Tomato Consumption and Health: Emerging Benefits

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Abstract: *Tomatoes and tomato products are one of the most familiar vegetables in the American diet. Quantitatively, they are the most consumed nonstarchy vegetable and are the most significant source of dietary lycopene; a powerful antioxidant that has greater bioavailability after cooking and processing (eg, canning). A large body of research supports an inverse relationship between consuming tomatoes and tomato products and risk of certain cancers, while emerging research is exploring the protective relationship between tomato intake and a host of conditions, including cardiovascular disease, osteoporosis, ultraviolet light–induced skin damage, and cognitive dysfunction. Initial studies of tomato consumption and disease risk reduction focused on lycopene and antioxidant activity. More recent hypotheses recognize the advantages of the whole tomato; and hence, research on the role of tomato products in health and disease risk reduction extends beyond antioxidant function to include other protective mechanisms such as antithrombotic and anti-inflammatory functions. Increasing daily vegetable intake in the American diet offers the potential to yield significant health benefits. In addition to the specific benefits of tomato consumption, encouraging greater tomato and tomato product consumption may help increase overall vegetable intake because of their wide availability, well-established acceptability, cost-effectiveness, and convenience of multiple forms. Leveraging emerging science about tomatoes and tomato products may be one simple and effective strategy to help individuals increase vegetable intake, leading to improved overall eating patterns, and ultimately, better health.*

Keywords: tomatoes; tomato products; cardiovascular disease; cancer; vegetable intake; inflammation; antioxidant; lycopene

Food-based dietary recommendations are the cornerstone of lifestyle approaches to reduce chronic disease risk. The health benefits of consuming more fruits and vegetables, for example, are strongly supported by scientific evidence; and hence, form the basis of national policy to promote health. However, despite the evidence and widespread initiatives to promote consumption, fruit and vegetable intake patterns remain below recommendations. Therefore, strategies to motivate consumers to consume more fruits and vegetables require attention.

One way to increase vegetable consumption may be to leverage the familiarity with, and emerging health benefits of, tomatoes. Tomatoes and tomato products are well known by adults and children alike and have the unique advantage of meeting consumer demands on cost, convenience, availability, and taste, while delivering a healthful food option with flexibility for inclusion in a variety of culturally diverse

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Table 1.

Lycopene Content per Serving in Tomato Products, Tomato-Based Foods, and Fruits[a]

Product	Serving Size	Lycopene (mg)
Tomato paste	¼ cup	18.84
Pasta with meatballs in tomato sauce canned entree	1 cup	18.14
Tomato sauce	½ cup	17.12
Spaghetti sauce	½ cup	15.82
Minestrone soup	1 cup	15.33
Tomato puree	¼ cup	13.60
Tomato soup	1 cup	13.04
Vegetable juice cocktail	½ cup	11.69
Tomato juice	½ cup	10.98
Stewed tomatoes	½ cup	5.21
Watermelon	½ cup	3.44
Salsa	2 tbsp	3.36
Tomatoes packed in tomato juice	½ cup	3.32
Catsup	1 tbsp	2.51
Raw tomatoes	½ cup	2.32
Grapefruit	½ grapefruit	1.75

[a] From the US Department of Agriculture National Nutrient Database for Standard Reference, Release 22.[1]

dishes. Igniting interest in tomatoes may increase vegetable consumption directly as well as improve vegetable consumption in general by prompting individuals to explore other vegetables for improved health.

Tomato Overview

Compositionally, the tomato has a unique nutritional and (phyto)chemical profile. Vitamin C, vitamin A (as carotenoids), fiber, potassium, and the antioxidant lycopene are natural components of tomatoes.[1] Lycopene is the major dietary carotenoid and tomatoes and tomato-based foods are the richest sources of lycopene in the American diet (Table 1).[1] Besides tomatoes, lycopene is also found in watermelon and red grapefruit; however, tomatoes and tomato products represent more than 85% of all the dietary sources of lycopene consumed in the North American diet.[2] Average daily lycopene intake of males and females is 5305 µg, higher than the average daily intake of all other carotenoids combined (3388 µg). Lycopene intake is about 3 times that of β-carotene (1742 µg).[3] There is a strong relationship between tomato intake and plasma/serum lycopene concentrations.[4-6] Several research investigations have shown an inverse relationship between plasma/serum lycopene concentrations and risk of some cancers.[7-13] Similar associations have been reported for markers of cardiovascular disease, osteoporosis, cognitive function, and body weight.[14-21]Moreover, relationships between dietary intakes of tomato products or tomato extract supplements have been observed in epidemiological studies and clinical trials examining markers of some cancers, cardiovascular disease, and ultraviolet light–induced skin erythema.[12,22-37]

Tomato: Fruit or Vegetable?

Botanically, a fruit is defined as the ovary that holds the seeds of a flowering plant. In that context, and with quick visual inspection, the tomato is undoubtedly a fruit. Vegetables, on the other hand, have no foothold on a botanical definition; any edible "vegetation" can be called a vegetable. The definition of vegetable in Western diets is driven more by cultural and culinary tradition than biology. Vegetables are generally savory and served as part of a main course, whereas fruits are customarily thought to be sweet and served as a dessert.

Historically, tomatoes were classified as a fruit. However, when a tax was levied on imported vegetables, but not fruits, the dual identity of tomatoes became of significant importance economically. The case of the tomato definition rose to the Supreme Court, who ruled in *Nix v. Hedden* that in fact tomatoes fit the common definition of vegetables and should be classified as such. Although the 1893 Supreme Court ruling did not change the botanical definition of tomatoes as a fruit, the savory tomato plays the traditional role of vegetable in meals, and is classified as a vegetable by the US Department of Agriculture.

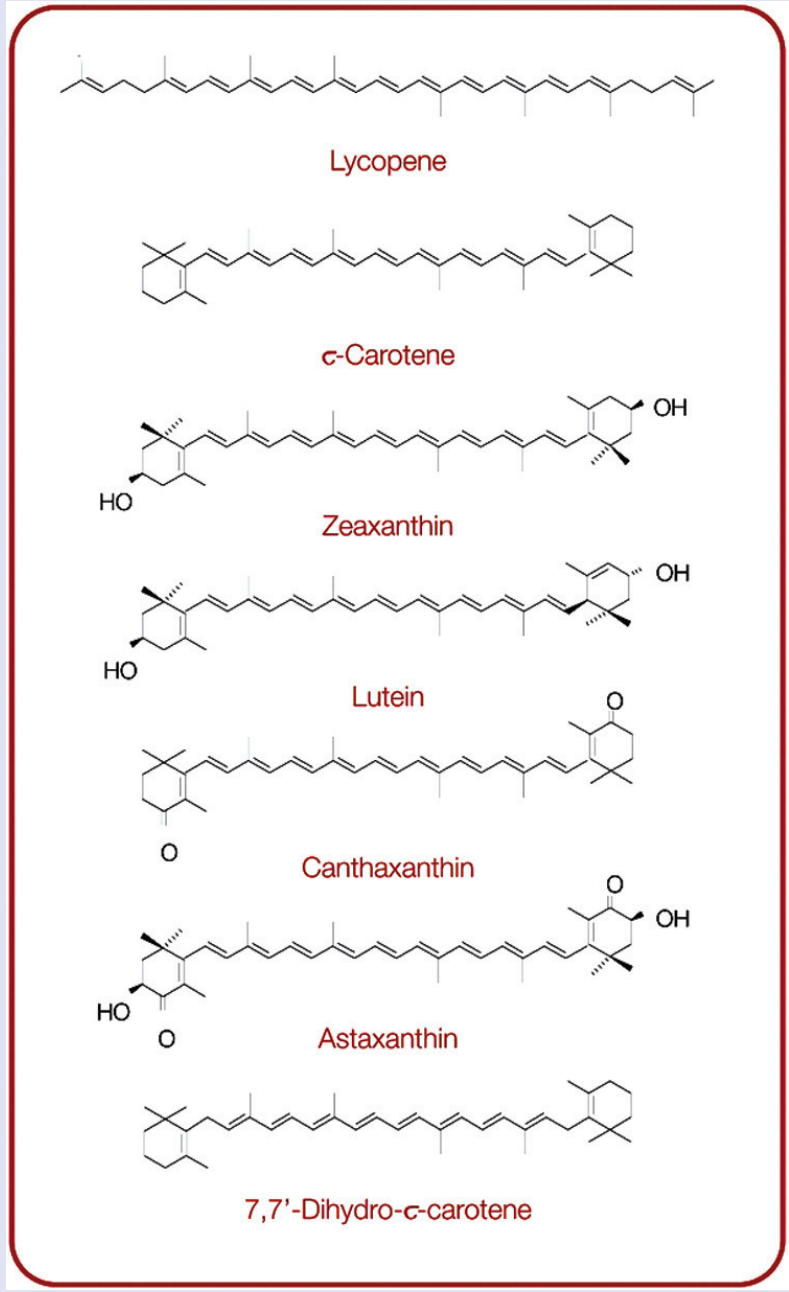
Lycopene

Lycopene is a carotenoid pigment principally responsible for the characteristic deep-red color of ripe tomato fruits and tomato products. All carotenoids posses a polyisoprenoid structure, a long conjugated chain of double bonds, and a near bilateral symmetry around the central double bond (Figure 1[38]).[39] Different carotenoids are derived by modifications in the base structure by cyclization of the end groups and by introduction of oxygen giving them their specific colors and antioxidant properties.[40] Unlike some carotenoids, lycopene lacks the terminal β-ionic ring and thus does not have provitamin A activity.[40] Because of the high number of conjugated dienes within lycopene, its potency as an effective singlet oxygen quencher is about 2 times greater than β-carotene and 10 times greater than vitamin E.[41,42] As one of the most potent antioxidants in food, lycopene has attracted the interest of scientists and health professionals alike for its potential to reduce disease risk and promote health.

Lycopene exists in foods primarily in the *trans* sterisomeric configuration; however, cooking and processing help convert *trans*-lycopene to *cis*-lycopene, which is more readily absorbed.[43,44] Lycopene is found in appreciable levels in human serum and tissues when tomatoes and tomato products are consumed frequently. In addition to lycopene, tomatoes also contain other carotenoids, including phytoene, phytofluene, ζ-carotene, γ-carotene, β-carotene, eurosporene, and lutein. These carotenoids have also attracted attention for benefiting health.[45] Thus, in addition to their culinary role in the diet, tomatoes represent a low energy dense food with unique constituents that may positively affect health.

Figure 1.

Chemical Structures of Dietary Carotenoids.



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Lycopene Versus Tomatoes

As data linking tomato intake with disease risk reduction have multiplied, investment in determining the responsible tomato components has expanded. Identifying lycopene as a principal bioactive component of tomatoes has spawned hundreds of research investigations to determine its potential mechanisms of action. In addition to lycopene's well-documented antioxidant potency, evidence is accumulating to suggest that it also can modulate intercellular gap junction communication and hormonal, immune system, and metabolic pathways.[46]

The safety and efficacy of lycopene supplementation has received considerable attention. Lycopene supplementation in prostate cancer patients has been shown to be safe and well tolerated in

doses up to 120 mg/d for up to 1 year.[47] Clark et al[47] also showed that peak concentrations of lycopene were achieved in 3 months, reaching a plateau that did not differ significantly among doses of 15 to 90 mg/d. Evidence for improving disease status among lycopene supplementation studies ranging in dose (15-120 mg/d) and duration (3 weeks to 1 year) is equivocal, as measured by changes in insulin-like growth factor (IGF)-1, including IGF binding proteins,[27,48-50] prostate-specific antigen,[47,51-55] and benign prostate hyperplasia.[51,55] In contrast, data consistently support a protective relationship between tomatoes and tomato product intake and prostate cancer risk as well as improvements in markers of disease status.[28-30,56-59]

Similarly, research suggests that lycopene supplementation for lowering cardiovascular disease risk is safe and well tolerated. Reduced blood pressure after lycopene supplementation was reported in 2 studies[32,60] out of 3 available studies.[32,60,61] To our knowledge, tomatoes'/tomato products' effect on blood pressure have not been reported. Several supplementation investigations examined the antioxidant effects of lycopene and tomatoes. Results consistently show improved antioxidant status with tomato/tomato products consumption and after lycopene supplementation[33,50,62]; however, 2 large clinical trials of lycopene supplementation reported neutral effects on oxidative stress markers.[45,63] Similar large randomized controlled trials on tomato intake and oxidative stress markers have not been reported. However, one study (n = 60) in relatively healthy individuals[33] and 2 studies (n = 40 and n = 57) in individuals with type 2 diabetes, who are in a relatively pro-oxidant state, showed decreased lipid peroxidation rates[64] and decreased susceptibility of low-density lipoproteins (LDL) to oxidation[35] after daily consumption of tomatoes or tomato juice. Others have reported less susceptibility to oxidation of DNA[65,66] and LDL[67] after tomato product consumption delivering approximately half (or more) of the lycopene dose typically used in lycopene supplementation studies. These data suggest that the health benefits of tomato/tomato product consumption are not solely because of lycopene content, but rather the result of the combination of nutrients and bioactive constituents delivered when the whole food is consumed. These data underscore recommendations for "food first" approaches to health and improved quality of life.

Cancer

The majority of research conducted in the area of tomato and lycopene intake and cancer risk has been observational. The difficulty posed in studying the effect of an intervention to reduce risk of cancer is that acceptable and validated study endpoints include incidence of the cancer itself; or in the case of colon cancer, recurrent colon or rectal polyps in otherwise healthy people.[68] Because cancer often takes decades to present, conducting randomized, controlled clinical trials with these endpoints is generally not feasible. Instead, observational studies of populations showing associations but not cause and effect have been the primary source of knowledge on tomatoes/tomato products and cancer. In a recent review of the literature, 178 original research articles were compiled reporting findings in humans on the relationship between lycopene, tomatoes and tomato-based products, and cancer risk.[69] Among these publications, nearly 90% were observational, highlighting the paucity of cause and effect investigations in this area. Reports on 13 cancer types were identified, of which breast, colorectal, gastric/upper gastrointestinal, and prostate cancers have the most original research published in humans, ranging from 17 to 60 publications. For breast, colorectal, and gastric cancers, the data support a neutral, although potentially protective, relationship between tomato/lycopene intake and cancer risk. Although the data are limited for gastric and lung cancers; the protective association is strongest with tomato intake verses dietary lycopene intake.

Among the cancers investigated relative to lycopene and tomato intake, prostate cancer is the most widely researched. Although randomized controlled trial data are less available than observation data, a small number of dietary intervention trials using processed tomato products have been conducted. The results have been relatively successful as measured by improvements in prostate-specific antigen concentrations[26,29,59,70] or increased apoptotic cell death in carcinomas.[30] Of note, these trials vary in quality, have small sample sizes, use biomarkers instead of cancer as the outcome, and use people already presenting with disease. Validated cancer markers and larger clinical trials in *at risk* populations are warranted to better understand the cause and effect relationship between lycopene, tomatoes and tomato products, and cancer.

Cardiovascular Disease

The research examining tomatoes and cardiovascular disease (CVD) is emerging as the etiology of CVD expands from a basic lipid storage disease to include endothelial dysfunction, severe inflammation, and oxidative damage. Tomatoes, with their distinctive nutritional attributes may play an important role in reducing the risk of cardiovascular and associated diseases through their bioactivity in modulating disease process pathways. In 2004, Sesso et al[18] reported an inverse association for women consuming greater intakes (>7 servings per week) of tomato-based products and CVD; an association not observed with lycopene intake alone.[18]

Several hypotheses are being tested related to the antioxidant properties of lycopene and a combination of carotenoids with coexisting water-soluble constituents delivered by tomatoes, such as vitamin C. The antioxidant capacity of plasma decreases when tomatoes and tomato products are removed from the diet and increased when they are added back.[33] Consuming tomato products daily for 2 to 4 weeks increases antioxidant enzyme defenses and has been shown to reduce plasma lipid peroxides and the susceptibility of LDL to oxidation.[31,35,71] Oxidative modification of LDL is a key step in the development of atherosclerotic lesions.[72] Consuming diets with appreciable amounts of antioxidants from

plant foods, such as tomatoes, to inhibit the oxidative process of LDL may be one way to reduce the risk of cardiovascular atherosclerotic disease.

Tomatoes and tomato products are also being investigated for possible anti-inflammatory, antithrombotic, and lipid-lowering effects. Supplementation of a low tomato diet with tomato products produces mixed results as measured by changes in inflammatory markers such as C-reactive protein (CRP), interleukin-6, and tumor necrosis factor-α. Jacob et al[34] reported decreased CRP after a 2-week tomato juice supplementation containing approximately 21 mg lycopene and 2 levels of vitamin C (45.5 mg and 435 mg, respectively). Both juices reduced CRP as well as total cholesterol concentration. In contrast, others have reported neutral effects on inflammatory markers after juice supplementation[73,74] as well as on lipid profile.[64,75] To date, research describing the potential benefits of tomatoes and tomato products on inflammation and immune function is limited. However, this remains an important underinvestigated area of research. Future work will significantly contribute to our understanding of the role of tomatoes in inflammation and immune function related to CVD.

Natural antithrombotic agents that influence platelet function or fibrinolytic activity are of interest as primary and secondary cardiopreventive strategies. Aqueous extracts from tomatoes have been shown to display antiplatelet activity in vitro.[76] Subsequent research in humans shows significant reductions in ex vivo platelet aggregation 3 hours after supplementation with tomato extract from the yellowish membrane surrounding seeds in amounts equivalent to 2 or 6 fresh tomatoes.[77]

Emerging Areas: Skin, Bone, and Brain Health

Research in cancer and cardiovascular disease, particularly related to the antioxidant effects of tomatoes, has lead to research in other areas where oxidative stress and damage play significant roles in disease etiology. Skin protection, bone and brain health are attracting attention for a possible role of tomato products. Although the human literature is far from replete in these areas, promising results have been reported. For skin protection, tomato intake (40 g tomato paste corresponding to a lycopene dose of approximately 16 mg) for more than 8 weeks reduced ultraviolet light–induced erythema.[36,37,78] Epidemiological studies suggest a beneficial relationship between dietary sources of lycopene and bone mass.[79-81] Likewise, lower serum lycopene concentrations have been documented in osteoporotic women compared with controls.[19,20] Rao et al[17] have also reported an inverse association between serum lycopene and markers of oxidative stress and bone turnover in 33 postmenopausal women aged 50 to 60 years. Research for a possible role of tomatoes in brain health has largely been limited to case–control studies investigating the relationship between plasma/serum lycopene and oxidative stress markers in people with documented Alzheimer's disease, Parkinson's disease, vascular dementia, and mild cognitive impairment compared with control/noncognitively impaired individuals. In general, plasma/serum lycopene concentrations are lower in cognitively impaired compared with control individuals[14-16,82] and oxidative stress markers are elevated and inversely correlated with plasma carotenoids concentrations.[14,15,83]

Tomato Processing: Does It Increase the Nutritional Benefits?

Raw fruits and vegetables are typically touted as superior to their processed (ie, canned and frozen) counterparts. However, in the case of tomatoes, processing adds value by increasing the availability of lycopene for absorption. Several studies have shown that a higher serum lycopene concentration is correlated with lower cancer risk,[9,11-13] CVD risk,[2,18,33,40,69] and osteoporosis.[20] Processing assists with lycopene's bioavailability by softening cell walls, making lycopene in tomato tissues more accessible, and by converting some of the *trans*-isomers of lycopene to *cis*-isomers.[84,85] *Cis*-lycopene stereoisomers are more bioavailable than the *trans*-isomer, which is primarily found in raw, ripe tomatoes.[43,44,86-90] *Cis*-isomers are more readily absorbed through the intestinal wall into the plasma because of the greater solubility in micelles, preferential incorporation into chylomicrons, less tendency to aggregate and crystallize, more efficient volatilization in lipophilic solutions, and easier transport within cells, across plasma membranes, and the tissue matrix.[43,91] The greatest increase in *cis*-isomer formation occurs when tomato products are heated at very high temperatures. Likewise, lycopene bioavailability increases in the presence of oil.[89,90,92,93] Whether oil needs to be present in the tomato product during thermal processing to solubilize and free the lycopene from its matrix to enhance isomerization is still uncertain.[44] In summary, processed tomato products have enhanced bioavailability of lycopene due in part to heat applied in cooking and processing methods and the addition of small amounts of fat or oil.

Reaching Vegetable Consumption Goals

The emerging research on tomatoes exemplifies the health benefits of consuming adequate amounts of fruits and vegetables as encouraged in federal public health policy and Food and Drug Administration (FDA) regulation.[94,95] In all, 3 of the 12 original authorized FDA Health Claims for food labels pertain to fruits and vegetables and reduced risk of cancer and CVD (21 CFR 101.76, 101.77 and 101.78).[95]

The mechanism by which tomatoes and other fruits and vegetables decrease risk of disease is complex and largely unknown. Various components of the whole food are likely to contribute to the overall health benefit. Components with antioxidant properties, such vitamin C and carotenoids may work directly by quenching free radicals or indirectly by participating in cell signaling pathways sensitive to redox balance. Nutrients such as potassium contribute to blood pressure regulation. The fiber content and

type of different fruits and vegetables may also contribute to the overall health benefit, such as improving bowel transit, lowering cholesterol, and helping manage blood glucose concentrations. Finally, increasing fruits and vegetables in the diet may reduce the intake of saturated fats, trans fats, and foods with higher caloric density; all of which may be related to a healthier overall diet.

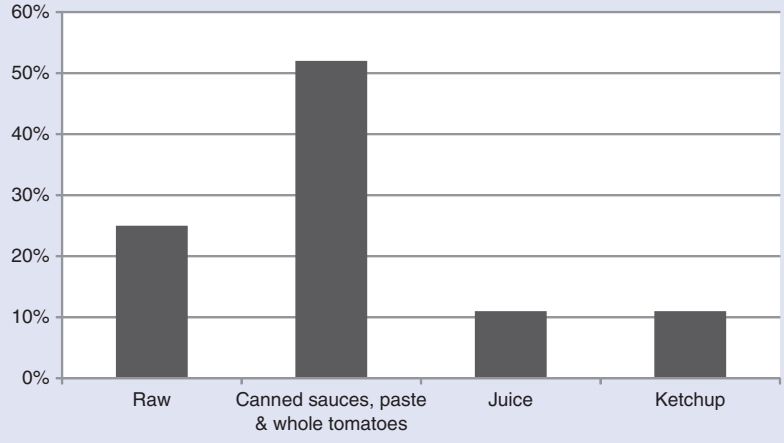
Over the past 50 years, the US Department of Agriculture–recommended daily amount of vegetables has gradually increased from 2 servings in 1956 to 5 servings (2½ cups) currently. Despite these recommendations and the scientific evidence supporting the benefits of eating more vegetables, Americans fall short of incorporating adequate vegetables into their daily diets. The National Cancer Institute's Usual Dietary Intakes report indicates that adult Americans' median vegetable consumption is about 1½ cups daily, compared with the recommended 2½ cups of vegetables daily for a 2000-calorie diet. Approximately 90% of adults fall short of the recommended amount.[96]

National efforts to promote higher vegetable intake have been implemented. Increasing vegetable intake continues to be a goal in the US Department of Health and Human Services' Healthy People 2020. The National Cancer Institute has driven this initiative, initially with *5 a Day*, and more recently with *Fruits and Vegetables More Matters* campaign. Data indicate that these efforts have not had a measurable effect on vegetable consumption.[97]

Many barriers have been identified that inhibit the intake of vegetables—lack of availability of raw produce, cost, bitter or unpleasant flavor, and unfamiliarity, to name a few. Tomato products are one of the few non-starchy vegetables that circumvent these barriers. In fact, tomatoes are second only to potatoes in total consumption by Americans.[98] Tomatoes account for 22% of total vegetable consumption; approximately 86 pounds (mostly canned tomato products) are consumed per capita per year (Figure 2).[98,99] Thus, the variety and availability of tomatoes and tomato products, as well as their culinary and cultural adaptability, increases the potential of focusing attention on tomato consumption as a feasible strategy to help Americans meet the challenging goal of increased vegetable consumption.

Figure 2.

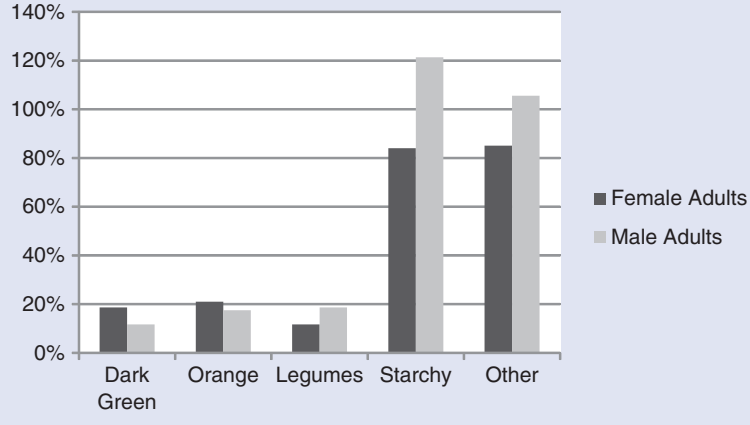
Distribution of Tomato and Tomato Products Consumption.



Source: Economic Resource Service.[98,99]

Figure 3.

Usual Intake as a Percentage of Recommended Intake for Vegetable Subgroups.



Source: US Department of Agriculture.[94,96]

An "Other" Vegetable?

USDA classifies vegetables into 5 subgroups, each with unique nutrient contributions Dark Green, Orange, Starchy, Legumes and Other. The Other Vegetable subgroup provides 55% of the total vegetable intake, of which tomatoes account for 39%. As shown in Figure 3, intakes of Dark Green, Orange, and Legume subgroups fall well below recommendations. For example, the recommended intake of Orange Vegetables is 2 cups a week, and current consumption is 0.29 cups a week, about 15% of the recommended

Table 2.

Food Sources of Potassium, per 100 kcal[a]

	Potassium, mg/100 kcal
Tomatoes, canned	915
Milk, nonfat	457
Potato, baked	422
Orange juice	422
Bananas	402
Ground beef, 95% lean	204
Coffee	116 (per 8-oz serving)

[a] From the US Department of Agriculture National Nutrient Database for Standard Reference, Release 22.[1]

amount for a 2000-calorie diet.[94,96] Given the distinctive nutritional profile of tomatoes, and the emerging yet robust body of research showing health supporting attributes of tomatoes, placing tomatoes in the generic other category misses an opportunity to highlight tomatoes as a positive selection for Americans who are trying to improve their diets. Elevating the profile of tomatoes by creating a new vegetable subgroup called Red-Orange to include tomatoes is recommended by the 2010 Dietary Guidelines Advisory Committee.[100] The addition of "red" to this subgroup will add nutritional value to the category, and featuring the familiar tomato in the Red-Orange Vegetable subgroup may increase exposure to other vegetables in this category as well as make it more feasible for Americans to meet the weekly intake recommendation from this subgroup for health promotion.

Potassium

In addition to lycopene, tomatoes are one of the top contributors of potassium to the American diet. Based on 1999-2000 National Health and Nutrition Examination Survey food intake data, tomatoes rank seventh after milk, potatoes, beef, coffee, poultry, and orange/grapefruit juice as a potassium source.[101] Potassium is a nutrient of concern, as most Americans consume amounts well below the Dietary Reference Intake (DRI). In 2004, the new adult DRI for potassium (4700 mg) was substantially higher than the amount previously reported in the 1989 Recommended Dietary Allowance (3500 mg).[102,103] The increased recommendation was based on evidence indicating that 4700 mg potassium should help lower blood pressure, reduce the adverse effect of excess sodium intake on blood pressure, reduce the risk of kidney stones, and possibly reduce age-related bone loss. Meeting potassium intake recommendations is challenging when consuming a typical American diet. To increase potassium intake without increasing calorie intake, calories currently consumed as solid fats, added sugars, and alcohol will need to be replaced in part by foods rich in potassium. Table 2 shows the potassium content per 100 kcal of the top potassium sources. Tomatoes provide at least twice the potassium per 100 kcal compared with other common sources, except coffee, a nonsignificant calorie source of potassium. Consuming potassium from fruits and vegetables is ideal because it occurs with a biologically advantageous ratio of bicarbonate or citrate, important for bone health. Increasing potassium intake through increased tomato intake is a healthful, calorically sensible strategy for Americans.

Summary and Conclusions

Tomatoes are quantitatively the most important nonstarchy vegetable in the American diet. They offer significant nutritional advantages, including providing a significant source of dietary lycopene and other carotenoids, vitamin C, potassium, and fiber in a low energy dense food. Emerging research underscores the relationship between consuming tomatoes and tomato products with reduced risk of certain cancers, heart disease, ultraviolet light–induced skin damage, osteoporosis, and other conditions. Although lycopene has been extensively investigated apart from the tomato, the preponderance of evidence suggests that consumption of whole tomatoes and tomato products should be preferentially recommended because of greater consistency of documented positive outcomes with the whole tomato and the concomitant supply of other important essential nutrients and nonessential nutrient-like bioactive substances. In addition to the specific nutritional benefits of tomato consumption, encouraging greater tomato and tomato product consumption may be a simple and effective strategy for increasing overall vegetable intake. Tomatoes are widely available, have an established record of acceptability among people of all ages and across cultures, are cost-effective, and offer the convenience of multiple forms. These factors increase the likelihood for compliance and high potential for improving overall dietary patterns in general.

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