Potassium (K) | mg/100 g | 403.02 ± 254.41 | 16.63–1097.00 | |
| Calcium (Ca) | mg/100 g | 105.21 ± 22.76 | 48.47–162.07 | |
| Magnesium (Mg) | mg/100 g | 172.58 ± 58.92 | 76.87–265.93 | |
| Phosphorus (P) | mg/100 g | 300.99 ± 32.12 | 173.00–379.31 | |
| Chlorine (Cl) | µg/100 g | 517.24 ± 0.00 | 517.24 | |
| Boron (B) | µg/g | 36.83 ± 3.27 | 25.84–48.59 | |
| Nickel (Ni) | mg/100 g | 0.66 ± 0.00 | 0.66 | |
| Nitrate ($NO_3^-$) | mg/100 g | 274.37 ± 156.75 | 86.21–459.00 | |
| Iron (Fe) | mg/100 g | 4.55 ± 2.18 | 1.50–6.45 | |
| Zinc (Zn) | mg/100 g | 2.48 ± 1.05 | 0.17–3.17 | |
| Cobalt (Co) | mg/100 g | 19.66 ± 9.66 | 10.00 -29.31 | [61][62][63] |
| Copper (Cu) | mg/100 g | 0.67 ± 0.15 | 0.06–1.10 | |
| Manganese (Mn) | mg/100 g | 0.60 ± 0.12 | 0.11–1.88 | |
| Chromium (Cr) | µg/100 g | 193.80 ± 133.80 | 60.00–327.59 | |
| Iodine (I) | mg/100 g | 2.65 ± 1.44 | 0.18–3.97 | |
| Fluorine (F) | µg/100 g | 413.79 ± 0.00 | 413.79 | |
| Aluminum (Al) | µg/100 g | 1241.38 ± 0.00 | 1241.38 | |
| Silicon (Si) | µg/100 g | 46.55 ± 0.00 | 46.55 | |
| Selenium (Se) | µg/100 g | 13.45 ± 3.45 | 10.00–16.90 | |
| Lead (Pb) | µg/ g | 1.21 ± 0.06 | 1.15–1.27 | |
| Cadmium (Cd) | µg/ g | 0.17 ± 0.06 | 0.11–0.22 | |
| Arsenic (As) | µg/ g | 0.20 ± 0.005 | 0.19–0.20 | |

Concentrations are expressed as mean ± standard deviation.

## 2.3. Vitamin Content

The accurate and precise analysis of vitamin content is important for a standard balanced diet because low or excessive amounts of vitamins can contribute to disease conditions by hampering normal cell growth [64]. Tomatoes are one of the most versatile and widely consumed vegetables in many countries and are a rich source of vitamins [65][66]. Vitamins C, B-complex, A, E and K are the main types of vitamins present in tomato, with vitamin C reported to be the highest (Table 3). Vitamins C and E (tocopherol) exhibit antioxidant activities making tomato a useful therapeutic agent for the prevention of various diseases, including CVDs and cancer [67][68][69][70]. Among the various types of vitamin B-complexes, the amount of folate is comparatively high in tomatoes. Nevertheless, excessive amounts of water-soluble vitamin B do not cause any toxicity because these vitamins can be easily excreted from the body. Vitamins perform various functions, such as maintaining the nervous system, producing red blood cells and enzymatic function [71][72].

**Table 3.** Vitamin contents in tomato.

| Vitamins | Units | Concentrations | Range | References |
|---|---|---|---|---|
| Vitamin A | IU/100 g | 614.44 ± 248.18 | 267.33–833.00 | |
| Vitamin E | μg/100 g | 15.08 ± 1.06 | 14.02–16.13 | |
| Vitamin K | μg/100 g | 98.28 ± 0.00 | 98.28 | |
| Vitamin C | mg/100 g | 36.16 ± 29.64 | 10.86–85.00 | |
| Thiamine | mg/100 g | 0.66 ± 0.44 | 0.04–0.98 | |
| Riboflavin | mg/100 g | 0.48 ± 0.34 | 0.02–0.81 | [73][74][75][76] |
| Niacin | mg/100 g | 9.68 ± 0.00 | 9.68 | |
| Pantothenic Acid | mg/100 g | 4.93 ± 0.41 | 4.52–5.34 | |
| Vitamin $B_6$ | mg/100 g | 1.51 ± 0.22 | 1.29–1.72 | |
| Biotin | μg/100 g | 68.97 ± 0.00 | 68.97 | |
| Folate | mg/100 g | 14.00 ± 1.00 | 13.00–15.00 | |

Concentrations are expressed as mean ± standard deviation.

## 2.4. Fatty Acid Content

Tomato contains many different types of fatty acids (Table 4). Among them, linoleic and polyunsaturated fatty acids are the highest. Linoleic and linolenic acids are two essential fatty acids. Since the essential fatty acids cannot be synthesized by humans or animals, they must come from the dietary sources and tomato provides a good source of these acids. On the other hand, polyunsaturated fatty acids are also very important for the body since they are essential for the maintenance of plasma membrane integrity, cell growth and prevention of disease [77][78]. From this point of view, tomato is therefore a rich and highly nutritious food product.

**Table 4.** Fatty acid contents in tomato.

| Fatty Acids | Concentrations (g/100 g) | Range | References |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Myristic acid | 0.56 ± 0.22 | 0.32–0.93 | [62] |
| Palmitic acid | 18.07 ± 2.90 | 12.40–22.50 | |
| Stearic acid | 4.81 ± 1.50 | 2.80–6.84 | |
| Palmitoleic acid | 0.25 ± 0.10 | 0.03–0.32 | |
| Oleic acid | 14.24 ± 3.50 | 9.00–19.14 | |
| Linoleic acid | 49.40 ± 4.16 | 46.33–54.10 | |
| Linolenic acid | 10.17 ± 4.46 | 4.26–15.53 | |
| Caproic acid | 0.03 ± 0.02 | 0.01–0.05 | |
| Caprylic acid | 0.06 ± 0.04 | 0.02–0.10 | |
| Capric acid | 0.04 ± 0.03 | 0.01–0.07 | |
| Heptadecanoic acid | 0.26 ± 0.05 | 0.18–0.13 | |
| Lauric acid | 0.09 ± 0.05 | 0.04–0.15 | |
| Pentadecanoic acid | 0.12 ± 0.03 | 0.08–0.15 | |
| Arachidic acid | 0.88 ± 0.24 | 0.61–1.26 | |
| Eicosadienoic acid | 0.04 ± 0.02 | 0.02–0.06 | |
| Arachidonic acid | 0.04 ± 0.02 | 0.01–0.06 | |
| Eicosapentaenoic acid | 0.05 ± 0.01 | 0.03–0.06 | |
| Erucic acid | 0.02 ± 0.01 | 0.01–0.03 | |
| Docosadienoic acid | 0.07 ± 0.03 | 0.03–0.10 | |
| Behenic acid | 0.59 ± 0.19 | 0.31–0.82 | |
| Tricosanoic acid | 0.68 ± 0.54 | 0.16–1.52 | |
| Lignoceric acid | 0.74 ± 0.20 | 0.45–1.01 | |
| Saturated fatty acid | 27.40 ± 3.74 | 22.37–33.22 | |
| Monounsaturated fatty acid | 13.80 ± 2.42 | 11.00–17.66 | |

| | | |
|---|---|---|
| Polyunsaturated fatty acid | 57.55 ± 23.51 | 55.78–58.63 |
| Vaccenic acid | 0.53 ± 0.05 | 0.50–0.60 |
| Eicosanoic acid | 0.10 ± 0.03 | 0.05–0.12 |

Concentrations are expressed as mean ± standard deviation.

## 2.5. Amino Acid Content

Amino acids are the building blocks of proteins that conduct important bodily functions, including the maintenance of cellular structure, transport and storage of nutrients, wound healing, and repair of damaged tissues [79]. A total of 17 amino acids have been identified in tomato (Table 5). It is estimated that essential amino acids constitute 39.75% of the total protein in tomato. Among these, the highest was glutamic acid (approximately 10.13 g/100 g protein). Among the various types of essential amino acids present in tomato, leucine is present in the highest concentration, while methionine is the lowest. Among the nonessential amino acids, glutamic acid is the most common, while cysteine is the least.

**Table 5.** Amino acid contents of tomato.

| **Amino Acids** | **Concentrations (g/100 g Protein)** | **Range** | **References** |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Threonine * | 1.37 ± 0.97 | 0.40–2.34 | |
| Valine * | 2.49 ± 2.09 | 0.40–2.49 | |
| Methionine * | 0.57 ± 0.45 | 0.12–1.02 | |
| Isoleucine * | 2.13 ± 1.73 | 0.40–3.86 | |
| Leucine * | 2.80 ± 2.28 | 0.52–5.07 | |
| Phenylalanine * | 1.77 ± 1.36 | 0.41–13.12 | |
| Histidine * | 1.93 ± 1.71 | 0.22–3.64 | |
| Lysine * | 2.45 ± 1.95 | 0.50–4.40 | |
| Arginine * | 2.33 ± 2.02 | 0.31–4.34 | [80][81] |
| Aspartic Acid ** | 1.40 ± 0.70 | 0.70–2.09 | |
| Serine ** | 1.78 ± 1.30 | 0.48–3.08 | |
| Glutamic Acid ** | 10.13 ± 4.44 | 5.69–14.56 | |
| Proline ** | 1.53 ± 1.25 | 0.28–2.78 | |
| Glycine ** | 2.30 ± 1.99 | 0.31–4.29 | |
| Alanine ** | 2.74 ± 2.29 | 0.45–5.02 | |
| Cystine ** | 0.21 ± 0.19 | 0.02–0.39 | |
| Tyrosine ** | 1.82 ± 1.61 | 0.21–3.42 | |

Concentrations are expressed as mean ± standard deviation. * denotes essential amino acids. ** denotes nonessential amino acids.

## 2.6. Carotenoid Content

Tomato contains various types of carotenoids and is rich in lycopene and β-carotenoids (Table 6). Carotenoids are plant pigments that play crucial roles in protecting plants from photo-oxidative processes. They are natural antioxidants useful for combating cellular oxidative damage [82]. Recent studies have suggested that carotenoids play important roles in improving vision [83], are effective for preventing CVDs [84], protect against sperm health [85] and can prevent various types of cancer [86][87]. On the other hand, carotenoids such as lutein and zeaxanthin improve skin health [88]. Lycopene is a type of carotenoid found in tomato that is helpful in the prevention of liver, lung, prostate, breast, and colon cancers [89].

**Table 6.** Carotenoid contents in tomato.

| | Units | Concentrations | Range | References |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| β-carotene | μg/100 g | 9942.16 ± 264.74 | 3677.42–10,206.90 | |
| α-carotene | μg/100 g | 101.00 | 101.00 | |
| Lycopene | μg/100 g | 8002.50 ± 243.54 | 5020.00–11,110.00 | |
| Lutein + zeaxanthin | μg/100 g | 60.67 ± 43.86 | 18.07–123.00 | |
| Phytoene | μg/100 g | 668.33 ± 361.95 | 430.00–1860.00 | [90][91][92][93][94] |
| Phytofluene | μg/100 g | 500.00 ± 100.49 | 390.00–820.00 | |
| All trans-lutein | mg/kg | 5.00 ± 0.82 | 4.00–6.00 | |
| All trans-β carotene | mg/kg | 29.25 ± 27.26 | 4.00–75.00 | |
| 9-cis-β carotene | mg/kg | 6.50 ± 2.29 | 3.00–9.00 | |

Concentrations are expressed as mean ± standard deviation.

## 2.7. Sterol Content

Sterols are mainly found in plants, animals, and microorganisms. Plant sterols, also known as phytosterols, commonly occur as a mixture of β-sitosterol, campesterol and stigmasterol. Phytosterols play important roles in human health. Phytosterols block cholesterol absorption sites in the human intestine and reduce cholesterol absorption, leading to a reduction in low-density lipoprotein cholesterol (LDL-C) and prevention of CVD [95]. Research has also suggested that phytosterols exhibit an anticancer effect by inhibiting cancer cell growth, carcinogens, angiogenesis, and invasion of metastasis by promoting the apoptosis of cancerous cells [96][97]. Phytosterols also act as antioxidants to prevent oxidative stress [98]. Additional important functions of phytosterols are stimulation of the immune system and anti-inflammatory activities [99][100]. In fact, tomato is an excellent source of phytosterols. Approximately 1283 mg of phytosterols are present per kg of tomato. Among them, β-sitosterol and stigmasterol are the main ones (Table 7).

**Table 7.** Sterol contents in tomato.

| | Concentrations (mg/kg) | Range | References |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Campesterol | 147.50 ± 31.13 | 100.00–18.00 | |
| Stigmasterol | 387.50 ± 88.71 | 260.00–510.00 | |
| Stigmastanol | 28.25 ± 10.92 | 10.00–38.00 | |
| β-sitosterol | 720.00 ± 175.64 | 520.00–1000.00 | |
| Δ5-Avenasterol | 62.30 ± 2.21 | 10.00–65.87 | |
| Cholestanol | 9.70 ± 1.80 | 2.10–11.54 | [92] |
| Cholest-7-en-3-ol | 3.60 ± 0.13 | 0.42–4.40 | |
| Cholesterol | 41.90 ± 2.10 | 8.40–43.45 | |
| Lanost-8-en-3-β-ol | 52.40 ± 6.80 | 4.50–60.65 | |
| 24-Oxocholesterol | 67.50 ± 3.20 | 14.20–70.69 | |
| Total | 1283.25 ± 239.39 | 918.00–1570.00 | |

Concentrations are expressed as mean ± standard deviation.

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