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Nutritional attributes of tomatoes

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1 *Executive summary*

1.1 *Background*

This report is intended to provide an information resource from which material can be selected for incorporation into promotional and educational booklets for the various VegFed sector groups. We have gathered relevant literature, including medical research and scientific papers, and, where possible, information specific to New Zealand. This report focuses on the nutritional attributes of tomatoes, but also includes factors that may influence these, such as bioavailability, agronomical issues, cooking or processing and storage. Some additional material of general interest has also been included.

1.2 *Composition*

Tomatoes contain a variety of phytochemicals, the most well known being lycopene. In addition, other carotenoids (e.g. β -carotene, phytoene, phytofluene), phenolics (e.g. coumaric and chlorogenic acids, quercetin, rutin and naringenin), moderate amounts of the antioxidant vitamin C (ascorbic acid) and a little vitamin E (tocopherol) are present. Carotenoids are present in many vegetables and fruit but lycopene is more restricted in its distribution, being concentrated in tomatoes, guava, rosehip, watermelon and pink grapefruit. Lycopene imparts the red colour to these fruits.

1.3 *Lycopene and human health*

Globally, considerable research is being conducted into the health benefits of lycopene. It is a powerful antioxidant; antioxidants neutralise free radicals, which may cause damage to cell components (e.g. DNA, protein, lipids). It may also have a range of other modes of action. The strongest scientific evidence is for a role of lycopene in reducing the incidence of prostate cancer. Lycopene may also help reduce the incidence of other cancers and cardiovascular diseases, and play a role in eye health.

1.4 *The role of other tomato components in human health*

There has been less study of the role of other tomato phytochemicals. β -Carotene is an important precursor of vitamin A and, like lycopene, may play a role in cancer prevention. The phenolic compounds, especially the flavonoids, are important antioxidants. Other potential health-promoting bioactivities of the flavonoids include anti-allergic, anti-inflammatory, anti-microbial and anti-cancer properties. The yellow jelly around tomato seeds may stop platelet aggregation and help prevent heart attacks, strokes and blood vessel problems.

1.5 *Bioavailability*

Lycopene is absorbed in the human body and is one of the most common circulating carotenoids. Other tomato carotenoids may also be bioavailable. Many factors affect the bioavailability of lycopene and other carotenoids, including the nature of the food matrix, thermal processing and presence of fat. Of the phenolics, naringenin from tomatoes has been shown to be bioavailable. Data on other phenolics are lacking.

1.6 *Tomato consumption and major disease patterns*

New Zealanders would appear to consume fewer tomato and tomato-based products than do Mediterranean peoples and have a higher incidence of prostate cancer. Heart disease mortality figures are also higher. Whether these higher incidences of disease are related to lower tomato consumption remains to be proven, but this association may at least be part of the answer.

1.7 *Optimum intake levels*

To date there is no clear consensus on the intake of lycopene required to reduce disease risk. Suggestions range from about 5 up to 35 mg lycopene per day. This could be achieved by consuming at least one or two servings of tomatoes or tomato products every day.

1.8 *Factors affecting phytochemical levels in tomatoes*

Levels of tomato phytochemicals may be affected by cultivar, growing conditions, degree of ripeness and cooking or processing. It may be possible to enhance the levels of lycopene and other phytochemicals in tomatoes and tomato products by managing these factors.

1.9 *Promoting nutritional benefits*

Since lycopene intake levels are comparatively low in New Zealand compared to in Mediterranean countries, promotion could build on the notion that tomato consumption may reduce disease incidence, particularly that of some cancers and cardiovascular disease. Prostate and skin cancer could be of special interest because of their high levels of occurrence here.

The intense red colour and therefore high lycopene content of some New Zealand-grown tomatoes over the paler Australian imports could be a differentiating factor for promotional purposes.

Consumption of the whole tomato, including skins and seeds, consumed with a little good quality oil optimises the delivery of the potential benefits of tomatoes in general, as well as lycopene specifically. Cooking also enhances lycopene bioavailability, but can also reduce levels of other nutrients, such as vitamin C.

2 *Introduction*

The much heralded 'Mediterranean diet' is widely believed to confer health benefits with respect to preventing particular cancers and cardiovascular disease. It typically contains a significant proportion of fruit and vegetables, cereals, fish, olive oil and red wine. Initially, the general components of this diet were studied and the benefits of the Mediterranean diet attributed variously to the high amounts of fibre, the high vitamin intake, and the omega 3 polyunsaturated fish oils and omega 6 polyunsaturated oils in whole grains and monounsaturated olive oil. More recently, the contributions made by antioxidants and other phytochemicals, such as the sulfur compounds present in the onion family and the phenolics in red wine, have been recognised. More recently still, attention has turned to the ubiquitous tomato and the pigment that gives it the characteristic red colour, lycopene.

Originating from South America, and taken back to Europe by the Spaniards in the early 16th century, the tomato was initially viewed with suspicion in northern Europe and English speaking countries where it was also known as the "wolf peach". A rough translation of its botanical name, *Lycopersicon*, is "edible wolf peach", which is an echo of this. Nowadays, however, it is widely cultivated and consumed worldwide, although particularly prominent in Italian, Spanish, Greek and Mexican cuisine. It is frequently consumed fresh as a salad vegetable, but is also processed into a wide range of products including ketchup, soup, puree, paste, pasta sauces; canned in various forms; and combined with various other vegetables, herbs and spices. Salsa is an increasingly popular product. It has been estimated that in the United States more salsa is now consumed than ketchup (Virginia Tech 2003). In the United States and Australia it is the second most commercially important vegetable crop after potatoes (Yeung & Rao 2001; Australian Bureau of Statistics 2003). In New Zealand, consumption of fresh and processed tomatoes is second only to potatoes (VegFed 2005).

There is a large array of commercially available cultivars, reflecting the plant's adaptability for different growing conditions and end uses. The fruit produced ranges from as small as 1.5 cm in diameter and weighing about 8 g to around 18 cm in diameter and weighing about 800 g (Yeung & Rao 2001 - units converted to metric). They can vary also in colour from white to red to purplish black, including green, yellow and orange, as well as in shape (Yeung & Rao 2001). In red tomatoes some researchers maintain that it is often only the flesh that supplies the red colour, the skin itself often being yellow or orange (Virginia Tech 2003). However, other reports state that the skins contain more lycopene, the red pigment, than the pulp (Sharma & Le Maguer 1996). A New Zealand study of three hydroponically grown greenhouse cultivars. similarly found that on a per weight basis the skins contained more lycopene than the pulp, but that when considering the fruit as a whole, more lycopene was provided by the pulp (Toor & Savage 2005).

This report provides information on the nutritional attributes of tomatoes and their role in a healthy diet. It also describes factors that may affect these attributes. Additional material of general interest is provided in Appendix I.

3 *Composition*

The major nutritional components of the tomato are shown in Table 1. Further data on the nutritional composition of fresh tomatoes and tomato-based products are given in Appendix II. As can be seen, tomatoes are a good source of vitamin C and vitamin A equivalents (in the form of β -carotene, see Section 3.2) and also provide some vitamin E, folic acid, potassium and other trace elements. Protein and dietary fibre are also present, although the major constituent is water, comprising 94-95% of the fruit by weight (Davies & Hobson 1981). Processed tomatoes may have higher levels of some nutrients because their concentration may be higher in these forms.

Vitamin C is important to prevent scurvy but it is also a powerful antioxidant and may help prevent a range of degenerative diseases. It has been estimated that tomato production in the United States could provide about one-third of the recommended dietary allowance (RDA) for Americans (Pantos & Markakis 1973). The actual contribution to the vitamin C supply is considerably lower than this (12.2% in 1972), but nevertheless only oranges and potatoes contribute more to the American diet (Senti & Rizek 1975). Another nutritionally important component is β -carotene, since it is converted to vitamin A in our bodies. Vitamin A is important for night vision, maintenance of skin, immune function and prevention of infections. Potassium is an essential nutrient for normal health maintenance and growth. Potassium, along with calcium and magnesium, may play a role in reducing high blood pressure. Dietary fibre is important to maintain a healthy digestive system and may also help to control high cholesterol levels in the blood. Tomatoes are a considerable source of fibre, especially when eaten with the skin and seeds.

Table 1: Major dietary components per 100 g red raw tomato.

Nutrient	NZ ¹	USA ²	Other ³
Vitamin A	92 μ g RAE	31 μ g RAE; 623 IU	1000 IU
Vitamin B1 (μ g)	20	59	60
Vitamin B2 (μ g)	10	48	40
Folic Acid (μ g)	14	15	28
Vitamin C (mg)	23.7	19.1	22
Vitamin E (mg)	0.77	0.38	1.2
Potassium (mg)	265	222	290
Calcium (mg)	11	5	21
Magnesium (mg)	12.1	11	14

¹ NZ Food Composition Database (Athar et al. 2001).

² USDA National Nutrient Database for standard reference, Release 15 - Year round average.

³ Data from Yeung & Rao (2001).

In addition to the general nutrients above, tomatoes contain an array of phytochemicals (= plant-derived chemicals). Many of these compounds are antioxidants, substances that inactivate certain harmful reactive compounds in the body (free radicals). There are many different antioxidants, including vitamins C (ascorbic acid) and E (tocopherols), carotenoids, flavonoids and other phenolics, the trace elements selenium and zinc, some sulfur compounds and other individual substances (e.g. lipoic acid and coenzyme Q). These antioxidants are substances that have beneficial effects in the body beyond providing the nutrients necessary to prevent deficiency diseases such as scurvy, pellagra and beriberi. Instead, they are believed to prevent or delay the onset or progression of many chronic diseases, such as cancer and cardiovascular disease. They may deactivate free radicals that may be present in the body through diet, pollution, smoking, exposure to radiation or UV light or merely as part of the body's normal processes. As can be seen from Table 2, tomatoes contain a significant number of these antioxidants and in reasonable quantities. Of these, lycopene is of particular interest since it is available in relatively few other foods, yet is present in tomatoes in reasonable quantities.

The levels of these antioxidant components may vary according to such factors as cultivar (Hayman 1999; Orłowski et al. 2002; Thompson et al. 2000), growing conditions (Lacatus et al. 1995; Zushi & Matsuzoe 1998), method of ripening (Arias et al. 2000), processing (Shi & Le Maguer 2000; Thompson et al. 2000; Takeoka et al. 2001) and storage conditions (Hayman 1999). These agronomic issues will be discussed in greater detail in Section 8. As will be seen, some of these micronutrients are destroyed by processing but with others, such as lycopene, bioavailability may be enhanced.

Table 2: Summary of the levels of the main antioxidant components in tomatoes (data from a range of sources).

Component	Typical concentration (mg/100 g FW)
Ascorbic acid	15-48
Carotenoids (total)	4-24
β-carotene	0.4-1
lycopene	3-18
phytoene	1-3
phytofluene	~1
Phenolic acids	16-29
caffeic acid	0.2-10
chlorogenic acid	1.3-3.8
coumaric acid	0.1-1.6
ferulic acid	0.1-0.7
Flavonoids	
naringenin	0.4-4.2
quercetin glycosides (primarily rutin)	0.3-4.3
kaempferol glycosides	0.02-0.10
Vitamin E	0.04-1.2

3.1 Antioxidant vitamins

Tomatoes contain high levels of vitamin C (Fig. 1) and it has been stated that for Americans tomatoes and tomato products are the third most important source of this, after citrus fruit and potatoes (Senti & Rizek 1975). Besides preventing scurvy, vitamin C is a powerful antioxidant, scavenging practically all free radicals and oxidants, protecting membranes from oxidative damage and working in combination with vitamin E to inhibit low density lipoprotein (LDL) oxidation. It also assists the proper functioning of certain enzymes.

Only a minor amount of vitamin E (Fig. 1) is present in tomatoes, mostly in the seeds. Besides its function as a vitamin, there is increasing evidence of its role as an antioxidant, particularly with respect to protecting against cardiovascular disease. There is evidence that vitamin E has synergistic effects in combination with certain other antioxidants.

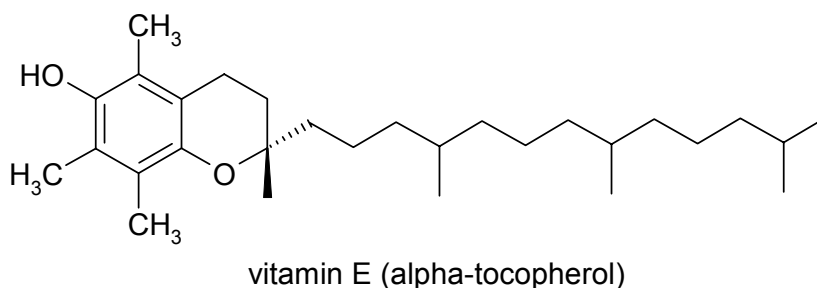
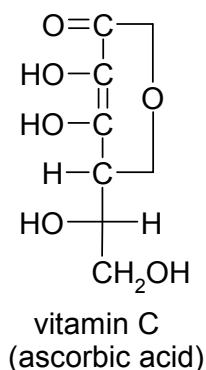


Figure 1: Chemical structures of vitamins C (ascorbic acid) and E (tocopherol).

3.2 Carotenoids

Yellow, orange, and red carotenoids are among the most widespread and important natural pigments. They are found in higher plants, algae, fungi and bacteria, both in nonphotosynthetic tissues and in photosynthetic tissue, (where they accompany the chlorophylls). Their name is derived from the main representative of their group, β -carotene, the orange pigment first isolated from carrots. The carotenoids are classed into two main groups: (1) carotenes that are hydrocarbons ($C_{40}H_{56}$), and (2) their oxygenated derivatives (xanthophylls). Carotenoids are lipids and can specifically absorb light in the UV and specific visible regions of the spectrum, the rest of the spectrum is transmitted or reflected and they appear coloured. The particular structure of individual carotenoid compounds influences their colour.

The main carotenoids present in tomatoes are shown in Tables 2 and 3, and the structures of some of these compounds are shown in Figure 2. The red colour of the tomato is due to its major carotene, lycopene, which is present at levels up to 90% of the total carotenoids. A range of other carotenoids is commonly reported including β -carotene, δ -carotene, γ -carotene and neurosporene (Gross 1991), but reports sometimes include other

carotenoids. Lycopene epoxide, an oxidation product of lycopene, was reported as the second most predominant carotenoid in tomatoes (Khachik et al. 1992). Abushita et al. (2000) also report that it was present, but at lower levels. The common red tomato also contains the colourless precursors phytoene and phytofluene. Composition of carotenoids does vary considerably between cultivars. Some tomato strains are orange because they do not synthesise lycopene or because other carotenes, such as β -carotene, predominate. The composition of tomato seeds is slightly different than the flesh, with lutein being the main carotenoid followed by β -carotene and lycopene (Rymal & Nakayama 1974).

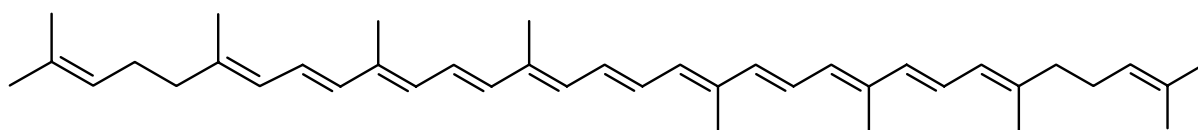
Table 3: Carotenoid content (mg/100 g FW) of tomatoes and selected tomato products (fresh data from Dumas et al. (2003) and processed data from Tonucci et al. (1995), as given in Beecher (1998)).

Carotenoid	Vitamin A activity ^a	Tomato product			
		Fresh tomatoes	Canned tomatoes	Tomato catsup	Tomato sauce
Phytoene	-	1.8	1.9	3.4	3.0
Phytofluene	-	1.1	0.8	1.5	1.3
zeta-Carotene	-	0.1	0.2	0.3	0.8
Neurosporene	-	t ^b	1.1	2.6	7.0
Lycopene	-	4.1	9.3	17.2	18.0
gamma-Carotene	+	t ^b	1.5	3.0	3.2
beta-Carotene	++	0.8	0.2	0.6	0.5

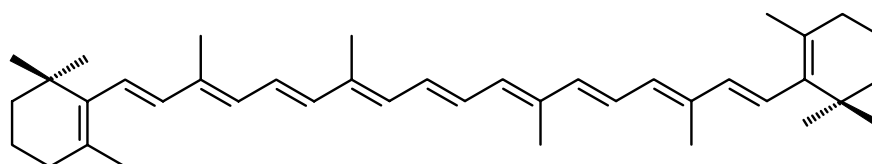
^a Vitamin A activity based on similarity of chemical structure or part of carotenoid molecule to retinal.

^b Trace.

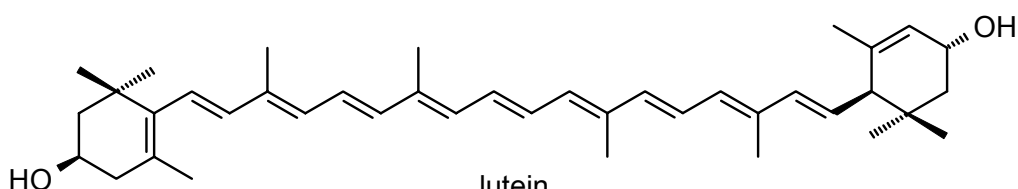
Lycopene comprises a long straight chain, with 11 conjugated double bonds (double bonds on adjacent carbon atoms) (Fig. 2). This structure is not only responsible for conferring colour, but also for its physical properties, chemical reactivity and its biological activity. It exists as various isomers (Fig. 3), but in fresh fruit is usually in the all-*trans* configuration. However, during the heat treatment involved in cooking or processing, exposure to light and some chemical reactions, some lycopene may be converted to the *cis* configuration. This change in the geometry of the molecule is significant because it appears to make lycopene more bioavailable. This is discussed further in Sections 6 and 8.1.4.



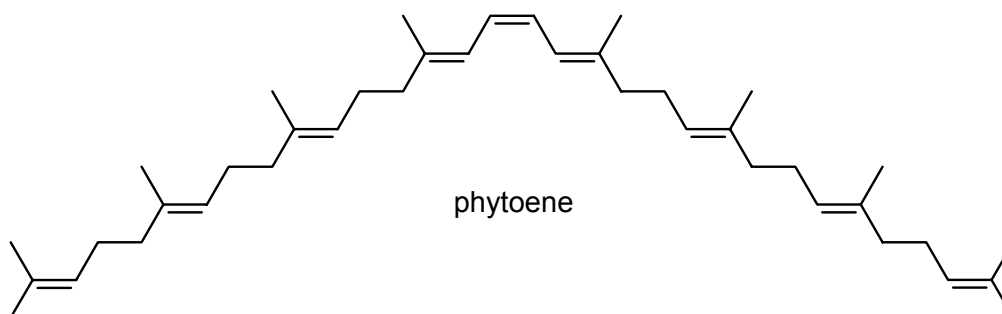
lycopene



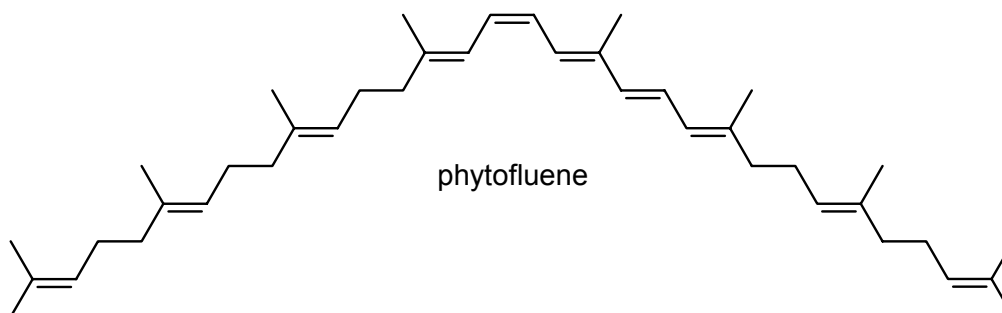
beta-carotene



lutein



phytoene



phytofluene

Figure 2: Chemical structures of lycopene and the other main carotenoids present in tomatoes.

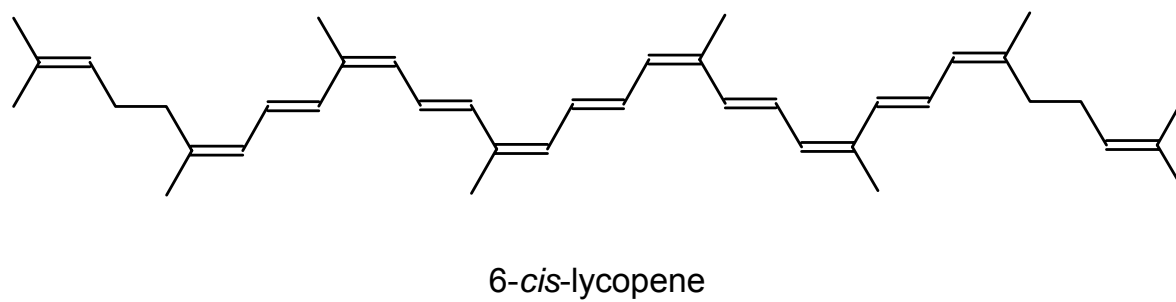
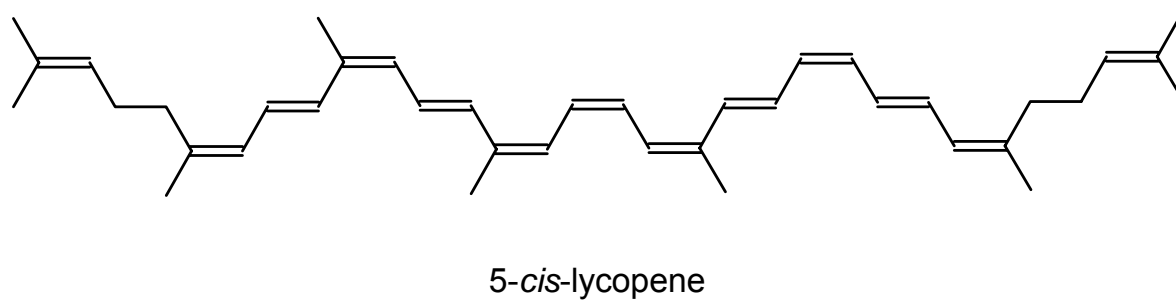
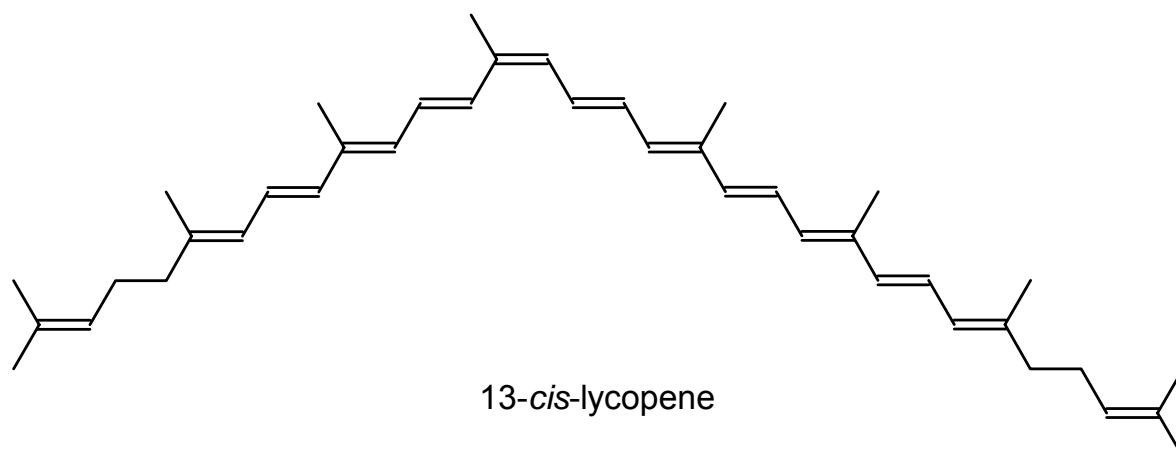
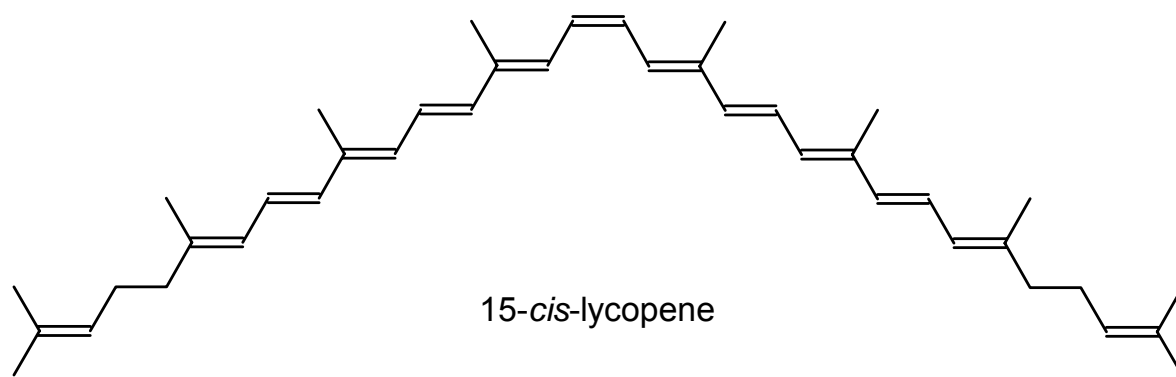


Figure 3: The chemical structure of *cis*-isomers of lycopene.

Lycopene is only present in a few foods, the most common being tomatoes, with watermelon, pink grapefruit, guava, red papaya and rosehips being other sources. Tomatoes, however, are abundant, cheap, versatile and commercially useful, making them by far the most predominant dietary source (Bramley 2000). Table 4 below gives the lycopene content of various foods. The lycopene content of fresh tomatoes can vary from virtually none up to 18 mg/100 g FW, but most values for typical red tomatoes are between 5 and 8 mg/100 g FW (Dumas et al. 2003). Some reports state that lycopene is not present in significant quantities in the tomato skin. However, Sharma & Le Maguer (1996) state that skins contain about five times more lycopene than the pulp (54 mg/100 g FW compared to 11 mg/100 g FW). Toor & Savage (2005) found lycopene in the skin of the three varieties tested averaged around three times more than in the pulp, with a small amount also present in the seeds (although in this study the jelly around the seeds was considered to be 'seed' rather than 'pulp').

Table 4: Lycopene content (mg/100 g FW) of fruit and tomato products (data from Bramley (2000), Holden et al. (1999), Rao & Agarwal (1999), Hart & Scott (1995), Tonucci et al. (1995) and Yeung & Rao (2001).

Food	Lycopene content (mg/100 g FW)
Watermelon	2.3-7.2
Pink guava	5.4
Pink grapefruit	0.5-4.0
Papaya	2.0-5.3
Fresh tomato (raw)	0.9-18.1
Canned tomatoes	4.5-9.7
Tomato sauce	6.2-14.1
Tomato paste	5.4-42.2
Tomato puree	16.7
Tomato juice	5.0-11.6
Tomato ketchup	9.9-17.0
Tomato soup	5.0-7.2
Pizza sauce	12.7

As with many constituent nutrients in plants, levels of lycopene may vary according to cultivar, maturity, growing conditions, harvesting, storage and processing (for more discussion of this see Section 8.1). The levels of lycopene in processed tomato products are significantly higher than in the fresh product. It appears that processing may in fact enhance lycopene content, firstly due to a concentration factor but also by making it more bioavailable (Stahl & Sies 1992). Two major reasons have been postulated for this. Firstly, the act of processing breaks down the food matrix, releasing

lycopene for absorption. It is also believed that the *cis*-isomer formed after the thermal energy of cooking or processing is more absorbable than the all-*trans* isomer (Boileau et al. 1999). For further discussion of bioavailability see Section 6.

In addition to lycopene, a range of other carotenoids is present in tomatoes. The most significant of these is probably β -carotene, which attracts considerable interest nutritionally as it can be converted to vitamin A in the human body while lycopene cannot. As mentioned earlier, cultivar has a big influence on the presence/absence of other carotenoids. However, the composition of carotenoids appears to be reasonably consistent over a range of tomato products (Table 5).

Table 5: Carotenoid content (mg/100 g FW) in tomatoes and various tomato products (from Tonucci et al. 1995).

Sample	Carotenoid								Lycopene-5,6-diol
	β -Carotene	γ -Carotene	δ -Carotene	Lutein	Lycopene	Neurosporene	Phytoene	Phytofluene	
Whole tomatoes	0.23	1.50	0.21	0.08	9.27	1.11	1.86	0.82	0.11
Catsup	0.59	3.03	0.33	nd ^a	17.23	2.63	3.39	1.54	0.18
Spaghetti sauce	0.44	3.02	0.34	0.16	15.99	3.15	2.77	1.56	0.17
Tomato paste	1.27	9.98	0.84	0.34	55.45	6.95	8.36	3.63	0.44
Tomato puree	0.41	2.94	0.25	0.09	16.67	2.11	2.40	1.08	0.17
Tomato sauce	0.45	3.17	0.29	t ^b	17.98	2.48	2.95	1.27	0.16

^a Not detected.

^b Trace.

3.3 Phenolic compounds

Other phytochemicals present in tomatoes, though less studied than the carotenoids, are the phenolic compounds. Phenolic compounds are a large group of secondary plant products, present in most if not all plants, that differ in chemical structure and reactivity. The chemical structures range from quite simple compounds like caffeic acid to highly polymerised substances like tannins. Their contribution to the pigmentation of plants is well recognised (the anthocyanins may be red, blue or purple). However, not all phenolics are coloured. There are numerous different groups of phenolics but the most common phenolics found in foods are generally phenolic acids, flavonoids, lignans, stilbenes, coumarins and tannins (Harbourne 1993). The first two of these groups are present in significant amounts in tomatoes.

Various total phenolic levels for fresh tomatoes have been reported in the literature: 15.82-22.68 mg/100 g FW (Davies & Hobson 1981), 23 mg/100 g FW (Brune et al. 1991), 25.9-49.8 mg/100 g FW (Martinez-Valverde et al. 2002), and 13.15 mg/100 g FW (Minoggio et al. 2003). There are a number of different groups of phenolic acids present, with the main ones being phenolic acids and flavonols (rutin) (Table 2). The structures of the main phenolics present in tomato fruit are shown in Figure 4. No data were found on the phenolic composition of tomato seeds.

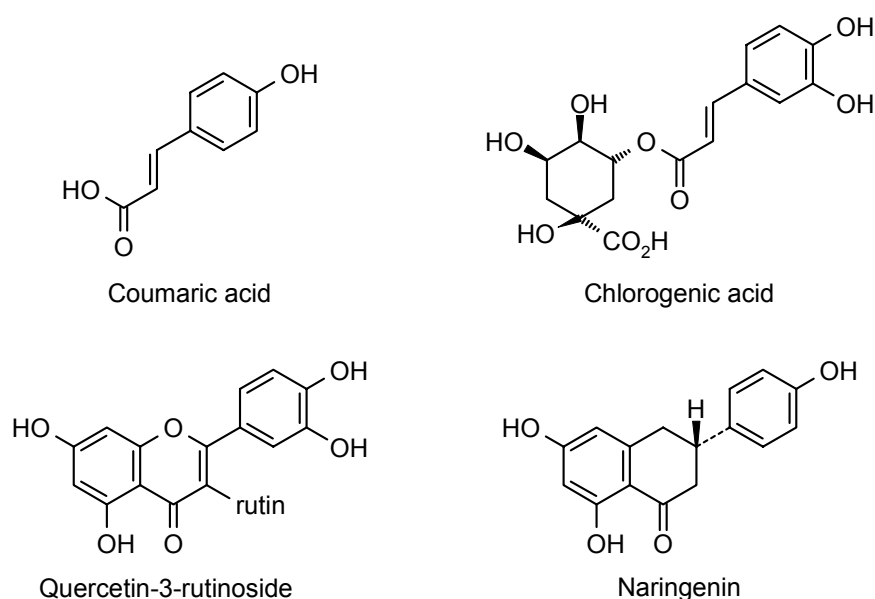


Figure 4: Chemical structures of the main phenolics in tomato fruit.

A range of phenolic acids is present, the main ones being caffeic and chlorogenic acids (Table 2). Some authors report that coumaric acid is the main phenolic acid (e.g. Machiex et al. 1990) while others report chlorogenic acid (e.g. Minoggio et al. 2003). These differences could be due to variety/cultivar. Other phenolic acids such as coumaric, ferulic, sinapic, vanillic and salicylic acids may also be present in smaller amounts (Davies & Hobson 1981; Machiex et al. 1990). Cultivars vary in phenolic acid levels and composition (Table 6). There are limited data on the distribution of phenolic acids in the fruit, with most indicating similar contents in flesh and skin. The total hydroxycinnamic acid level of the skin has been reported as 9.4 mg/100 g, while the flesh contains 8.4 mg/100 g (Macheix et al. 1990). However, Herrmann (1973) reported that chlorogenic acid was as high as 50 mg/100 g FW in tomato skin.

Table 6: Content of hydroxycinnamic acids (mg/100 g FW) in tomato cultivars (adapted from Martinez-Valverde et al. 2002).

Tomato cultivar	Phenolic acid			
	Chlorogenic	Caffeic	<i>p</i> -Coumaric	Ferulic
Rambo	2.79	0.26	0.11	0.19
Senior	3.28	0.14	0.13	0.17
Ramillete	2.61	1.30	0.40	0.38
Liso	3.28	0.14	nd ^a	0.16
Pera	1.43	1.23	0.25	0.32
Canario	1.70	1.29	0.24	0.27
Durina	2.23	0.99	0.42	0.54
Daniella	1.47	0.59	0.58	0.30
Remate	2.32	0.24	nd ^a	0.19

^a Not detected.

Tomatoes also contain flavonols, which belong to a sub group of the phenolics family and have been shown to have potent antioxidative activity (Shahidid & Wanasundara 1992). Quercetin glycosides have very high antioxidant activity relative to α -tocopherol (vitamin E) (Hertog et al. 1992). Total flavonol levels for whole tomatoes have been reported to vary between 0.13 and 4.4 mg/100 g FW (Davies & Hobson 1981; Stewart et al. 2000; Martinez-Valverde et al. 2002). However, typical red tomatoes usually contain around 0.5–2 mg/100 g FW of flavonols (Table 7).

Table 7: Content of flavonoids (mg/100 g FW) in tomato cultivars (adapted from Martinez-Valverde et al. 2002).

Tomato cultivar	Flavonoid		
	Quercetin	Kaempferol	Naringenin
Rambo	0.72	nd ^a	0.69
Senior	1.72	nd ^a	0.49
Ramillete	2.87	0.21	0.81
Liso	1.25	nd ^a	0.51
Pera	1.03	0.12	nd ^a
Canario	2.81	nd ^a	0.85
Durina	2.23	nd ^a	0.95
Daniella	4.36	nd ^a	1.26
Remate	2.13	nd ^a	0.45

^a Not detected.

The main flavonol in tomatoes is a quercetin glycoside, rutin (quercetin 3-rutinoside), but other quercetin and kaempferol glycosides may be present in some cultivars in small amounts (Macheix et al. 1990). As with many phytochemicals, the flavonol content may vary according to many factors including cultivar, the size of the fruit, maturity and environmental/growing conditions (factors influencing the phenolic levels in plants have been reviewed by Parr & Bolwell (2000)) Stewart et al. (2000) showed that the highest concentration of flavonols occurs in tomato skins (Table 8), and thus, in general, smaller tomatoes have higher amounts of this on a per weight basis because of their higher surface area to weight ratio. Purple fruit, which contain anthocyanins, contain much higher levels of flavonols than standard cultivars (Table 9). The rutin level apparently drops during ripening (Macheix et al. 1990). Levels of quercetin glycosides dropped from 1.2-2.4 mg/100 g FW in immature green fruit to 0.3-0.7 mg/100 g FW in red fruit (Davies & Hobson 1981). Woldecke & Herrmann (1974) also reported that the flavonol content, on a per weight basis, decreased during the development of tomato fruits; and it was higher in field-grown than in glasshouse tomatoes. See Section 8.2 for further discussion of factors affecting phenolics in tomatoes, including processing.

Table 8: Distribution of flavonols (mg/100 g FW) in Spanish cherry tomatoes (adapted from Stewart et al. 2000).

Tomato	Free quercetin	Free kaempferol	Conjugated quercetin	Conjugated kaempferol	Total flavonol
Whole	0.02	0.05	2.34	0.12	2.53
Skin	0.07	0.04	13.78	0.44	14.33
Flesh	nd ^a	0.01	0.09	0.02	0.12
Seed	0.01	0.02	0.1	0.02	0.15

^a Not detected.

Table 9: Flavonol content (mg/100 g FW) of skins of different coloured tomatoes (adapted from Stewart et al. 2000).

Tomato cultivar	Skin colour	Free quercetin	Free kaempferol	Conjugated quercetin	Conjugated kaempferol	Total flavonol
Noire Charbonneuse	Red/purple	0.39	0.02	40.2	1.42	44.0
Anthocyanin Gainer	Deep red	0.30	0.04	25.2	2.09	27.6
Aubergine	Red/dark patches	0.03	nd ^a	10.3	0.45	10.8
Anthocyanin Free	Red	0.06	0.01	20.6	1.73	22.4
Dark Green	Red/yellow	0.08	nd ^a	18.3	0.49	18.9

^a Not detected.

Another group of flavonoids present in tomatoes are the flavonones, with the main one being naringenin (Macheix et al. 1990). Some reports state that naringenin is present in the free form only (Wardale 1973), but others clearly show a naringenin glycoside is also present (Hunt & Baker 1980). Hunt & Baker (1980) reported the presence of chalconaringenin (also called naringenin chalcone), naringenin and naringenin-7-glucoside. As with the flavonols, levels of naringenin vary between cultivars (Table 7). Flavan-3-ols are not present and nor are anthocyanins, except in a few unusual lines (Macheix et al. 1990).

It has been postulated that phenolic compounds could be responsible for the antioxidative activity in tomatoes beyond that accounted for by their lycopene content (Takeoka et al. 2001). Other studies, including our own, have found that in many assays the phenolics actually make a greater contribution to antioxidant activity than the carotenoids.

4 *Lycopene and human health*

Most research on lycopene has been undertaken by researchers working on prostate cancer and cardiovascular disease. As knowledge about this compound has increased, however, so too has interest in its possible effect in a number of health areas, including other cancers (skin, breast, bladder, cervix, lung, digestive tract, and female reproductive organs), osteoporosis, and diabetes. Although it is still too early to draw conclusions, results are promising in many of these areas. In addition, research is continuing to expand our understanding of the metabolism of lycopene and its mode of action.

4.1 *Proposed mechanisms of action*

Lycopene first caught the interest of the scientific community in the late 1980s when it was found that of all the carotenoids, including the better known β -carotene, it was the most potent quencher of the highly reactive compound, singlet oxygen (Di Mascio et al. 1989). It is also a potent scavenger of peroxyl radicals (Mortensen & Skibstead 1997; Woodall et al. 1997) and nitrogen dioxide (Bohm et al. 1995). By increasing lycopene levels in the body, oxidative stress is reduced and antioxidant potential increased. Antioxidative activities are believed to reduce damage to lipids, both lipoproteins and membrane lipids (Tsuchiya et al. 1993), proteins, particularly enzymes, and DNA (Clinton 1998). There is a range of other possible modes of action for lycopene (Fig. 5). Lycopene may regulate gene functions (Siler et al. 2004), improve intercell gap junction communication (Zhang et al. 1997), moderate hormone function and immune response or regulate metabolic pathways (Rao & Argawal 2000). It is also possible that these mechanisms are interrelated and operate simultaneously. There may also be other modes of action that have not yet been uncovered.

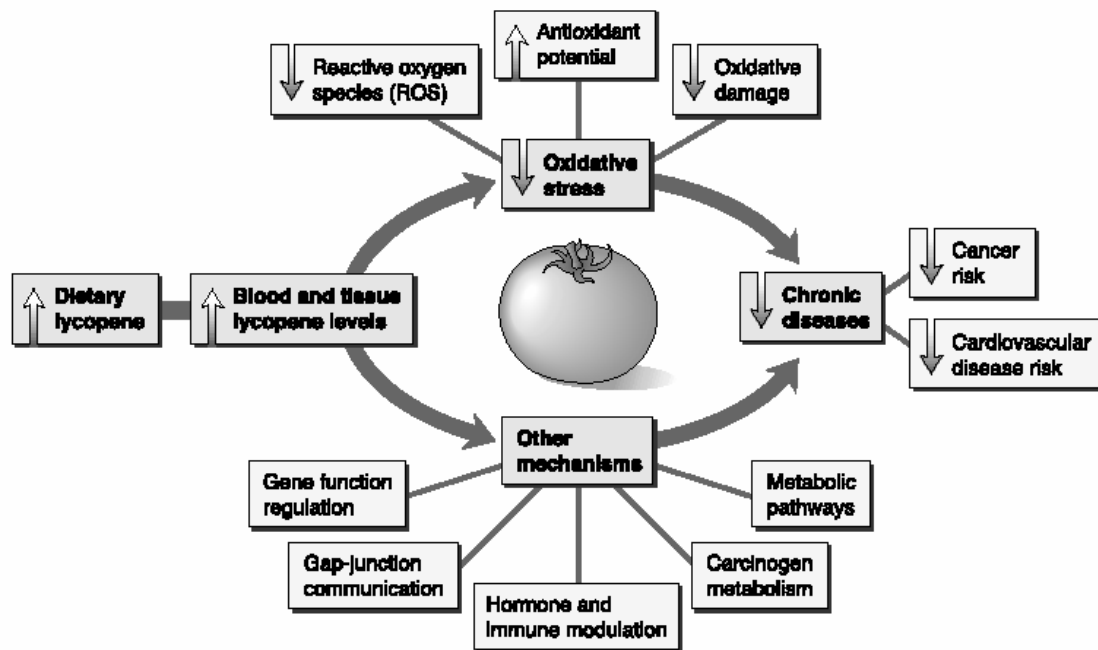


Figure 5: Proposed mechanisms for the role of lycopene in preventing chronic diseases (from Rao & Argawal 2000).

4.2 Prostate cancer

4.2.1 Epidemiologic studies

Epidemiologic studies (also called observational or population studies) look at disease patterns to see if certain diseases are more common in some groups of people than others. Prostate cancer is a leading cause of cancer deaths worldwide, but particularly in developed countries. According to figures obtained from Globocan, a joint initiative between the International Agency for Research on Cancer (IARC), part of WHO, and the European Commission, New Zealand has one of the world's highest age standardised incidence rates at 139.06 per 100 000 people, with Australia at 108 and the USA at 104.33. The rate for the United Kingdom is 40.24, for Italy, 24.89, Spain, 24.23, and Greece 20.17 (International Agency for Research on Cancer, 2000 estimates). Non modifiable risk factors include older age, family history of the disease, and race (Giovannucci 2003). In addition, certain types of prostate cancer appear to be associated with a diet high in red meat and dairy products (Michaud et al. 2001). Other dietary factors may also be important (e.g. trace elements), making it very difficult to precisely determine critical factors relating to the disease. A recent overview of the chemoprevention of prostate cancer details not only results relating to phase III trials of a new pharmaceutical treatment, finasteride, but also potential non-pharmaceutical treatments (Klein & Thompson 2004). The authors conclude that while there is substantial evidence that selenium and vitamin E act as preventative agents with respect to prostate cancer, there is also good epidemiological and molecular support for lycopene, soy, green tea and

cyclooxygenase-2 inhibitors having a similar effect. Whilst studies undertaken to date are not unanimous in concluding a beneficial effect of tomatoes in general, and lycopene in particular, and further research is needed, there is strong and growing evidence of both a protective and inhibitory effect of a diet rich in tomatoes and tomato products, with respect to this disease. There are numerous potential reasons for why an actual association could be missed in a study. For example, intake of tomato products or sources of bioavailable lycopene could have been too low to be informative.

Epidemiologic studies vary in approach. Some correlate risk of prostate cancer with either the consumption of tomatoes and tomato products or lycopene itself. These diet-based investigations have been either case-control in which the diet of men prior to prostate cancer diagnosis is compared with that of a group of cancer-free controls, or prospective, where the diet of the sample population is measured at the beginning of the study and the subjects followed for subsequent prostate cancer occurrence.

4.2.2 *Prospective studies*

An early study, considering the impact of diet and lifestyle on prostate cancer in a population of 14 000 Adventist men, found that a higher tomato intake was statistically significant in lowering the risk of developing prostate cancer (Mills et al. 1989). Later, a Harvard School of Medicine study, involving 47 894 male health professionals, found that, unlike a number of other carotenoids that had no effect, high lycopene consumption lowered the risk of developing prostate cancer by 21% (Giovannucci et al. 1995). Furthermore, high consumption of tomatoes and tomato products (more than 10 servings per week) reduced the risk for all types of prostate cancer by 35%, and advanced prostate cancer by 53%, compared with those who consumed fewer than 1.5 servings per week. Of the tomato-based products, tomato sauces had a high inverse association with prostate cancer risk, with a moderate (inverse) association for fresh tomatoes and pizza and none for tomato juice. Significantly, these gradations of association corresponded to lycopene levels in the plasma of a sample group of the men. Of the 46 food items analysed, tomato sauces were found to confer the greatest protection. A recent follow up to this study, by Giovannucci et al. (2002), evaluated additional data to see if the original associations persisted. It was concluded that whilst frequent consumption of tomato products was associated with a lower risk of prostate cancer, the association was only moderate and so could be missed in a small study, a study with substantial errors in measurement, or one based upon a single dietary assessment. In contrast, a prospective cohort study in the Netherlands, comprising 58 279 men aged between 55 and 69 at baseline in 1986, found no association between lycopene, various other carotenoids, retinal, or vitamins C and E and prostate cancer (Schuurman et al. 2002).

4.2.3 *Case-control studies*

One of the earliest case-control studies took place in Minnesota from 1976 to 79. In this it was also found that men with prostate cancer had a lower reported tomato intake than men free from prostate cancer (Schuman et al. 1982), although the result was not statistically significant, possibly because

the study was relatively small. A later case-control study in Hawaii, using a multi ethnic population and considering the relationship between fruit and vegetable intake and prostate cancer occurrence, found no association between raw or cooked tomatoes and the likelihood of developing cancer (Le Marchand et al. 1991). However, in this study actual intake levels were not reported, nor were processed tomato products, such as tomato-based sauces, specifically considered. Similarly, a case-control study in the United Kingdom (Key et al. 1997) found no relationship between raw or cooked tomatoes and the risk of prostate cancer. However, the strongest diet-related association was found for baked beans, where the beans are generally processed in a tomato sauce in which lycopene is present in a highly bioavailable form. A New Zealand study during 1996-97 found that dietary intake of lycopene and tomato-based products was only weakly associated with a reduced risk of prostate cancer (Norrish et al. 2000). There was approximately a 30% reduction in risk, but it was not statistically significant. In the same study it was found that dietary intake of β -carotene and its major vegetable sources was not protective against prostate cancer. A recent study in China, where the prostate cancer rate is amongst the lowest in the world, similarly found that both lycopene and consuming vegetables and fruits rich in lycopene (as whole cooked tomatoes and watermelon) reduced the risk of developing this disease. A protective effect of other carotenoids and carotenoid-rich vegetables was also observed (Jian et al. 2005).

4.2.4 *Clinical studies/blood and tissue studies*

As mentioned earlier, lycopene has been shown to concentrate in prostate tissues, with lycopene present in higher levels than any other carotenoid. This has been one of the factors instigating investigation of the relationship between lycopene and prostate cancer. Studies using levels of lycopene in blood and/or tissue have thus investigated both the prospective and actual incidence of prostate cancer and its virulence.

Hsing et al. (1990) used the serum taken from 25 802 people in 1974 to compare levels of various micronutrients between those who developed prostate cancer and those who did not. In this study lycopene was the only carotenoid to be inversely associated with cancer risk. A study at the University of Toronto found that levels of lycopene in serum and prostate tissue were lower in prostate cancer patients than in cancer-free controls (Rao et al. 1999). Gann et al. (1999) used blood samples taken and stored in 1982 when following up on the 578 cases of prostate cancer that had occurred over the following 13 years. Comparing the baseline plasma lycopene level with that of age-matched, cancer-free controls, it was found that a lower risk of prostate cancer was associated with higher levels of plasma lycopene. This was particularly evident in relation to aggressive prostate cancer. A similar study using prediagnostic serum from Japanese Americans in Hawaii found no association between serum lycopene levels and risk of prostate cancer (Nomura et al. 1997). However, other researchers have commented that flaws inherent in this study, such as the use of a single assessment of serum lycopene to characterise a 22-year period and the unusually low serum concentration among the controls, may account in part for the null results (Giovannucci 2002).

Another study, examining how prostate levels of various antioxidants related to plasma levels and self-reported usual dietary intake, found that levels of tocopherols and carotenoids in the prostate correlated best with respect to lycopene, β -carotene and gamma-tocopherol (Freeman et al. 2000). In a case-control study examining the effects of plasma lycopene and various other antioxidants on the risk of prostate cancer, Lu et al. (2001) found inverse associations between plasma lycopene and certain other carotenoids and prostate cancer. A small intervention study, in which a group of 15 randomly selected patients with prostate cancer and awaiting prostatectomy received a twice daily dose of 15 mg lycopene, found an indication that the progression of the disease was reduced in the group under treatment compared with the 11 controls who received no supplementation (Kucuk et al. 2001).

Studies have investigated the higher prostate cancer rates in American Blacks than American Whites, and found that serum lycopene levels were significantly lower in Blacks than Whites (Hayes et al. 1999; Vogt et al. 2002). This raised the possibility that the difference in prostate cancer rates might be attributable to a difference in lycopene exposure. Though not statistically significant, the results were suggestive of serum lycopene being inversely related to risk of prostate cancer in both racial groups (Vogt et al. 2002).

Further evidence for the beneficial effects of lycopene has been demonstrated in a number of laboratory studies. In a cell culture study, Pastori et al. (1998) demonstrated how lycopene in combination with vitamin E prevented the growth of prostate cancer cells. A Japanese *in vitro* study investigated the effects of a number of carotenoids on three lines of human prostate cells and found that, together with neoxanthin from spinach and fucoxanthin from brown algae, the acyclic phytofluenes in the tomato, including lycopene, significantly reduced the viability of these cells (Kotake-Nara et al. 2001).

4.3 *Lycopene and other cancers*

In 1999 a long-time lycopene researcher, Edward Giovannucci, from the Harvard Medical School reviewed 72 epidemiological studies regarding the relationships between tomatoes and tomato-based products, lycopene and cancer (Giovannucci 1999). In 57 of these studies an inverse association between tomato intake or blood lycopene levels and the risk of several types of cancer was shown; in 35 of these, the relationship was statistically significant. The strongest associations were shown for the prostate and stomach. For cancers of the lung, pancreas, colon and rectum, oesophagus, oral mucosa, breast and cervix, the association appeared to be only suggestive. These conclusions were consistent across diverse populations and studies utilising various designs. None of the studies reviewed showed evidence of increased risk of cancer from tomato/tomato-based products/lycopene intake (Giovannucci 1999).

4.3.1 *Skin cancer*

Of great potential interest to New Zealanders, since skin cancer rates here are amongst the highest in the world, are findings relating to a possible protective effect of tomato-based products or constituent tomato

phytochemicals. Since the role of carotenoids in plants appears to be primarily to quench oxidative products induced by UV exposure, it is not unreasonable to assume that lycopene could have similar activity in human skin. An early study, considering the effects of solar-simulated light on human skin, showed a 31-46% decrease in the lycopene of exposed skin compared with that of adjacent non-exposed skin in a group of 16 women (Ribaya-Mercado et al. 1995), suggesting that lycopene is actively involved in protecting skin. A small study by Stahl et al. (2001) found that ingesting tomato paste resulted in 40% less erythema formation at the end of a 10-week period compared with a control group. Protection against UV light-induced erythema after regular ingestion of lycopene from tomato paste has also been demonstrated in cell culture (Stahl & Sies 2002). Cesarini et al. (2003), using a lycopene, β -carotene α -tocopherol and selenium mixture, similarly showed a reduction in UV erythemas, as well as in other parameters of epidermal defence, such as a reduction in sun burn cells, in UV-induced p53 expression and in lipoperoxide levels. Andreassi et al. (2004) found a lower UV-induced erythematous response in subjects applying a topical lycopene preparation compared with those using a vitamin C and E preparation and the control group.

In addition to skin cancer, other diseases resulting from photo-oxidative stress induced by UV-radiation may be protected against by carotenoids such as lycopene. These disorders include erythema formation, premature aging of the skin, development of photodermatitis, cataract and age-related macular degeneration (Stahl et al. 2001).

4.3.2 *Cancers of the digestive tract*

The various cancers of the digestive tract (oesophagus, stomach, colon and rectum) each have individual features in terms of causation and process and thus ideally need specific investigation. The relationship between lycopene and cancer of the oesophagus in northern Iran was the subject of one of the first studies to examine the role of lycopene in relation to human cancer (Cook-Mozaffari et al. 1979). In this case-control study, weekly consumption of tomato-based foods was associated with a 40% reduction in risk for this cancer—a particularly prevalent cancer in this region. Similar results were also shown much later in an Italian case-control study (Franceschi et al. 1994). A case-control study in Uruguay also showed a reduced risk of upper aerodigestive tract (oral, pharynx, larynx and esophagus) cancers with high tomato intake and this related to lycopene content (De Stefani et al. 2000).

With respect to stomach cancer, a number of diversely located studies have again reported a protective effect of a tomato rich diet (Bjelke 1974; Correa et al. 1985; Buiatti et al. 1989; Tsugane et al. 1992; Franceschi et al. 1994). However, others have found no association (Tajima et al. 1985; Ramon et al. 1993). Another study examined the possible relationship between levels of lycopene, α -carotene and β -carotene in the gastric mucosa and the presence of *Helicobacter pylori*, a pathogen thought to provoke an inflammatory response that precipitates the train of events leading to the development of gastric cancer. No difference in the levels of these carotenoids was found between *H. pylori*-infected subjects and controls (Sanderson et al. 1997).

Cancers of the colon and rectum are major health problems in developed countries and have been consistently found to be inversely associated with high dietary intakes of fruits and vegetables. Whilst there are many studies in which tomatoes have not been specifically considered, a number have reported an inverse relationship between the intake of tomatoes and tomato-based products and these health problems (Modan et al. 1981; Maquart-Moulin et al. 1986; Benito et al. 1990). However, a Canadian prospective cohort study of carotenoids (including lycopene) and colorectal cancer risk did not support any association (Terry et al. 2002).

In vitro effects have also been reported for these types of cancer. Lycopene has been shown to inhibit cell proliferation and enhance gap-junction communication in human oral tumour cells (Livny et al. 2002). Antiproliferative effects have also been shown against other digestive cancers (Velmurugan et al. 2002).

4.3.3 *Breast cancer*

There have been mixed results with respect to the association between lycopene intake and breast cancer. No association was found in studies in the early 1990s by Potischman et al. (1990), London et al. (1992), and Garland et al. (1993), looking at potentially protective effects of carotenoids and antioxidants. A Finnish study of 4697 women equally showed no relationship between consumption of tomato-based products and the risk of developing breast cancer (Jarvinen et al. 1997). More recent Italian (La Vecchia 2002) and Canadian (Terry et al. 2002) studies also showed no consistent association for lycopene and breast cancer. Samples from the Breast Cancer Serum Bank in Missouri were analysed for levels of carotenoids, selenium and retinal, with only lycopene being found to be related to a reduced risk of developing breast cancer (Dorgan et al. 1998). A recent case-control Swiss study investigating the relationship between 17 micronutrients and breast cancer found that lycopene was significantly inversely associated with breast cancer risk (Levi et al. 2001).

Various mechanisms of action against breast cancer have been demonstrated in animal studies or *in vitro*. In a Boston study using induced mammary cancers in a population of rats, it was found that an injection of lycopene-enriched tomato oleoresin appeared to correlate with fewer and smaller tumours in treated animals than in those who were treated either with β -carotene or who were untreated (Zhang et al. 1997). Similarly, another study (Nagasawa et al. 1995) showed that spontaneous mammary tumours were inhibited in mice fed a lycopene-rich diet. Using cell-cultured human mammary cancer cells a 1995 study reported lycopene-inhibited proliferation, whereas other carotenoids, β - and α -carotene, were less effective (Levy et al. 1995).

4.3.4 *Ovarian and cervical cancer*

A number of studies have also investigated the role of lycopene in preventing ovarian and cervical cancers. A recent population based study of pre- and post-menopausal women found that in both groups lycopene intake was significantly inversely associated with ovarian cancer (Cramer et al. 2001). Of the foods investigated, for raw carrots and tomato ketchup the (inverse)

association was strongest. Examining the role of various micronutrients and in the development of cervical cancer, a 1998 study found that of a number of micronutrients, only lycopene was lower in cancer patients than in the controls (Goodman et al. 1998). Similarly, Sengupta & Das (1999) found that higher levels of lycopene were inversely associated with risk, and Kanetsky et al. (1998) found that among black, non-Hispanic women, the risk of developing cervical cancer was reduced by 33% in women with higher blood levels of lycopene. However, again there have been other studies in which no evidence was found between either lycopene intake or serum concentrations and risk (Potischman et al. 1991, 1994; Batieha et al. 1993).

4.3.5 *Bladder cancer*

As with many other cancers, it has been found that a diet rich in fruit and vegetables is associated too with a protective role against bladder cancer (Block et al. 1992). Looking at tomatoes, lycopene and other micronutrients with respect to bladder cancer risk, Helzlsouer et al. (1989) found an inverse association only with lycopene and selenium concentrations. Conversely, however, a laboratory study of induced bladder tumours in mice showed a mild but statistically non significant effect of lycopene or β -carotene on the number of transitional cell carcinomas (Okajima et al. 1997).

4.3.6 *Lung cancer*

To date, studies considering the relationship between lycopene and lung cancer have not shown strong effects. Holick et al. (2002) found that a diet rich in carotenoids, including tomatoes and tomato-based products, might reduce the risk of cancer. Similarly an English study found that together with fish liver oil, vitamin pills and carrots, tomato juice decreased the risk of contracting lung cancer in a case-control study of smokers (Darby et al. 2001). Kim et al. (2000) found that lycopene inhibited the development of carcinogenises in the lungs of male, but not female mice. Hecht et al. (1999) found that administration of lycopene-enriched tomato oleoresin had no effect on the development of induced lung tumours in mice.

4.4 *Cardiovascular disease*

Cardiovascular disease (CD) is the leading cause of illness and death in most developed countries. It includes myocardial infarction (heart attack), ischaemic heart disease (narrowing of the arteries) and cerebrovascular disease (stroke), and has been estimated to be responsible for around 40% of deaths in Australasia (Lister 2003). Whilst certain strategies can be adopted to reduce risk factors for this health problem, such as maintaining a healthy body weight, eliminating cigarette smoking and taking more physical exercise, evidence has now accumulated to suggest that dietary factors may also be important. Just as the Mediterranean diet is believed to prevent various cancers, so too is it believed to protect against cardiovascular problems.

The free radicals responsible for initiating the oxidative damage that lead to cancer are also believed to be responsible for the oxidation of the low density lipoproteins (LDL) that carry cholesterol in the bloodstream. Evidence increasingly supports the hypothesis that oxidatively damaged

macromolecules derived from the lipoproteins that have been deposited on the blood vessel wall may initiate the cellular and cytokine networks involved in the development of vessel lesions (Ross 1993). This is an early stage in the development of the atherosclerosis that precedes wider cardiovascular health problems. Thus, antioxidant nutrients may retard the progression of this disease by interfering with the oxidative process. In addition, however, mechanisms besides lycopene's antioxidant properties have been shown to reduce the risk of CD. In a small clinical trial and laboratory experiment it was demonstrated by Fuhrman et al. (1997) that lycopene inhibited the activity of a particular enzyme involved in cholesterol synthesis. It has been hypothesised that other activity could include enhanced LDL degradation, LDL particle size, and composition, plaque rupture and altered endothelial functions (Rao 2002).

In the past, many studies have credited the antioxidant activity of vitamin E for providing a protective effect against lipid oxidation (Rimm et al. 1993; Morris et al. 1994). However, this was not confirmed in the Heart Outcomes Prevention Evaluation Study in the United States, which found no evidence of beneficial effects in cardiovascular terms for high risk patients (Hoogwerf & Young 2000). However, other studies specifically examining the effects of consuming tomatoes and tomato products found a decreased risk of CD with intake of these foods. In a multi-centre case-control study, with subjects recruited from 10 European countries, the relationship between antioxidant status and acute myocardial infarction was evaluated. Adipose tissue samples were taken from subjects directly after the infarction and analysed for various carotenoids. These were then compared with matched controls. After statistical adjustment for potentially confounding variables, the only carotenoid that showed a protective effect was lycopene (Kohlmeier et al. 1997). In a small intervention study, Argawal & Rao (1998) examined the effects of various forms of lycopene (tomato juice, spaghetti sauce and tomato oleoresin soft gel capsules) that were added to the diet of the 19 subjects for a period of one week each. All treatments resulted in higher levels of serum lycopene and significantly decreased LDL oxidation and serum lipid peroxidation, but had no effect upon cholesterol levels. In contrast with the latter finding, a study investigating cholesterol metabolism using cell culture and a small clinical trial found that, firstly, incubation of human macrophage cells with lycopene inhibited cholesterol synthesis and augmented macrophage LDL receptors and that, secondly, dietary supplementation of 60 mg lycopene daily in six males over the course of three months resulted in a 14% reduction in plasma LDL cholesterol levels (Elinder et al. 1995). In a study comparing Lithuanian and Swedish men from populations with differing mortality rates from coronary artery disease, it was also found that lower blood lycopene levels were associated with a higher risk of both developing and dying from the disease (Kristenson et al. 1997). The findings of a Finnish study (Rissanen et al. 2003) found greater thickening of the wall of the common carotid artery in men with lower serum lycopene concentrations than in men with higher than median lycopene plasma, although the difference for women was not significant. A second study, by the same group, found that men in the lowest quartile of serum levels of lycopene had a 3.3 fold higher risk of an acute coronary event or stroke than the others.

4.5 *AIDS*

Many studies have observed reduced levels of micronutrients in HIV patients, despite dietary intakes that would normally be considered adequate. Lower concentrations of serum lycopene were recorded in HIV-positive women (Coodley et al. 1995), and children (Periquet et al. 1995). It has been postulated that this may result from the problem of lipid malabsorption, a common feature of progressive HIV disease (Clinton 1998).

4.6 *Diabetes*

Type 2 diabetes, in which the body is unable to utilise insulin, is another chronic disease associated with the oxidation of LDL. It is a disease in which, amongst other health outcomes, there is frequently an increased risk of CD. It has been found *in vitro* that high levels of glucose, as present in Type 2 diabetes, increase LDL oxidation (Bierman 1991) and that glycated LDL is particularly prone to oxidation (Semenkovich & Heinecke 1997). Also, diabetic subjects have increased levels of small, dense, LDL which is more readily oxidised than larger LDL (Semenkovich & Heinecke 1997), as well as elevated levels of certain biological markers that suggest stimulation of the inflammatory activity that increases the risk of coronary events (Libby & Ridker 1999). Data analysed from the Third National and Nutrition Examination Survey in the United States found significantly lower levels of lycopene in subjects with impaired glucose tolerance and levels that were lower again in newly diagnosed diabetic patients than in controls with normal glucose tolerance (Ford et al. 1999). Similarly, diabetic Asian Indian physicians living in the USA were found to have lower levels of lycopene than non-diabetic counterparts (Chuang et al. 1998), as did elderly Type 2 subjects in an Italian study (Polidori et al. 2000). In a recent New Zealand clinical trial, involving supplementation with two cups of tomato juice daily in a group of Type 2 diabetic patients, it was found that plasma levels of lycopene markedly increased and that the resistance of localised LDL to oxidation also increased (Upritchard et al. 2000).

4.7 *Eye disease*

Some carotenoids, such as lutein and zeaxanthin, are well known to play an important role in eye health (Meltzer & Kravets 1998). Less is known about the potential role of lycopene. High concentrations have been reported in certain parts of the eye (ciliary body and retinal pigment epithelium) and so may have some function in protecting against age-related macular degeneration (AMD) and other eye diseases (Khachik et al. 2002). In a population-based, case-controlled study regarding the relationship of AMD and carotenoid levels it was found that individuals with low serum levels of lycopene were twice as likely to have AMD as those with higher serum levels (Mares-Perlman et al. 1995). An Australian study, however, found no evidence of protective effects of lycopene and other antioxidants on the early (within five years) age-related maculopathy (Flood et al. 2002).

A study with rats showed lycopene to have an inhibitory effect on cataract development (Pollack et al. 1996). Lycopene has also been shown to offer protection against galactose-induced cataract changes in lens tissue (Trivedi et al. 2001a) and be protective against selenite-induced stress (Trivedi et al. 2001b).

5 *The role of other tomato components in human health*

There has been less specific study of the importance of other tomato components on human health, although the groups of compounds themselves have been studied.

5.1 *Other carotenoids*

Although the above studies have largely focused on lycopene, other carotenoids in tomatoes are likely to contribute to their health benefits. Other carotenoids may have similar effects to lycopene, although some health benefits do seem to be specific to lycopene. Lycopene does have stronger antioxidant activity than many other carotenoids, such as β -carotene (Di Mascio et al. 1989). However, some other carotenoids play important physiological functions that lycopene does not. Those carotenoids with at least one unsubstituted β -ring and an unchanged side chain (e.g. β -carotene, α -carotene, cryptoxanthin, γ -carotene) may be converted to vitamin A in the body. Such carotenoids are referred to as having provitamin A activity. Because lycopene does not have the ring structure it cannot be converted to vitamin A.

As with lycopene, most other carotenoids are being considered as potential cancer prevention agents, although there have been mixed results in trials. Studies of β -carotene indicate that its benefits may only occur when it is derived from food and not when it originates from a supplement form. β -Carotene has been used as a so-called oral sun protectant due to its antioxidant properties, and its efficacy has been shown in human studies (Stahl et al. 2000). However, these studies were not with tomatoes. It is unlikely that the level of β -carotene in tomatoes is high enough, alone, to offer this level of protection.

Another group of carotenoids, the xanthophylls (e.g. lutein and zeaxanthin), have specific distribution patterns in human tissue, especially in the retina of the eye (Zaripheh & Erdman 2002). These carotenoids are thought to be important for normal eye function and play a role in the prevention of various eye diseases, including macular degeneration, glaucoma and cataracts (Head 1999, 2001).

5.2 *Phenolic compounds*

The considerable diversity of the structure of phenolics makes them different from other antioxidants. Several thousands of natural polyphenols have been identified in plants, many of them in plant foods (Shahidi & Naczk 1995), although only a more limited number are at significant levels in most human diets. The chemical structure of polyphenols affects their biological properties: bioavailability, antioxidant activity, specific interactions with cell receptors and enzymes, and other properties. There has been little specific study of the role that tomato flavonoids, and other phenolics, may play in human health. However, this group of compounds has received considerable attention, in general, but particularly those compounds in red wine, tea, chocolate and onions.

Phenolic compounds, because of their structure, are very efficient scavengers of free radicals and they also serve as metal chelators (Shahidi & Naczk 1995). In addition to their antioxidant characteristics, other potential health-promoting bioactivities of the flavonoids include anti-allergic, anti-inflammatory, anti-microbial and anti-cancer properties (Cody et al. 1986; Harbourne 1993). There are many ways in which flavonoids may act to prevent cancer, including inducing detoxification enzymes, inhibiting cancer cell proliferation and promoting cell differentiation (Kalt 2001). Some flavonoids are also beneficial against heart disease because they inhibit blood platelet aggregation and provide antioxidant protection to LDL (Frankel et al. 1993). Studies on the health benefits of the phenolic acids to date have largely focused on their antioxidant activity.

5.3 *Other*

Research at the Rowett Research Institute in Scotland has identified a component in the yellow jelly around tomato seeds that, it is proposed, stops platelet cells in the blood from clumping together (Dutta-Roy et al. 2001). The aggregation of platelets triggers the cascade of reactions leading to blood clot formation (thrombosis). Heart attacks, strokes and blood vessel problems resulting from thrombosis currently kill or disable more people in developed countries than any other disease. In tests on volunteers, the compound (codenamed P3) from as few as four tomatoes reduced platelet activity by up to 72%. Larger scale studies are necessary to confirm these results but, if successful, P3 could represent a benefit over existing anti-platelet therapy, such as aspirin, which may have side effects such as stomach upsets and bleeding (Dutta-Roy et al. 2001). A Japanese study in 2003 tested various tomato cultivars in relation to anti-thrombotic effects using both *in vitro* and *in vivo* (rat model) methods. One variety showed not only significant anti-thrombotic activity with both methods, but also inhibited thrombus formation as well as having a thrombolytic effect (Yamamoto et al. 2003).

6 *Bioavailability of tomato phytochemicals*

6.1 *Lycopene*

A correlation between seven-day food diary lycopene intake and plasma lycopene has been noted (Forman et al. 1993). In contrast it has been found that there is no correlation between plasma lycopene and high fruit and vegetable intake (Campbell et al. 1994). This may be because lycopene only comes from one major food source (tomatoes and tomato products) and a high fruit and vegetable intake may not imply a high lycopene (tomato) intake. It has been shown that plasma lycopene can be increased in a relatively short time by increasing the dietary intake of this carotenoid (Johnson 1998).

It has been demonstrated that dietary lycopene is absorbed and distributed in humans. Its bioavailability depends on various factors such as food processing and co-ingestion of fat (Sies & Stahl 1999). Since lycopene is a fat-soluble compound, it follows the same intestinal absorption path as dietary fat. Absorption is influenced by the same factors that influence fat absorption. Thus, the absence of bile or any generalised malfunction of the lipid absorption system will interfere with the absorption of lycopene.

Lycopene is released from food matrices and solubilised in the gut. This is done in the presence of fat and conjugated bile acids. The efficiency of release is influenced by such factors as disposition of lycopene in the food matrix, particle size after mastication and stomach action, and the efficiency of digestive enzymes (Johnson 1998). Heating of plant foods before ingestion improves the bioavailability of lycopene, partly because protein-carotenoid complexes are weakened (Stahl & Sies 1992).

After absorption into the intestinal mucosa, lycopene is transported in the plasma exclusively by lipoproteins (Johnson 1998). Lycopene appears first in the very low density lipoprotein (VLDL) and chylomicron fractions of plasma and later in low density lipoprotein (LDL) and high density lipoprotein (HDL), with highest concentrations in the LDL (Krinsky et al. 1958). The distribution of lycopene among lipoproteins is similar to β -carotene and similar between men and women (Forman et al. 1998; Reddy et al. 1989). Serum concentrations can vary substantially (50 to 900 nM), both within the individual and between individuals (Bramley 2000). It is hydrophobic and is, therefore, generally located within cell membranes. Although lycopene is found in most human tissues, it is not distributed evenly, with substantially larger amounts found in the adrenals and testes (Table 10).

Table 10: Lycopene levels in human tissues (Bramley 2000 - data taken from Schmitz et al. 1991; Stahl et al. 1992; Clinton et al. 1996).

Tissue	Lycopene (nmol/g wet weight)
Adipose	0.2-1.3
Adrenal	1.9-21.6
Brainstem	nd ^a
Breast	0.8
Colon	0.3
Liver	1.3-5.7
Lung	0.2-0.6
Ovary	0.3
Prostate	0.8
Skin	0.4
Stomach	0.2
Testis	4.3-21.4

^a Not detected.

Cis-isomers of lycopene make up >50% of the total lycopene in human serum and tissues (Stahl et al. 1992; Clinton et al. 1996). This is in contrast to the food sources from which they originate; in tomatoes and tomato-based food products all *trans*-lycopene comprises 79-91% of total lycopene (Clinton et al. 1996). Stahl & Sies (1992) studied the uptake of lycopene and its geometrical isomers from heat-processed and unprocessed tomato juice in humans. Lycopene concentrations in human serum increased only when processed tomato juice was consumed. Lycopene uptake varied with individuals, but peak serum concentrations were always reached between 24 and 48 hours. The carotenoid was eliminated from serum with a half-life of two to three days. The increase in peak serum concentrations was dose-dependent but not linear with the dose. Repeated doses led to a continual rise of lycopene in human serum. Of the different geometrical isomers (all-*trans*, 9-*cis* and 13-*cis*), the *cis*-isomers seemed to be somewhat better absorbed than the all-*trans* form. More detailed studies with ferrets have shown that the *cis*-isomers of lycopene are more bioavailable than *trans*-lycopene, probably because they are more soluble in bile acid micelles and may be preferentially incorporated into chylomicrons (Boileau et al. 1999).

In addition to examining the effect of heat treatment, van het Hof et al. (2000) looked at the effects of the degree of homogenisation on the bioavailability of lycopene. Both additional heat treatment (one hour at 100°C, compared to just heating before serving) and homogenisation increased carotenoid (lycopene and β -carotene) bioavailability from tomatoes (canned, so already had heat treatment during manufacture), although the effect of additional heating was not always significant. Disruption of the tomato matrix also enhanced the ease with which carotenoids could be extracted from the

tomatoes. Homogenisation and heat treatment disrupt cell membranes, enhancing extractability, and heat treatment has also been suggested to disrupt further the protein-carotenoid complexes. Homogenisation under high pressure was more effective in increasing carotenoid bioavailability than homogenisation under normal pressure. Thus, the release of carotenoids from cells is a limiting factor in bioavailability.

The bioavailability of lycopene from fresh tomatoes versus tomato paste was compared in human volunteers (Gärtner et al. 1997). The lycopene intake from both the fresh tomatoes or the tomato paste was 23 mg and the meals were ingested together with 15 g of corn oil. The lycopene isomer pattern was the same in both cases. Ingestion of tomato paste yielded much higher peak concentrations and under the curve responses for all-*trans* lycopene and its *cis*-isomers. No difference was observed for the α - and β -carotene response. Porrini et al. (1998) also reported that lycopene from tomato puree (16.5 mg/day) resulted in significantly higher plasma concentrations than fresh tomatoes. Thus, in humans the bioavailability of lycopene is higher from processed tomato products than fresh tomatoes, independent of the doses.

Lycopene serum concentrations increased significantly after ingestion of 39-75 mg/day lycopene from spaghetti sauce, tomato juice and lycopene capsules (Rock & Swendseid 1992). This study did not indicate any significant differences in absorption between the differing food matrices. Lycopene absorption from supplements (oleoresin capsules) and from processed tomato products were comparable (Bohm & Bitsch 1999).

It has further been noted that absorption of carotenoids, including lycopene, is improved when consumed in conjunction with dietary lipids (Bohm & Bitsch 1999). It has been proposed that high-dose intake of a particular carotenoid may antagonise the bioavailability and absorption of other carotenoids. However, one study found that ingestion of a combined dose of β -carotene and lycopene had little effect on the absorption of β -carotene but improved that of lycopene (Johnson et al. 1997). A recent study investigated possible interactions between the transport of β -carotene and lycopene and found that they may compete for the same transport mechanism (Gaziano et al. 1995). When extremely high doses of β -carotene were fed to humans compared to the magnitude of β -carotene uptake into LDL, the concentration of lycopene in LDL reduced. However, the doses fed were well beyond those achieved in a healthy diet.

There are a range of physiologic factors that influence plasma concentrations of carotenoids. For example, for β -carotene plasma concentrations are higher in women than men, although for lycopene there appears to be no sex difference in its absorption or utilisation. Increasing age has been found to be inversely related to plasma lycopene (Brady et al. 1996). One explanation for this observation is that younger individuals consume more of some lycopene-rich foods such as pizza and ketchup. However, it would appear to only partially explain the difference (Johnson 1998). Smoking is well known to decrease plasma β -carotene levels but lycopene seems to be affected to a lesser extent (Johnson 1998). Alcohol intake appears not to affect plasma lycopene levels (LeCompte et al. 1994; Forman et al. 1995).

A lycopene formulation where lycopene was entrapped with whey proteins (named “lactolycopene”) was shown to be as bioavailable as lycopene from processed tomatoes (Richelle et al. 2002).

6.2 Other carotenoids

The bioavailability of some other carotenoids, especially β -carotene, has been well demonstrated from a variety of fruit, vegetable and supplement sources (Castenmiller & West 1998; van het Hof et al. 2000; Yeum & Russell 2002; Zaripheh & Erdman 2002). As noted with lycopene, various dietary factors have an effect on the bioavailability of carotenoids (Table 11). The type of food matrix in which carotenoids are located is a major factor. The bioavailability of β -carotene from vegetables in particular has been shown to be low (14% from mixed vegetables) compared to when purified β -carotene is added to a simple matrix (e.g. salad dressing), whereas for lutein, the difference is much smaller (relative bioavailability of 67% from mixed vegetables). Processing, such as mechanical homogenisation or heat treatment, has the potential to enhance the bioavailability of carotenoids from vegetables (from 18 to nearly 120%). The amount of dietary fat required to ensure carotenoid absorption is moderate (~3–5 g per meal), although it depends on the physicochemical characteristics of the carotenoids ingested, but the presence of fat is important. Unabsorbable, fat-soluble compounds reduce carotenoid absorption, and interaction among carotenoids may also result in a reduced carotenoid bioavailability.

Table 11: Estimation of the quantitative effects of various dietary factors on the bioavailability of carotenoids^a (from van het Hof et al. 2000).

Dietary factor	<i>n</i> ^b	Carotenoid		
		β-Carotene	Lutein	Lycopene
Matrix type (carotenoids in oil = 1.0)				
Mixed vegetables	10–22	0.14 ± 0.011	0.67 ± 0.08	na ^c
Green leafy vegetables	56–62	0.04	na ^c	na ^c
Whole-leaf spinach	10–12	0.04	0.45	na ^c
Whole-leaf spinach	26–67	0.03 ± 0.5	na ^c	na ^c
Carrots	7–15	0.19	na ^c	na ^c
Carrots	5	0.19	na ^c	na ^c
Carrots	12–13	0.26	na ^c	na ^c
Broccoli	5	0.22	na ^c	na ^c
Broccoli	26–67	0.74 ± 0.64	na ^c	na ^c
Green peas	26–67	0.96 ± 0.71	na ^c	na ^c
Matrix disruption (undisrupted vegetables = 1.0)				
Chopped v. whole-leaf spinach	26	1.0	1.18	na ^c
Liquefied v. whole-leaf spinach	12	1.69	1.0	na ^c
Homogenized v. whole carrots	13	[1.7] ^d	na ^c	na ^c
Homogenized v. whole carrots	7–10	5.9	na ^c	na ^c

Dietary factor	n ^b	Carotenoid		
		β-Carotene	Lutein	Lycopene
Tomato paste v. raw tomatoes	5	na ^c	na ^c	na ^c
Tomato paste v. raw tomatoes	9	na ^c	na ^c	1.2–1.5
Homogenized and heated v. raw carrots and spinach	8	3.1	na ^c	na ^c
Amount of dietary fat (high amount of fat = 1.0)				
0 g fat v. 5 g fat present in carotenoid-supplemented meal	22–26	0.48 ^f	na ^c	na ^c
0 g fat v. 10 g fat present in carotenoid-supplemented meal	22–26	0.48 ^g	na ^c	na ^c
5 g fat v. 10 g fat present in carotenoid-supplemented meal	22	1.0	na ^c	na ^c
3 g fat v. 18 g fat present in meal containing sweet potatoes	41–43	0.63 ^f	na ^c	na ^c
3 g fat v. 36 g fat present in carotenoid-supplemented meal	15	1.0	0.43 ± 0.062 ^g	na ^c
Indigestible fat-soluble compounds (regular dietary fat = 1.0)				
3 g/d sucrose polyester v. regular dietary fat with main meal	26–27	0.80 ± 0.03	na ^c	0.62 ± 0.05
12.4 g/d sucrose polyester v. regular dietary fat with main meal	21	0.66 ± 0.02	0.80 ± 0.04	0.48 ± 0.05
18 g/d sucrose polyester v. regular dietary fat at v.arious times during day	65–67	0.73	0.81	0.77
Dietary fibre (no dietary fibre = 1.0)				
12 g/d citrus pectin added to carotenoid-supplemented meal	7	0.42	na	na
Beet root fibre added to liquefied spinach	12	1.0	1.0	na

^a Values are presented as means ± SEM or as mean. The factors were calculated from changes in plasma or serum concentrations of carotenoids, unless otherwise stated. The plasma or serum carotenoid response after the treatment stated was divided by the plasma or serum carotenoid response after the treatment, which was taken as a reference at 1.0 (identified between brackets for each dietary factor), and corrected if necessary for differences in carotenoid intake. In case no change was expected from the reference treatment (e.g. in case of indigestible v. regular fat), the factors were calculated as the percentage of change from baseline, corrected if necessary for the change in the control group. A factor <1.0 indicates that the bioavailability of carotenoids is reduced compared with the reference chosen; a factor >1.0 indicates an enhanced carotenoid bioavailability.

^b Number of subjects per treatment.

^c Not assessed.

^d Value is not significantly different from 1.0 (α= 0.05).

^e Calculated from area under the curve of the carotenoid response in triglyceride-rich lipoproteins.

^f Calculated from changes in serum concentrations of retinol.

^g Lutein was present as lutein esters.

There are few xanthophylls (e.g. lutein) in tomatoes but they are an important group of carotenoids. The xanthophylls, lutein and zeaxanthin, have specific distribution patterns in human tissue, especially in the retina of the eye (Zaripheh & Erdman 2002). The presence of these xanthophylls is thought to provide protection from macular degeneration. Like other carotenoids, environmental factors, food processing, food matrix, structural differences and the interaction among other food components all have an effect on their efficiency of uptake and absorption. From the limited human studies described in the literature, lutein appears to be more bioavailable from food sources than does β -carotene (Zaripheh & Erdman 2002). The disruption of the food matrix seems to improve β -carotene's bioavailability more than that of lutein. There is no evidence that a negative interaction between carotenoids occurs when foods are ingesting. However, interactions do occur between xanthophylls and carotenes when supplements are consumed. Several studies found that when they were consumed simultaneously, β -carotene reduced lutein bioavailability. With the broad consumption of lutein supplements from marigold flowers, some of which are high in lutein diesters, the question of lutein diester bioavailability arises. More dietary fat seems to be required for efficient absorption of lutein from lutein diester sources.

Despite these studies there are limited data on the bioavailability of carotenoids other than lycopene from tomatoes. Studies examining the bioavailability of lycopene have also demonstrated that β -carotene, and some other carotenoids, from tomatoes are bioavailable (Richelle et al. 2002; van het Hof et al. 2000), although these data are quite limited. Phytofluene has been shown to be better absorbed than lycopene from tomatoes (Richelle et al. 2002).

6.3 *Phenolics*

There have been various studies of the bioavailability of different phenolics (reviews by Rice-Evans et al. 2000; Ross & Kasum 2002; Scalbert & Williamson 2000). Phenolic acids account for about one-third of the total dietary phenols and flavonoids account for the remaining two-thirds (Scalbert & Williamson 2000). A total intake of polyphenolics of ~1 g/d was suggested over 25 years ago (Kühnau 1976). However, large uncertainties in the polyphenol intake and in the variations of intake remain. Comprehensive surveys on the content of some important polyphenol classes (e.g. anthocyanins, proanthocyanidins, phenolic acids) are still lacking. The intestinal absorption of polyphenols can be high, but differs markedly between the different groups (Table 12). Some flavonol glycosides are better absorbed than their aglycones, but very little is known about the influence of other structural parameters. However, the plasma concentration of any individual molecule rarely exceeds 1 μ M after the consumption of 10–100 mg of a single compound. Measurement of the plasma antioxidant capacity suggests that more phenolic compounds are present, largely in the form of unknown metabolites, produced either in our tissues or by the colonic microflora. Further research is required in this area.

Table 12: Bioavailability in humans of polyphenols consumed alone or in foods^a (taken from Scalbert & Williamson 2000).

Polyphenol	Source	Quantity of polyphenol ingested (mg)	Maximum concentration in plasma (µM)	Excretion in urine (%)
Phenolic acids				
Caffeic acid		1000		27
Flavonols				
Quercetin	Onion	68	0.74	1.39
Quercetin	Apple	98	0.30	0.44
Quercetin-4-O-rhamnogluco- side	Pure compound	202	0.30	0.35
Quercetin-4-O-glucoside	Pure compound	144	3.2	
Quercetin	Onion	139	1.34	0.8
Quercetin	Mixed black currant and apple juice, 1000 ml/d for 7 d	6.4		0.5
Catechins				
Epigallocatechin gallate	Green tea infusion, 1.2 g	88	0.33	nd ^b
Epigallocatechin		82	0.67	3.6
Epicatechin gallate		33	nd ^b	nd ^b
Epicatechin		32	0.27	6.2
Epigallocatechin gallate	Green tea infusion, 5 g	105	0.13–0.31	
Epigallocatechin gallate	Green tea infusion, 6 g		5.0	
Epigallocatechin gallate	Green tea extract	525	4.4	
Catechin	Red wine, 120 ml	34	0.072	
Catechin	Pure compound	500	2.0	0.45
Isoflavones				
Genistein	Soy milk	19	0.74	19.8
Daidzein		25	0.79	5.3
Genistein	Soy proteins, 60 g/d for 1 mo	20		9.2
Daidzein		25		2.5
Genistein	Soy proteins, 60 g/d for 28 d	80	0.50	
Daidzein		36	0.91	
Genistein	Soy proteins, 20 g/d for 9 d	23		8.7
Daidzein		13		26
Flavanones				
Naringin	Grapefruit juice, 120 m	43	<4	8.8
Naringin	Grapefruit and orange juice, 1250 ml each	689		6.8
Hesperidin		89		24.4
Naringin	Pure compounds	500		4.9
Hesperidin		500		3.0
Anthocyanins				
Anthocyanins	Red wine, 300 ml	218		1.0–6.7

^a Polyphenols, principally in the form of conjugated metabolites, as sulfate esters or glucuronides, in plasma and urine, were hydrolysed by acid or enzymes before chromatographic or colorimetric analysis.

^b Not detected.

Only one study was found that looked specifically at the bioavailability of tomato phenolics. Naringenin from cooked tomato paste has been shown to be bioavailable in men (Bugianesi et al. 2002). Although rutin and chlorogenic acid were detected in the tomato paste used in this study they were not detected in plasma after tomato paste consumption. The levels of many of the phenolics in tomato may not be sufficiently high enough to be picked up in plasma in bioavailability studies using current methodology. Although there has only been one specific study on the bioavailability of phenolics from tomatoes, some of the compounds present have been shown to be bioavailable from other foods. Rutin has been shown to be bioavailable, although less so than some other quercetin glycosides or the aglycone (Erlund et al. 2001; Graefe et al. 2001). In one study examining quercetin and rutin, they were found in plasma as glucuronides and/or sulfates of quercetin and as unconjugated quercetin aglycone, but no unchanged rutin was detected (Erlund et al. 2000). Other studies on the bioavailability of phenolic acids have demonstrated that coumaric acid, from coffee and blackcurrant juice, was bioavailable (Nardini et al. 2002; Rechner et al. 2002). However, for coffee although chlorogenic acid was present in high amounts it was not detected in plasma (Nardini et al. 2002). It is possible that it is metabolised to other compounds, which may or may not have biological activity.

7 *Tomato/lycopene consumption and major disease patterns*

As discussed earlier, epidemiologic studies (also called observational or population studies) look at disease patterns to see if certain diseases are more common in some groups of people than others. By examining these data together with dietary information, patterns can be identified as to the influence of protective components from the diet. Table 13 shows the incidence of certain diseases in New Zealand populations compared to some other selected countries.

Not surprisingly, there is no official recommended daily intake for tomatoes or tomato products or their constituent compounds. More research is needed to identify the active compounds and establish the full health benefits derived from tomatoes. Researchers to date, who have largely been concerned with investigating the benefits of lycopene and have considered optimum intake levels, vary somewhat in what they consider to be necessary to have an efficacious effect. After considering results from the Health Professionals Follow-Up Study, Giovannucci suggests that two to four servings of tomato sauce per week (not ketchup) reduce the risk of prostate cancer by one-third to one-half (Giovannucci et al. 1995; Giovannucci 2003). Yeung and Rao in their book, 'Unlock the power of lycopene', recommend at least one serving of processed tomato daily. Other researchers mention a recommended intake of 35 mg of lycopene daily (Rao & Agarwal 2000), but this may be rather high. Roughly estimated, this amount could be obtained, for example, from two glasses of tomato juice (500 ml) or through a combination of tomatoes and tomato products (e.g. pasta sauce, fresh tomatoes).

Carotenoid intake has been estimated from food frequency questionnaires. In Great Britain the daily consumption of lycopene-rich food was equivalent to a lycopene intake of about 1.1 mg per day (Scott et al. 1996). In a study from the United States a daily intake of about 3.7 mg per day was reported (Forman et al. 1993). However, another study (Rao & Agarwal 1998) estimated it to be 25 mg/day, with processed tomato products accounting for 50% of the total intake (Table 14). This figure seems incredibly high and unlikely to be achieved by many people. Even Mediterranean diets may not achieve these levels. No such specific data have been reported for New Zealand and Australian populations.

Table 13: Prostate cancer incidence and mortality and mortalities from major cardiovascular diseases in some Mediterranean and non-Mediterranean countries.

Disease rates per 100 000	NZ	USA	Italy	Spain	Greece	UK
Prostate cancer cases (age standardised) ¹	139.1	104.3	24.9	24.2	20.2	40.2
Prostate cancer mortalities (age standardised) ¹	21.2	17.9	12.1	15.0	10.7	18.5
Diseases of circulatory system mortalities ²	343.6	362.0	302.9	272.5	382.5	363.8
Ischaemic heart disease mortalities ²	199.9	181.1	103.3	90.9	117.7	209.6
Acute myocardial infarction mortalities ²	98.4	84.9	54.6	62.2	88.6	114.3
Cerebrovascular disease mortalities ²	68.9	55.7	80.4	73.4	127.0	81.0

Sources of data:

1. Globocan 2000 estimates Figures age standardised according to Segi's world population.
 2. Global Cardiovascular Infobase 1997 age standardised death rates are generated using the world standard population based on J. Waterhouse et al. (ed). Cancer incidence in five continents, Lyon, IARC, 1976 (Vol. 3, pl 456), as used by WHO.
- Age-standardised data: An age-standardised rate (ASR) is a summary measure of a rate that a population would have if it had a standard age structure. Standardisation is necessary when comparing several populations that differ with respect to age because age has such a powerful influence on the risk of cancer. The most frequently used standard population is the World standard population. The calculated incidence or mortality rate is then called World Standardised incidence or mortality rate. It is also expressed per 100 000 (from Globocan).

Table 14: Estimates of daily intake of lycopene from tomatoes and tomato products, as determined from a food-frequency questionnaire (from Rao et al. 1998).

Product	Serving size	Lycopene intake (mg/d per subject)	% of total daily lycopene intake
Tomatoes	200 g	12.70	50.5
Tomato puree	60 ml	1.02	4.1
Tomato paste	30 ml	2.29	9.1
Tomato sauce	227 ml	1.52	6.0
Spaghetti sauce	125 ml	2.44	9.7
Pizza sauce	60 ml	0.66	2.6
Chilli sauce	30 ml	0.30	1.2
Tomato ketchup	15 ml	0.53	2.1
Barbecue sauce	30 ml	0.06	0.2
Tomato juice	250 ml	2.20	8.7
Tomato soup	227 ml	0.79	3.1
Clam cocktail	250 ml	0.50	2.0
Bloody Mary mix	156 ml	0.15	0.6
Total		25.16	

8 *Factors affecting phytochemical levels in tomatoes and tomato products*

8.1 *Lycopene and other carotenoids*

The levels of lycopene in tomatoes and tomato products vary considerably, as seen in Table 4 (Section 3.2). There is variation between variety (which may also be related to shapes, size and colour), degree of ripeness at harvest, method of production, growing conditions, and extent of processing. Unfortunately there are only a few studies relating particularly to New Zealand varieties and growing conditions.

8.1.1 *Cultivar*

A number of researchers have shown that significant differences in lycopene content occur between cultivars (Saini & Singh 1994; Hart & Scott 1995; Chen et al. 2000; Molyneux 2001; Toor & Savage 2005; Kerkhofs 2003), the latter three studies being New Zealand-based. Abushita et al. (2000) have examined the variation in carotenoid levels in tomato cultivars grown on a commercial scale (Table 14). As already discussed, since lycopene is related to the redness of the tomato, some cultivars, such as the yellow cultivars and

'extended shelf life' cultivars (with slow ripening characteristics, bred for the fresh tomato market), contain minimal amounts of lycopene. It has also been noted that cultivars with smaller fruits, such as the cherry tomatoes, appear to have higher concentrations of antioxidants than larger tomatoes (Leonardi et al. 2000; Raffo et al. 2002). Orlowski et al. (2001) noted that in addition to the high lycopene levels in the three cherry-type cultivars they studied, vitamin C content was also high. It has been hypothesised that this is due to the fact that they possess a larger surface area to weight ratio, which is important as lycopene reportedly concentrates in the pulp close to the skin of the fruit.

A wild relative of the domestic tomato, *Lycopersicon pimpinellifolium*, produces tiny, currant-like fruit that are said to contain 40 times more lycopene than regular tomatoes (Cox 2000) and is therefore a prime candidate for use in the breeding of new hybrids. Researchers have also isolated a crimson gene and found higher lycopene content in varieties carrying this gene than in those without it (Thompson et al. 2000). A new, conventionally bred tomato, Health Kick, is being advertised as possessing "50% more lycopene compared to common tomato varieties" (www.seminisgarden.com). A genetically modified cultivar, purportedly containing twice the lycopene level of conventional cultivars, was reported by Manzano (2001). Gomez et al. (2001) grew 15 different cultivars (standard red type) under the same conditions and fruit harvested at optimum ripeness had lycopene levels that varied from 5.04 to 13.46 mg/100 g FW.

Table 14: Carotenoid content of different tomato cultivars grown on a commercial scale (adapted from Abushita et al. 2000).

Cultivar	Carotenoids (mg/100 g FW)					Total carotenoids
	Lutein	Lycopene epoxide	Lycopene	cis-Lycopene	β-Carotene	
Amico	0.145	0.215	7.726	0.133	0.447	9.036
Casper	0.115	0.154	6.614	0.096	0.245	7.786
Gobe	0.143	0.116	5.918	0.127	0.402	7.150
Ispana	0.123	0.182	6.222	0.100	0.317	7.525
Pollux	0.348	0.148	5.140	0.097	0.210	6.799
?Soprano	0.429	0.361	8.646	0.107	0.321	11.026
Tenger	0.103	0.152	7.656	0.114	0.228	8.824
Uno	0.131	0.171	7.086	0.091	0.323	8.321
Zephyre	0.303	0.173	6.950	0.113	0.375	8.907
Draco	0.076	0.208	6.868	0.090	0.291	8.191
Jovanna	0.138	0.282	11.606	0.082	0.339	13.205
K-541	0.118	0.256	9.954	0.092	0.283	11.248
Nivo	0.116	0.231	8.456	0.133	0.260	9.722
Simeone	0.361	0.200	9.879	0.103	0.296	11.882
Sixtina	0.332	0.249	10.510	0.111	0.318	12.521
Mean	0.199	0.207	7.949	0.106	0.310	9.476

8.1.2 *Growing conditions*

Using lycopene content quantified in studies of field-grown tomatoes (Abushita et al. 2000; Gomez et al. 2001; Takeola et al. 2001) and comparing data with those from studies of greenhouse-grown tomatoes, Leonardi et al. (2000) found tomatoes grown outdoors had a higher lycopene content than those grown indoors. This may of course be related to different cultivars. An old study found that β -carotene was lower in tomatoes grown under glass or plastic than in the open field. Similarly, lycopene was lowest in tomatoes grown under glass and highest in field-grown tomatoes (McCollum 1954). It is difficult to know which parameters caused these results, but they may include the level of intercepted light, and the high temperatures that occur under protected growth conditions (Dumas et al. 2003). In some cases tomatoes exposed to direct sunlight in the field may develop a poor colour because of exposure to too high temperatures. Temperatures above 35°C stop lycopene synthesis altogether, and temperatures below 12°C strongly inhibit this process. However, in tomatoes harvested for processing, lycopene levels have been shown to be enhanced by 5% at incubation temperatures of 30 and 34°C and by 33% at 37°C (Boothman et al. 1996). It has been postulated that high temperatures inhibit the accumulation of lycopene because they stimulate the conversion of lycopene to β -carotene. Best conditions appear to be sufficiently high temperatures. However, outdoor-grown tomatoes require good foliage cover to protect the fruit from direct exposure to the sun. It has been shown that at favourable temperatures (22-25°C) the rates of synthesis of lycopene and β -carotene can be increased by illuminating tomato plants during the ripening of the fruit (Dumas et al. 2003).

Arias et al. (2000) found that tomatoes ripened on the vine had one-third higher lycopene than those ripened off the vine. In a study comparing tomatoes grown in organic media with those grown in soil, Lacatus et al. (1995) found lower dry matter and acidity, but increased sugar and lycopene contents in the former. Looking at antioxidative activity in general, Leonardi et al. (2000) found that plants under salt stress produced fruit with significantly higher carotenoid levels than those irrigated with lower salinity water. It was postulated that this was due to the concentration of the phloem sap, since high salinity restricts water supply to the fruit via the phloem with the result being a higher concentration of soluble solids and dry matter (including carotenoids). Another study on tomatoes irrigated with water of varying salinity showed an increase in lycopene levels only up to a certain point (about 0.25%NaCl w/v) and a decrease after that (De Pascale et al. 2001). One Japanese study found that in pink and red-type cultivars soil water deficit increased the amount of lycopene per fresh weight in the outer pericarp region of the tomato, and either increased or decreased vitamin C content depending on the cultivar (Matsuzoe et al. 1998). However, another study showed that fruit lycopene content decreased in response to moisture stress (Naphade 1993). Further studies of the effects of water availability are needed before firm conclusions can be drawn.

Mineral nutrition also has an impact on carotenoid levels. Highest fruit lycopene levels have been achieved with lowest nitrogen (N) levels (Aziz 1968). N fertilisers have generally been thought to increase carotene concentrations in plants but there are few data to confirm this. In one study

tomatoes grown in pots did show an increase in fruit lycopene levels when the N supply was increased (Montagu & Goh 1990). For tomatoes to develop a good colour the N supply should be as low as possible without reducing the fruit yield (Dumas et al. 2003). In contrast, increasing phosphorus levels in tomatoes grown hydroponically (up to 100 mg/L) improved fruit colour and lycopene content (Saito & Kano 1970). Various studies have looked at the effect of potassium (K) on lycopene and other carotenoids and found it produced more evenly coloured fruit and higher lycopene levels (Trudel & Ozbun 1971; Winsor 1979). However, the levels used were very high and could not be achieved with modern agricultural practices (Dumas et al. 2003). In one study calcium was shown to significantly increase lycopene in tomatoes grown in pots, from 8.5 to 34 mg/100 g FW (Subbiah & Perumal 1990). However, lycopene was lowered in another (Paiva et al. 1998), although it has been suggested that this was due to a decrease in K absorption.

Some growth and development regulators (e.g. CPTA and/or ethephon) have also been shown to increase the carotenoid content of tomatoes (Dumas et al. 2003).

8.1.3 *Degree of ripeness and postharvest storage*

Since the conversion of chlorophyll to lycopene is part of the ripening process, it is not surprising that the highest levels of lycopene occur when the fruit is at its reddest and ripest. It is also important that the degree of maturity is determined if comparisons of lycopene content are made between cultivars. The increase in lycopene content during ripening for one cultivar is illustrated in Figure 11. It is interesting to note that lycopene content continues to increase markedly during a period of storage at 18°C. Similar patterns have been noted by other researchers with respect to other cultivars (Hayman 1999; Molyneux 2000). Various patterns of carotenoid accumulation have been reported. In a study in the open field, β -carotene increased steadily during ripening whereas lycopene showed a sharp increase at the 'breaker' stage (Cabibel & Ferry 1980). The lycopene content is regarded as a good index of maturation. In greenhouse-grown, vine-ripened tomatoes the lycopene and β -carotene concentrations showed a gradual, linear increase during the ripening process, whereas in postharvest-ripened fruit the lycopene and β -carotene levels followed an exponential trend (Giovanelli et al. 1999). The lycopene and β -carotene concentrations in postharvest-ripened tomatoes (12.5-13.0 and 1.2 mg/100 g FW respectively) were nearly twice as high as the vine-ripened tomatoes (7.5-8.0 and 0.5-0.7 mg/100 g FW respectively) that had the same colour index. Appropriate postharvest storage conditions can, therefore, increase the lycopene content of tomatoes (Dumas et al. 2003). Fruit bruising at the breaker stage can decrease carotenoids in the ripe fruit (Moretti et al. 1998).

Effects of stage of ripeness on fruit lycopene concentration of cherry tomato variety Favorita

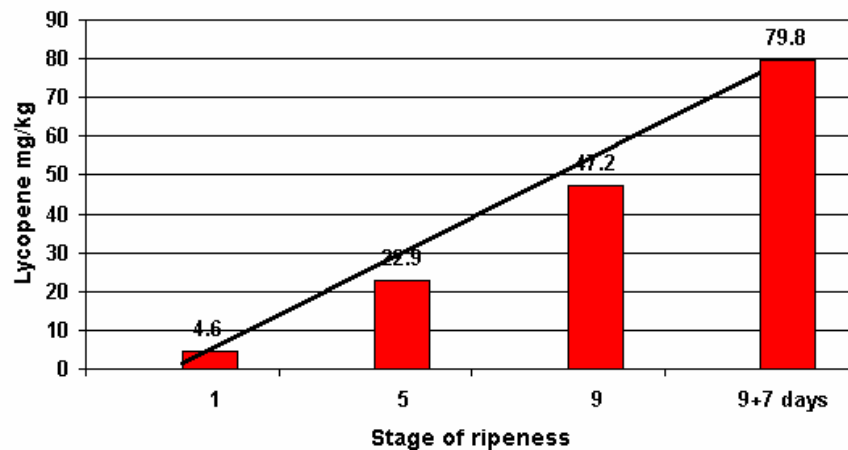


Figure 6: Changes in carotenoid levels during tomato fruit ripening (from www.britishtomatoes.co.uk). Stage of ripeness: 1 = first signs of colour change, sometimes referred to as "breaker" stage; 5 = half-ripe or orange; 9 = red; 9 + 7 days = colour stage 9 plus 7 days storage at room temperature (18°C).

8.1.4 Effects of cooking/processing

In the course of production, the availability of some nutrients may be enhanced, whilst quantities of others, such as the heat labile vitamin C, are lost. A number of factors affect the nutritional value of tomatoes, including storage conditions, method of processing, moisture, temperature and the presence of oxidants and lipids. Macrae et al. (1993) found that maximum ripening and colour development for tomatoes in storage occurred at between 20 and 24°C, with poor ripening at temperatures lower than 13°C.

The food matrix (i.e. the lipid and protein constituents of chromoplasts as well as the fibre contained within the tomato fruit) may contribute greatly to the stability of the all-*trans* form of lycopene in the fruit. This is supported by the observation that when tomatoes are heat processed only minor isomerisation is noted. Heat treatment improves the bioavailability of lycopene without significantly changing the *cis*-isomer composition of the heat-treated foods (Stahl & Sies 1992; Gärtner et al. 1997). Various types of dietary fibre have been shown to reduce the carotenoid bioavailability of some foods (Erdman et al. 1986).

The processing of tomatoes usually involves heat treatment and/or homogenisation. Tables 4 and 5 (see Section 3.2) and 15 give examples of lycopene concentration in some processed tomato products. These results reflect several different factors involved during processing.

Table 15: Change in the carotenoid content (mg/100 g DM) of tomato as a function of processing (adapted from Abushita et al. 2000).

Variety	Lutein	Lycopene epoxide	all-trans-Lycopene	Cis-Lycopene	all-trans- β -Carotene	cis-lycopene	Total carotenoids
Raw material	1.98	4.14	119.8	2.06	3.72	<0.10	143.0
Hot-break extract	1.85	3.70	122.0	2.55	3.85	0.39	131.9
Tomato paste	1.92	4.73	162.8	2.52	2.63	0.97	184.9

As already discussed in Section 6.1, processing appears to make lycopene more bioavailable (Stahl & Sies 1992; Gärtner et al. 1997). The health benefits resulting from isomerisation, however, are balanced to some extent by loss due to the same treatment that caused it. Table 24 gives the amount of lycopene lost from tomato juice over various temperatures and various heating times. It is evident that both temperature and the length of heating affect the extent of lycopene breakdown. It has also been reported that serious losses of lycopene can occur when the holding times at high temperatures are long (Shi & Le Maguer 2000). This process, however, was not observed by Nguyen & Schwarz (1999) who suggested that lycopene was relatively resistant to degradation, including by isomerisation, and Thompson et al. (2000) who found little difference in lycopene content between uncooked and samples cooked at 100°C, for 4, 8 and 16 minutes. Similarly Abushita et al. (2000) observed no change in lycopene concentration as fresh tomatoes were processed into paste.

Table 16: Loss rate in tomato juice during heating (from Shi & Le Maguer 2000).

Heating temperature (°C)	Lycopene loss (%)		
	Heating time 1 min	Heating time 3 min	Heating time 7 min
90	0.6	0.9	1.1
100	0.9	1.4	1.7
110	2.2	3.2	4.4
115	2.7	4.5	7.0
118	3.7	6.0	9.1
121	4.6	7.3	10.6
124	5.5	8.5	12.5
127	6.5	9.9	14.6
130	7.4	11.5	17.1

Shi & Le Maguer (2000) found that thermal processing in the forms of bleaching, retorting and freezing generally caused a loss of lycopene, due mainly to isomerisation and oxidation. However, once processed, frozen and heat sterilised foods exhibited excellent lycopene stability for the term of their normal shelf life. Takeoka et al. (2001) noted that the initial Brix level of the raw tomatoes appeared to influence the amount of lycopene that was lost during the processing of tomatoes into paste, but hypothesised that this could also have been the result of longer processing in order to obtain the desired Brix level. This study also found that overall antioxidant activity was greater with tomato paste than fresh tomatoes, but also found that in addition to the antioxidative effect of the lycopene present, there appeared to be significant antioxidant activity due to the polyphenols in the tomato.

There are varying reports on the presence of *cis*-isomers of lycopene. Nguyen & Schwartz (1998) showed only minor changes in their levels during a range of thermal treatments (Table 17). However, Schierle et al. (1996) did show some significant levels of *cis*-isomers in a range of tomato products (Table 18). The presence of other components or influence of factors may explain these effects rather than any thermal processing. Heat, light, acids and other factors have been reported to cause isomerisation (Schierle et al. 1996; Nguyen & Schwartz 1998; Shi et al. 1999). Swartz et al. (1999) have further investigated effects of thermal processing on isomerisation of lycopene and other tomato carotenoids. Upon thermal treatment β -carotene and lutein isomerise to a greater extent than δ -carotene, γ -carotene and lycopene. The presence of lipid was found not to influence the extent or likelihood of lycopene and other tomato carotenoids in the all-*trans* configuration to isomerise. Likewise the presence of different carotenoids did not influence the formation of lycopene *cis*-isomers.

Table 17: Lycopene isomers in various thermally processed tomato products (from Nguyen & Schwartz 1998).

Sample	Total lycopene (mg/100 g DW)	<i>Cis</i> -isomers (%)
Peeled tomato	149.89	5.37
Tomato juice (hot-break)	161.23	5.89
Tomato juice (retorted)	180.10	3.56
Tomato (whole, retorted)	183.49	3.67
Tomato paste (concentrated)	174.79	5.07
Tomato paste (retorted)	189.26	4.07
Tomato soup (retorted)	136.76	4.34
Tomato sauce (retorted)	73.33	5.13

Table 18: Lycopene isomers in commercial tomato products (data Schierle et al. 1996).

Sample	Total lycopene (mg/100 g FW)	All-trans (%)	5-cis (%)	9-cis (%)	13-cis (%)	Other cis (%)
Tomato paste (Tomatenmark, Panocchia, Italy)	52	96	4	<1	<1	<1
Tomato paste (Maracoli, Kraft, Germany)	3.7	91	5	1	2	<1
Tomato ketchup (Hot Ketchup, Del Monte, Italy)	9.5	88	7	2	3	1
Tomato ketchup (Hot Ketchup, Heinz, USA)	3.0	77	11	5	7	1
Instant meal (Eier-Ravioli, Hero, Switzerland)	0.6	76	8	5	6	5
Sauce (Hamberger Relish, Heinz, The Netherlands)	3.0	93	5	<1	3	<1
Sauce (Sauce Bolognaise, Barilla, Italy)	9.2	67	14	14	5	8
Canned tomatoes (Chris, Roger Sud, Italy)	7.1	84	5	5	5	3

Dewanto et al. (2002) showed that thermal processing elevated total antioxidant activity and bioaccessible lycopene content in tomatoes and produced no significant changes in the total phenolics and total flavonoid content, although loss of vitamin was observed (Table 19).

Table 19: Percent changes in selected antioxidants and antioxidant activity in processed tomatoes compared to unprocessed fruit (from Dewanto et al. 2002).

	Processing time at 88°C		
	2 min	15 min	30 min
Vitamin C	-10.2	-15.5	-29.4
Lycopene	54.4	171.1	164.3
Total antioxidant activity	28.1	33.9	62.2

8.2 *Phenolics*

8.2.1 *Raw tomatoes*

Factors affecting the levels of phenolics in vegetables have been studied by numerous researchers. Mineral nutrition can have a major influence on phenolic accumulation, and a limited nitrogen supply is typically associated with higher levels of phenolics in the plant (Parr & Bolwell 2000). Other environmental factors that can influence phenolic metabolism include ambient temperature. Lower temperature increases some phenolics, in particular the anthocyanins (although these are not present in tomatoes). Although many stresses tend to increase the levels of phenolics, water deficit usually tends to impair accumulation. One of the major environmental controls on phenolic production is light, where both photoperiod and light intensity can have an effect.

There have been limited studies specifically looking at tomatoes and the factors affecting the levels of phenolics in the fruit. Various researchers have noted significant differences in phenolic levels between cultivars (Stewart et al. 2000; Martinez-Valverde et al. 2002). However, Senter et al. (1988) found that the levels did not vary significantly in the three cultivars they tested. Interestingly Minoggio et al. (2003) found that almost all the tomato lines they tested with low carotenoid content produced high levels of phenolics, and consequently had the strongest antioxidant activity.

The most comprehensive study of factors affecting levels of phenolics in tomato was conducted by Stewart et al. (2000). Their main findings were:

- fruit size: greater skin/volume ratio enhances flavonol content,
- country of origin: tomatoes from Spain and South Africa contained higher levels of flavonols than UK fruits. Spanish tomatoes are usually field-grown whereas those from the UK are usually glasshouse-grown and therefore exposed to lower UV levels,
- effect of season: there was some fluctuation, but not dramatic. However, it was only examined in Spain,
- effect of cultivar: significant differences were observed even when cultivars were grown under same conditions.

In another study with cherry tomatoes, plants grown in greenhouses with high light had approximately a twofold higher content of soluble phenolics than plants grown in low light (Wilkens et al. 1996). In all parts of the tomato the phenolics tend to increase from the green stage to the mid-ripe stage before decreasing to original levels at the ripe stage (Senter et al. 1988). In other cultivars the highest quantities of phenolic acids were present in the pulp at the earliest stages of development and decreased during ripening (Buta & Spaulding 1997). A similar pattern was observed for rutin in the skin. Variations in phenolic content during vine and postharvest ripening were also investigated by Giovanelli et al. (1999). The total phenolic content was higher in postharvest-ripened fruit than in vine-ripened fruit.

Attempts have been made to increase the antioxidant level of tomatoes by modifying the flavonoid biosynthetic pathway (Bovy et al. 2002; Verhoeven et

al. 2002). In one case up to a 78-fold increase in total fruit flavonols was achieved (Verhoeyen et al. 2002). It was also possible to produce flavonoids in the tomato fruit flesh, a tissue that normally produces little or no flavonoids (Bovy et al. 2002).

8.2.2 Processing/cooking

There appears to have been little study of the effects of processing on the phenolic content of tomatoes. The flavonol content of some processed tomato products is shown in Table 20. In contrast to tomato fruit, which contain almost exclusively conjugated quercetin, up to 30% of the quercetin in processed products is in the free form (Stewart et al. 2000). Hydrolysis of flavonol conjugates during cooking of tomatoes was not noted in an earlier study by this research group (Crozier et al. 1997). Thus, it was hypothesised that the accumulation of free quercetin in juices, puree and paste may have been a consequence of enzymatic hydrolysis of rutin and other quercetin conjugates during pasteurisation and processing procedures. The concentration of flavonols in some tomato products is likely to depend on the extraction of flavonols from the skin during initial processing, which often involves heating. Low levels of flavonols in canned compared to fresh fruit could be due to boiling, as cooking in this manner results in up to an 80% loss of flavonols (Crozier et al. 1997), presumably by leaching from the skins. One study was found reporting that, of the flavonoids, naringenin was the main one affected (a reduction in concentration) during processing of tomatoes into sauce (Re et al. 2002).

Table 20: The flavonol content (mg/100 g FW or for juice and soup mg/100 ml) of selected tomato-based food products (adapted from Stewart et al. 2000).

Tomato product	Brand	Free quercetin	Free kaempferol	Conjugated quercetin	Conjugated kaempferol	Total flavonol	Free flavonol %
Fresh tomatoes ^a	-	0.01	0.02	0.77	0.05	0.85	3.4
Tomato soup	Safeway	0.03	Nd	0.12	nd	0.15	19.6
Tomato juice	Del Monte	0.29	0.04	1.15	0.04	1.52	21.6
	Libby's	0.35	0.04	1.27	0.03	1.69	22.9
Canned cherry tomatoes	Napolina	Nd	Nd	0.17	0.01	0.18	0
Canned plum tomatoes	Napolina	Nd	Nd	0.03	nd	0.04	0
Pasta sauce	Dolmio	0.12	Nd	0.79	0.01	0.92	12.6
Ketchup	Heinz	0.04	Nd	0.82	0.01	0.88	4.5
Puree	Casinop	0.38	0.06	3.25	0.02	3.71	11.9
	Masque D'or	0.54	Nd	1.09	0.03	1.66	32.5
	Safeway	0.95	Nd	6.14	0.13	7.22	13.2

^a Average of a number of cultivars.

8.3 *Vitamins*

Changes in antioxidant vitamins are probably less important than carotenoids or phenolics. Vitamin E is only present in very low amounts and there is little information on factors affecting its level in tomatoes. Variations in the vitamin E content amounting to about one to threefold (from 0.1 to 0.32 mg/100 g FW for α -tocopherol and from 0.12 to 0.40 mg/100 g FW for total tocopherols) have been observed in various Hungarian cultivars (Abushita et al. 1997).

Vitamin C is present in reasonable levels in the raw fruit but it is significantly affected by processing and so is comparatively low in processed products. Some authors have stated that the variations in vitamin C content due to cultivar are fairly small in comparison with those resulting from growth conditions (Hamner et al. 1945). However, there are large variations within tomato species (from 8 up to 119 mg/100 g FW in some wild species) (Stevens & Rick 1986). Attempts to increase the vitamin C content of the cultivated tomato through traditional breeding have had little success. Variations ranging from 25 to 48 mg/100 g FW were observed for various cultivars of tomato grown in Hungary (Abushita et al. 1997).

Fruit ripening at relatively high temperatures, whether on or off the plant, along with relatively low light intensity levels probably leads to a decrease in the ascorbic acid content due to oxidation (Murneek et al. 1954). Under greenhouse conditions seasonal variations in the vitamin C content ranged from 7 to 23 mg/100 g FW at the mature-green stage and were directly correlated with temperature variations (Liptay et al. 1986). Light intensity prior to harvesting can also affect ascorbic acid content. Transfer of fruit from shade to sun results in increases in ascorbic acid content (Hamner et al. 1945). Greenhouse-grown tomatoes were usually found to have lower vitamin C levels than those grown outdoors, chiefly due to the lower light intensity and shorter day length (Murneek et al. 1954). A seasonal increase has been observed in the ascorbic acid content of field-grown fruit from early to late summer (Dumas et al. 2003).

Water shortage seems generally to increase the vitamin C content of the fruit, as well as the dry matter and soluble solid content (Dumas et al. 2003). Supplementary nitrogen, especially at high rates, tends to decrease the tomato vitamin C content, possibly due to the increased shading caused by the greater development of plant foliage (Dumas et al. 2003). Increasing phosphorus concentrations in hydroponics did not significantly affect vitamin C content (Saito & Kano 1970). As with lycopene, calcium application to tomatoes grown in pots resulted in a significant increase in vitamin C (Subbiah & Perumal 1990). It has been reported in several papers that the vitamin C content of tomatoes could increase with the supply of combined fertilisers (Dumas et al. 2003). Some plant growth regulators (e.g. alar, gibberellic acid, cycocel and phosphon) have also been shown to increase the vitamin C content of tomatoes (Dumas et al. 2003).

A French study showed that vitamin C was higher in tomatoes grown by conventional methods than those produced organically (Auclair et al. 1995). The vitamin C content of tomatoes picked green and allowed to ripen at 22-24.5°C increased from 11 to 26 mg/100 g FW (Murneek et al. 1954). Similar patterns have been observed in other studies (Venter 1977; Shi et al. 1999),

but Abushita et al. (1997) reported an increase during initial reddening but then a decrease. The vitamin C content of fruit bruised at the breaker stage decreased at the ripe stage compared to undamaged fruit (Moretti et al. 1998). Variations in vitamin C content during vine and postharvest ripening were also investigated by Giovanelli et al. (1999). In postharvest-ripened fruit, ascorbic acid decreased and then returned to original levels, while in vine-ripened fruit it increased and then decreased to a similar or slightly lower level.

There are limited specific data on the loss of vitamin C in tomatoes during processing. One study by Abushita et al. (2000) did show loss of activity (Table 21). Dewanto et al. (2002) also showed that thermal processing resulted in a loss of vitamin C (Table 18).

Table 21: Change in ascorbic acid content of tomato as a function of processing (adapted from Abushita et al. 2000).

Processing steps	Ascorbic acid (mg/g dm)
Raw material	3.17
Hot-break extract	1.96
Tomato paste	1.45
Loss %	54.6%

8.4 Summary

Many of the studies of lycopene content in tomatoes and tomato products were carried out some time ago and many did not use commercially relevant cultivars. All experimental details are often not reported, which makes it difficult to compare results and may explain some of the contradictory findings. Some give different results for different antioxidants. For example, water storage during cropping may increase vitamin C level but reduce lycopene content. Direct sunlight may enhance accumulation of phenolics and vitamin C but foliage cover may help lycopene accumulation. Further research is required with commercially relevant processing cultivars to establish protocols for enhancing phytochemical content in tomatoes.

9 Promoting nutritional attributes

Dietary intakes of tomatoes and tomato products may be associated with decreased risk of various diseases, including cancers, especially prostate, and heart disease. The benefits have been attributed to the lycopene content, but it is probable other phytochemicals in tomatoes also contribute to these benefits. Lycopene is the main carotenoid present in tomatoes and

unlike β -carotene, has no provitamin A activity. However, it is a powerful antioxidant and other modes of action may also be responsible for its health benefits (e.g. modulation of intercellular gap junction communication, hormonal and immune systems and metabolic pathways). In addition to lycopene, and other carotenoids (e.g. β -carotene, phytoene, phytofluene), tomatoes contain a range of other phytochemicals with potential health benefits, including phenolic acids (e.g. coumaric and chlorogenic acids), flavonoids (e.g. quercetin-3-rutinoside, naringenin) and antioxidant vitamins (vitamins C and E). Lycopene is readily absorbed from different food sources, distributes to different tissues in the human body and has been demonstrated to have antioxidant properties within the body. Serum levels of lycopene have been related to a reduced risk of several types of cancer. However, more research is still required to fully understand the health benefits of tomatoes/lycopene, the interactions between the phytochemicals in tomatoes, and establish clear dietary guidelines.

The more intense red the tomato is, the more lycopene it is likely to contain. Locally grown fruit, especially some of the more niche tomatoes (e.g. vine) appear to be brighter in colour than the paler imported Australian varieties. Similarly, smaller tomatoes tend to have a higher lycopene content than larger cultivars. Storage can also affect lycopene levels and appropriate cooking methods appear to enhance the absorption of lycopene by the body.

Consuming the whole fruit, including the skins and seeds maximises the delivery of the potential health benefits of the tomato.

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Appendices

Appendix I Additional information of general interest

- The word "tomato" comes from the Aztec, "tomatl", which was used by the Spanish explorers who originally took the fruit back to Europe. In Italy, it was quickly adopted into local cuisine and was known as "pomo d'oro", or golden apple, which suggests that the first tomatoes there were yellow. In France it was called "pomme d'amour" or love apple. This may have been a corruption of the Italian or may have reflected the belief that tomatoes had aphrodisiac powers. It was for the latter reason that tomatoes were forbidden to women in some cultures! The botanical name is *Lycopersicon esculentum* meaning "edible wolf peach", which is derived from the German name for deadly nightshade, a relative of the tomato, which was believed to be used by witches to summon up werewolves.
- Although almost a staple in Western diets today, tomatoes were considered poisonous in some parts of Europe when early Spanish explorers brought them to the old world from their native South America. This belief was also held in North America, until, so the story goes, a champion for the tomato cause, Colonel Robert Gibbon Johnson, announced he would eat a bushel of tomatoes in front of the Boston courthouse. Apparently a 2000 strong crowd arrived, expecting to witness his demise, but to their amazement he lived and any remaining doubts about the tomato were dramatically and conclusively put to rest.
- Tomatoes are unusual amongst foods in that their consumption is not necessarily related to healthy eating choices. For example, whilst they may be part of a salad (healthy choice), they could also be consumed, as tomato sauce, along with fish and chips, French fries, pies or pizza (less healthy choices) or as a tomato-based sauce in a pasta meal (neither particularly healthy nor unhealthy). This makes it particularly interesting for researchers, as many potentially confounding issues are removed.
- In the USA, tomatoes contribute the second most dietary vitamin C, after citrus.
- "A world without tomatoes is like a string quartet without violins". Laurie Colwyn, Home Cooking

Appendix II

Composition of various tomato products from the New Zealand Food Composition Database

- Tomato-based pasta sauce
- Tomato sauce
- Tomato puree
- Tomato paste, salted
- Tomatoes, flesh, skin and seeds, raw

SAUCE, PASTA,TOMATO-BASED, commercial, heated

Amount in 100 g edible portion	Units Src.	Mean	Std Error	No.
PROXIMATES				
Water.....	g	85.35	-	1
.....z				
Energy.....	kcal	50	-	-
.....c				
Energy.....	kJ	205	-	-
.....c				
Protein (Nitrogen x 5.8).....	g	1.4	-	-
.....a				
Total fat.....	g	0.7	-	-
.....a				
Carbohydrate, available.....	g	9.4	-	-
.....a				
Dietary fibre (Englyst, 1988).....	g	0.6	-	-
.....b				
Ash.....	g	1.4	-	-
.....a				
NUTRIENT ELEMENTS				
Sodium.....	mg	470	-	-
.....a				
Magnesium.....	mg	17	-	-
.....a				
Phosphorus.....	mg	30	-	-
.....a				
Sulphur.....	mg	-	-	-
.....-				
Chloride.....	mg	830	-	-
.....b				
Potassium.....	mg	360	-	-
.....a				
Calcium.....	mg	24	-	-
.....a				
Manganese.....	µg	0.10	-	-
.....b				
Iron.....	mg	1.0	-	-
.....a				
Copper.....	mg	0.16	-	-
.....b				
Zinc.....	mg	0.25	0.08	10
.....z				
Selenium.....	µg	T	-	-
.....g				
VITAMINS				
Retinol.....	µg	1	-	-
.....a				
Beta-carotene equivalents.....	µg	260	-	-
.....a				
Total vitamin A equivalents.....	µg	44	-	-
.....a				
Thiamin.....	mg	0.02	-	-
.....a				
Riboflavin.....	mg	0.06	-	-
.....a				
Niacin.....	mg	1.0	-	-
.....a				

Potential niacin from tryptophan	mg	0.2	-	-
.....ac				
Vitamin B6	mg	0.06	-	-
.....b				
Pantothenate	mg	0	-	-
.....b				
Biotin	µg	0	-	-
.....b				
Folate, total	µg	10	-	-
.....b				
Vitamin B12	µg	0	-	-
.....b				
Vitamin C	mg	0	-	-
.....a				
Vitamin D	µg	0	-	-
.....b				
Alpha-tocopherol	mg	-	-	-
.....-				
Vitamin E	mg	0	-	-
.....p				
OTHER LIPIDS				
Cholesterol.....	mg	0	-	-
.....a				

AMINO ACIDS Src.	<u>g/100 g edible portion</u>		No.	Src.	<u>mg/g Nitrogen</u>		No.
	Mean	Std Error			Mean	Std Error	
Isoleucine.....	-	-	-	-	-	-	-
.....-							
Leucine	-	-	-	-	-	-	-
.....-							
Lysine	-	-	-	-	-	-	-
.....-							
Methionine	-	-	-	-	-	-	-
.....-							
Cystine.....	-	-	-	-	-	-	-
.....-							
Phenylalanine	-	-	-	-	-	-	-
.....-							
Tyrosine.....	-	-	-	-	-	-	-
.....-							
Threonine.....	-	-	-	-	-	-	-
.....-							
Tryptophan	-	-	-	-	-	-	-
.....-							
Valine.....	-	-	-	-	-	-	-
.....-							
Arginine.....	-	-	-	-	-	-	-
.....-							
Histidine	-	-	-	-	-	-	-
.....-							
Alanine.....	-	-	-	-	-	-	-
.....-							
Aspartic acid.....	-	-	-	-	-	-	-
.....-							
Glutamic acid	-	-	-	-	-	-	-
.....-							
Glycine.....	-	-	-	-	-	-	-
.....-							

Proline.....	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Serine	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Hydroxyproline	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-

Common Measure 1 cup, 258 g

FOODINFO New Zealand Institute for Crop & Food Research
1.S

SAUCE, PASTA,TOMATO-BASED, commercial, heated

FATTY ACIDS Src.	<u>g/100 g edible portion</u>		No.	Src.	<u>g/100 g total fatty acids</u>		No.
	Mean	Std Error			Mean	Std Error	
Total saturated fatty acids.....	0.1	-	-	a	-	-	-
..... -							
Total monounsaturated fatty acids.....	0.2	-	-	a	-	-	-
..... -							
Total polyunsaturated fatty acids.....	0.4	-	-	a	-	-	-
..... -							
Additional information (in 100 g edible portion)	Units		Mean		Std Error		No.
	Scr.						
Alcohol.....	g		0		-		-
..... a							
Cadmium.....	µg		1.39		0.21		10
..... z							
Carbohydrate, available.....	g		9.4		-		-
..... a							
Carbohydrate, total (by difference).....	g		11		-		-
..... c							
Density.....	kg/l		1.03		-		-
..... z							
Dietary fibre.....	g		1.8		-		-
..... a							
Dry matter.....	g		14.7		-		1
..... z							
Fructose.....	g		3.7		-		-
..... ac							
Glucose.....	g		3.8		-		-
..... ac							
Insoluble non-starch polysaccharides.....	g		0		-		-
..... bc							
Lactose.....	g		0		-		-
..... b							
Lead.....	µg		0.63		0.08		8
..... zl							
Maltose.....	g		0		-		-
..... b							
Soluble non-starch polysaccharides.....	g		0.6		-		-
..... bc							
Starch.....	g		1.9		-		-
..... a							
Sucrose.....	g		T		-		-
..... b							
Total available sugars.....	g		7.5		-		-
..... a							
Total niacin equivalents.....	mg		1.2		-		-
..... ac							
Total nitrogen.....	g		0.24		-		-
..... ac							
Carbohydrate exchange.....			0.94		-		-
..... c							

SAUCE, TOMATO

Composite of Cerebos, Watties 'Homestyle' and King tomato sauce.

Amount in 100 g edible portion	Units Src.	Mean	Std Error	No.
PROXIMATES				
Water.....	g	69.54	-	-
.....zc				
Energy.....	kcal	105	-	-
.....c				
Energy.....	kJ	432	-	-
.....c				
Protein (Nitrogen x 5.8).....	g	1.07	-	1
.....z				
Total fat.....	g	0.10	-	1
.....z				
Carbohydrate, available.....	g	24.87	-	-
.....zc				
Dietary fibre (Englyst, 1988).....	g	1.32	-	1
.....z				
Ash.....	g	2.36	-	1
.....z				
NUTRIENT ELEMENTS				
Sodium.....	mg	615.00	-	1
.....z				
Magnesium.....	mg	16.40	-	1
.....z				
Phosphorus.....	mg	23.78	-	1
.....z				
Sulphur.....	mg	18.86	-	1
.....z				
Chloride.....	mg	-	-	-
.....-				
Potassium.....	mg	397.70	-	1
.....z				
Calcium.....	mg	20.50	-	1
.....z				
Manganese.....	µg	151.70	-	1
.....z				
Iron.....	mg	1.35	-	1
.....z				
Copper.....	mg	0.11	-	1
.....z				
Zinc.....	mg	0.14	-	1
.....z				
Selenium.....	µg	3.28	-	1
.....z				
VITAMINS				
Retinol.....	µg	15	-	-
.....zr				
Beta-carotene equivalents.....	µg	104.47	-	-
.....zr				
Total vitamin A equivalents.....	µg	32.41	-	-
.....zr				
Thiamin.....	mg	0.02	-	1
.....z				
Riboflavin.....	mg	0.03	-	1
.....z				

Niacin.....	mg	1.20	-	1
.....z				
Potential niacin from tryptophan	mg	0.25	-	-
.....b				
Vitamin B6.....	mg	0.13	-	-
.....zr				
Pantothenate	mg	1.00	-	1
.....z				
Biotin	µg	8	-	-
.....br				
Folate, total.....	µg	11.65	-	-
.....zr				
Vitamin B12	µg	0	-	-
.....b				
Vitamin C	mg	7.85	-	1
.....z				
Vitamin D.....	µg	0	-	-
.....b				
Alpha-tocopherol	mg	-	-	-
.....-				
Vitamin E	mg	5.52	-	-
.....br				
OTHER LIPIDS				
Cholesterol.....	mg	0	-	-
.....p				

AMINO ACIDS Src.	<u>g/100 g edible portion</u>		No.	Src.	<u>mg/g Nitrogen</u>		No.
	Mean	Std Error			Mean	Std Error	
Isoleucine.....	-	-	-	-	-	-	-
.....-							
Leucine	-	-	-	-	-	-	-
.....-							
Lysine	-	-	-	-	-	-	-
.....-							
Methionine	-	-	-	-	-	-	-
.....-							
Cystine.....	-	-	-	-	-	-	-
.....-							
Phenylalanine	-	-	-	-	-	-	-
.....-							
Tyrosine.....	-	-	-	-	-	-	-
.....-							
Threonine.....	-	-	-	-	-	-	-
.....-							
Tryptophan	-	-	-	-	-	-	-
.....-							
Valine.....	-	-	-	-	-	-	-
.....-							
Arginine.....	-	-	-	-	-	-	-
.....-							
Histidine	-	-	-	-	-	-	-
.....-							
Alanine.....	-	-	-	-	-	-	-
.....-							
Aspartic acid.....	-	-	-	-	-	-	-
.....-							
Glutamic acid	-	-	-	-	-	-	-
.....-							

Glycine.....	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Proline.....	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Serine	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Hydroxyproline	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-

Common Measure 1 tablespoon, 16.5 g

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3.S

SAUCE, TOMATO

Composite of Cerebos, Watties 'Homestyle' and King tomato sauce.

FATTY ACIDS Src.	<u>g/100 g edible portion</u>		No.	Src.	<u>g/100 g total fatty acids</u>		No.
	Mean	Std Error			Mean	Std Error	
Total saturated fatty acids.....	T	-	-	g	-	-	-
..... -							
Total monounsaturated fatty acids.....	T	-	-	g	-	-	-
..... -							
Total polyunsaturated fatty acids.....	T	-	-	g	-	-	-
..... -							
Additional information (in 100 g edible portion)			Units	Mean	Std Error	No.	
			Scr.				
Alcohol.....			g	0	-	-	
.....P							
Aluminium.....			µg	984.00	-	1	
.....Z							
Arsenic.....			µg	0.57	-	1	
.....Z							
Boron.....			µg	98.40	-	1	
.....Z							
Cadmium.....			µg	1.60	-	1	
.....Z							
Carbohydrate, available.....			g	24.87	-	-	
.....ZC							
Carbohydrate, total (by difference).....			g	27	-	-	
.....C							
Chromium.....			µg	3.57	-	1	
.....Z							
Cobalt.....			µg	4.10	-	1	
.....Z							
Density.....			kg/l	1.13	-	-	
.....Z							
Disaccharides, total.....			g	12.70	-	1	
.....Z							
Dry matter.....			g	30.46	-	-	
.....ZC							
Fructose.....			g	6.10	-	1	
.....Z							
Glucose.....			g	5.60	-	1	
.....Z							
Insoluble non-starch polysaccharides.....			g	0.89	-	1	
.....Z							
Iodide.....			µg	1	-	-	
.....Z							
Lactose.....			g	T	-	1	
.....Z							
Lead.....			µg	1.11	-	1	
.....Z							
Lithium.....			µg	4.22	-	1	
.....Z							
Maltose.....			g	T	-	1	
.....Z							
Monosaccharides, total.....			g	11.70	-	1	
.....Z							
Mercury.....			µg	T	-	1	
.....Z							

Molybdenum	µg	4.51	-	1
..... Z				
Nickel.....	µg	17.22	-	1
..... Z				
Rubidium	mg	0.41	-	1
..... Z				
Silicon	µg	11480.00	-	1
..... Z				
Soluble non-starch polysaccharides.....	g	0.42	-	1
..... Z				
Starch	g	0.47	-	-
.....ZC				
Starch (monosacc).....	g	0.52	-	1
..... Z				
Sucrose.....	g	12.70	-	1
..... Z				
Tin	µg	82.00	-	1
..... Z				
Total available sugars	g	24.4	-	-
.....ZC				
Total dietary fibre (Prosky, 1984).....	g	1.4	-	-
..... u				
Total niacin equivalents.....	mg	1.45	-	-
..... bz				
Total nitrogen	g	0.19	-	1
..... Z				
Vanadium	µg	2.42	-	1
..... Z				
Carbohydrate exchange		2.5	-	-
..... c				

TOMATO PUREE

Amount in 100 g edible portion	Units Src.	Mean	Std Error	No.
PROXIMATES				
Water.....	g	74.9	-	-
.....	b			
Energy.....	kcal	80	-	-
.....	c			
Energy.....	kJ	330	-	-
.....	c			
Protein (Nitrogen x 6.25).....	g	5.0	-	-
.....	b			
Total fat.....	g	0.32	-	-
.....	u			
Carbohydrate, available.....	g	14.2	-	-
.....	ab			
Dietary fibre (Englyst, 1988).....	g	2.50	-	-
.....	b			
Ash.....	g	2.53	-	-
.....	u			
NUTRIENT ELEMENTS				
Sodium.....	mg	240	-	-
.....	b			
Magnesium.....	mg	26	-	-
.....	b			
Phosphorus.....	mg	94	-	-
.....	b			
Sulphur.....	mg	14	-	-
.....	x			
Chloride.....	mg	550	-	-
.....	b			
Potassium.....	mg	1200	-	-
.....	b			
Calcium.....	mg	35	-	-
.....	b			
Manganese.....	µg	240	-	-
.....	b			
Iron.....	mg	1.4	-	-
.....	b			
Copper.....	mg	2.9	-	-
.....	b			
Zinc.....	mg	0.5	-	-
.....	b			
Selenium.....	µg	0.87	-	-
.....	zr			
VITAMINS				
Retinol.....	µg	0	-	-
.....	p			
Beta-carotene equivalents.....	µg	634	-	-
.....	aug			
Total vitamin A equivalents.....	µg	106	-	-
.....	aug			
Thiamin.....	mg	0.4	-	-
.....	b			
Riboflavin.....	mg	0.19	-	-
.....	b			
Niacin.....	mg	4.00	-	-
.....	b			

Potential niacin from tryptophan	mg	0.7	-	-
.....	b			
Vitamin B6	mg	0.11	-	-
.....	b			
Pantothenate	mg	1.0	-	-
.....	b			
Biotin	µg	6	-	-
.....	b			
Folate, total	µg	22	-	-
.....	b			
Vitamin B12	µg	0	-	-
.....	b			
Vitamin C	mg	38	-	-
.....	bw			
Vitamin D	µg	0	-	-
.....	b			
Alpha-tocopherol	mg	-	-	-
.....	-			
Vitamin E	mg	5.37	-	-
.....	bw			
OTHER LIPIDS				
Cholesterol	mg	0	-	-
.....	p			

AMINO ACIDS Src.	<u>g/100 g edible portion</u>		No.	Src.	<u>mg/g Nitrogen</u>		No.
	Mean	Std Error			Mean	Std Error	
Isoleucine	0.099	-	-	b	124	-	-
.....							
.....							
Leucine	0.140	-	-	b	175	-	-
.....							
.....							
Lysine	0.149	-	-	b	186	-	-
.....							
.....							
Methionine	0.032	-	-	b	40	-	-
.....							
.....							
Cystine	0.032	-	-	b	40	-	-
.....							
.....							
Phenylalanine	0.090	-	-	b	113	-	-
.....							
.....							
Tyrosine	0.064	-	-	b	80	-	-
.....							
.....							
Threonine	0.115	-	-	b	144	-	-
.....							
.....							
Tryptophan	0.041	-	-	b	51	-	-
.....							
.....							
Valine	0.107	-	-	b	134	-	-
.....							
.....							
Arginine	0.107	-	-	b	134	-	-
.....							
.....							
Histidine	0.072	-	-	b	90	-	-
.....							
.....							
Alanine	0.124	-	-	b	155	-	-
.....							
.....							
Aspartic acid	0.578	-	-	b	722	-	-
.....							
.....							
Glutamic acid	-	-	-	-	-	-	-
.....							
.....							
Glycine	0.090	-	-	b	113	-	-
.....							
.....							

Proline.....	0.080	-	-	b	100	-	-
.....b							
Serine	0.132	-	-	b	165	-	-
.....b							
Hydroxyproline	-	-	-	-	-	-	-
.....-							

Common Measure 1 tablespoon, 16 g

FOODINFO New Zealand Institute for Crop & Food Research

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TOMATO PUREE

FATTY ACIDS Src.	<u>g/100 g edible portion</u>		No.	Src.	<u>g/100 g total fatty acids</u>		
	Mean	Std Error			Mean	Std Error	No.
Total saturated fatty acids.....u	0.045	-	-	u	20.0	-	-
Total monounsaturated fatty acids.....u	0.047	-	-	u	21.1	-	-
Total polyunsaturated fatty acids.....u	0.132	-	-	u	58.8	-	-
Additional information (in 100 g edible portion)	Units		Mean		Std Error		No.
	Scr.						
Alcohol.....p	g		0		-		-
Carbohydrate, available.....ab	g		14.2		-		-
Carbohydrate, total (by difference).....c	g		17.3		-		-
Density.....z	kg/l		1.07		-		-
Dietary fibre.....u	g		2.8		-		-
Dry matter.....b	g		25.1		-		-
Fructose.....b	g		7.6		-		-
Glucose.....b	g		6.5		-		-
Insoluble non-starch polysaccharides.....br	g		1.5		-		-
Lactose.....a	g		0		-		-
Lactose (monosacc).....a	g		0		-		-
Maltose.....a	g		0		-		-
Maltose (monosacc).....a	g		0		-		-
Soluble non-starch polysaccharides.....br	g		1.0		-		-
Starch.....b	g		0.1		-		-
Starch (monosacc).....b	g		0.1		-		-
Sucrose.....b	g		T		-		-
Sucrose (monosacc).....b	g		T		-		-
Total available sugars.....ab	g		14.1		-		-
Total available sugars (monosacc).....b	g		14.1		-		-
Total dietary fibre (Prosky, 1984).....a	g		1.9		-		-
Total niacin equivalents.....c	mg		4.70		-		-
Total nitrogen.....b	g		0.8		-		-

Carbohydrate exchange	1.4	-	-
..... C			

TOMATO PASTE, SALTED

Amount in 100 g edible portion	Units Src.	Mean	Std Error	No.
PROXIMATES				
Water.....	g	76.5	-	-
.....a				
Energy.....	kcal	67	-	-
.....c				
Energy.....	kJ	276	-	-
.....c				
Protein (Nitrogen x 5.8).....	g	3.1	-	-
.....a				
Total fat.....	g	0.3	-	-
.....a				
Carbohydrate, available.....	g	12.9	-	-
.....br				
Dietary fibre (Englyst, 1988).....	g	2.8	-	-
.....b				
Ash.....	g	2.67	-	-
.....u				
NUTRIENT ELEMENTS				
Sodium.....	mg	630	-	-
.....a				
Magnesium.....	mg	38	-	-
.....a				
Phosphorus.....	mg	68	-	-
.....a				
Sulphur.....	mg	-	-	-
.....-				
Chloride.....	mg	490	-	-
.....br				
Potassium.....	mg	960	-	-
.....a				
Calcium.....	mg	28	-	-
.....a				
Manganese.....	µg	T	-	-
.....br				
Iron.....	mg	1.6	-	-
.....a				
Copper.....	mg	0.53	-	-
.....br				
Zinc.....	mg	0.4	-	-
.....a				
Selenium.....	µg	T	-	-
.....br				
VITAMINS				
Retinol.....	µg	0	-	-
.....a				
Beta-carotene equivalents.....	µg	1320	-	-
.....a				
Total vitamin A equivalents.....	µg	220	-	-
.....a				
Thiamin.....	mg	0.12	-	-
.....a				
Riboflavin.....	mg	0.08	-	-
.....a				
Niacin.....	mg	2.8	-	-
.....a				

Potential niacin from tryptophan	mg	0.6	-	-
.....	br			
Vitamin B6	mg	0.44	-	-
.....	br			
Pantothenate	mg	1	-	-
.....	br			
Biotin	µg	6.1	-	-
.....	br			
Folate, total	µg	54	-	-
.....	br			
Vitamin B12	µg	0	-	-
.....	br			
Vitamin C	mg	15	-	-
.....	a			
Vitamin D	µg	0	-	-
.....	br			
Alpha-tocopherol	mg	-	-	-
.....	-			
Vitamin E	mg	5.37	-	-
.....	br			
OTHER LIPIDS				
Cholesterol	mg	0	-	-
.....	a			

AMINO ACIDS Src.	<u>g/100 g edible portion</u>		No.	Src.	<u>mg/g Nitrogen</u>		No.
	Mean	Std Error			Mean	Std Error	
Isoleucine	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Leucine	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Lysine	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Methionine	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Cystine	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Phenylalanine	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Tyrosine	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Threonine	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Tryptophan	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Valine	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Arginine	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Histidine	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Alanine	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Aspartic acid	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Glutamic acid	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Glycine	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-

Proline.....	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Serine	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-
Hydroxyproline	-	-	-	-	-	-	-
.....	-	-	-	-	-	-	-

Common Measure 1 cup, 277 g

FOODINFO New Zealand Institute for Crop & Food Research

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TOMATO PASTE, SALTED

FATTY ACIDS Src.	<u>g/100 g edible portion</u>		No.	Src.	<u>g/100 g total fatty acids</u>		No.
	Mean	Std Error			Mean	Std Error	
Total saturated fatty acids.....	0	-	-	a	-	-	-
..... -							
Total monounsaturated fatty acids.....	0	-	-	a	-	-	-
..... -							
Total polyunsaturated fatty acids.....	0	-	-	a	-	-	-
..... -							

Additional information (in 100 g edible portion)	Units Scr.	Mean	Std Error	No.
Alcohol.....	g	0	-	-
..... a				
Carbohydrate, available.....	g	12.9	-	-
..... br				
Carbohydrate, total (by difference).....	g	17.43	-	-
..... g				
Density.....	kg/l	1.10	-	-
..... z				
Dietary fibre.....	g	0	-	-
..... a				
Dry matter.....	g	23.5	-	-
..... a				
Fructose.....	g	6.6	-	-
..... br				
Glucose.....	g	6	-	-
..... br				
Insoluble non-starch polysaccharides.....	g	1.3	-	-
..... b				
Lactose.....	g	0	-	-
..... br				
Maltose.....	g	0	-	-
..... br				
Soluble non-starch polysaccharides.....	g	1.5	-	-
..... bc				
Starch.....	g	0.3	-	-
..... br				
Sucrose.....	g	T	-	-
..... b				
Total available sugars.....	g	12.6	-	-
..... br				
Total niacin equivalents.....	mg	3.4	-	-
..... ab				
Total nitrogen.....	g	0.53	-	-
..... ac				
Carbohydrate exchange.....		1.3	-	-
..... c				

TOMATOES, flesh, skin and seeds, raw

Lycopersicon esculentum

Amount in 100 g edible portion	Units Src.	Mean	Std Error	No.
PROXIMATES				
Water.....	g	94.22	0.38	5
.....Z				
Energy.....	kcal	17	-	-
.....C				
Energy.....	kJ	68	-	-
.....C				
Protein (Nitrogen x 6.25).....	g	0.89	-	1
.....Z				
Total fat.....	g	0.24	-	1
.....Z				
Carbohydrate, available.....	g	2.7	-	-
.....azc				
Dietary fibre (Englyst, 1988).....	g	1.21	-	1
.....Z				
Ash.....	g	0.59	-	1
.....Z				
NUTRIENT ELEMENTS				
Sodium.....	mg	3.74	-	1
.....Z				
Magnesium.....	mg	12.1	-	1
.....Z				
Phosphorus.....	mg	22.9	-	1
.....Z				
Sulphur.....	mg	10.9	-	1
.....Z				
Chloride.....	mg	48.3	-	1
.....Z				
Potassium.....	mg	265	-	1
.....Z				
Calcium.....	mg	10.9	-	1
.....Z				
Manganese.....	µg	56.8	9.0	3
.....Z				
Iron.....	mg	0.13	-	1
.....Z				
Copper.....	mg	0.049	0.024	3
.....Z				
Zinc.....	mg	0.09	-	2
.....Z				
Selenium.....	µg	0.110	-	1
.....Z				
VITAMINS				
Retinol.....	µg	0	-	-
.....P				
Beta-carotene equivalents.....	µg	549	-	1
.....zc				
Total vitamin A equivalents.....	µg	92	-	1
.....zc				
Thiamin.....	mg	0.024	-	1
.....Z				
Riboflavin.....	mg	0.005	-	1
.....Z				
Niacin.....	mg	0.543	-	1
.....Z				

Potential niacin from tryptophan	mg	0.1	-	-
.....	b			
Vitamin B6	mg	0.009	-	1
.....	z			
Pantothenate	mg	0.229	-	-
.....	u			
Biotin	µg	1.3	-	-
.....	b			
Folate, total	µg	14	-	-
.....	u			
Vitamin B12	µg	0	-	-
.....	p			
Vitamin C	mg	23.7	-	1
.....	z			
Vitamin D	µg	0	-	-
.....	p			
Alpha-tocopherol	mg	0.760	-	1
.....	z			
Vitamin E	mg	0.77	-	-
.....	zc			
OTHER LIPIDS				
Cholesterol	mg	0	-	-
.....	p			

AMINO ACIDS Src.	<u>g/100 g edible portion</u>		No.	Src.	<u>mg/g Nitrogen</u>		No.
	Mean	Std Error			Mean	Std Error	
Isoleucine	0.017	-	-	bz	120	-	-
.....							
.....							
Leucine	0.024	-	-	bz	170	-	-
.....							
.....							
Lysine	0.025	-	-	bz	180	-	-
.....							
.....							
Methionine	0.006	-	-	bz	40	-	-
.....							
.....							
Cystine	0.006	-	-	bz	40	-	-
.....							
.....							
Phenylalanine	0.015	-	-	bz	110	-	-
.....							
.....							
Tyrosine	0.011	-	-	bz	80	-	-
.....							
.....							
Threonine	0.020	-	-	bz	140	-	-
.....							
.....							
Tryptophan	0.007	-	-	bz	50	-	-
.....							
.....							
Valine	0.018	-	-	bz	130	-	-
.....							
.....							
Arginine	0.018	-	-	bz	130	-	-
.....							
.....							
Histidine	0.013	-	-	bz	90	-	-
.....							
.....							
Alanine	0.021	-	-	bz	150	-	-
.....							
.....							
Aspartic acid	0.101	-	-	bz	720	-	-
.....							
.....							
Glutamic acid	-	-	-	-	-	-	-
.....							
.....							
Glycine	0.015	-	-	bz	110	-	-
.....							
.....							

Proline.....	0.014	-	-	bz	100	-	-
.....b							
Serine	0.022	-	-	bz	160	-	-
.....b							
Hydroxyproline	-	-	-	-	-	-	-
..... -							
Common Measure	1 tomato, 127 g						
	1 cup, chopped, 190 g						
Edible Portion	100 % z						

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TOMATOES, flesh, skin and seeds, raw*Lycopersicon esculentum*

FATTY ACIDS Src.	<u>g/100 g edible portion</u>		No.	Src.	<u>g/100 g total fatty acids</u>		No.
	Mean	Std Error			Mean	Std Error	
Total saturated fatty acids.....u	0.033	-	-	uz	19.6	-	-
Total monounsaturated fatty acids.....u	0.036	-	-	uz	21.7	-	-
Total polyunsaturated fatty acids.....u	0.099	-	-	uz	58.7	-	-
Additional information (in 100 g edible portion)	Units		Mean		Std Error		No.
	Scr.						
Alcohol.....p	g		0		-		-
Alpha-carotene.....z	µg		0		-		1
Available non-reducing sugars.....z	g		0		-		1
Available reducing sugars.....z	g		2.65		-		1
Beta-carotene.....z	µg		549		-		1
Cadmium.....z	µg		0.20		-		2
Carbohydrate, available.....azc	g		2.7		-		-
Carbohydrate, total (by difference).....c	g		4.1		-		-
Chromium.....z	µg		1.99		-		2
Density.....z	kg/l		0.76		-		-
Dietary fibre.....z	g		1.21		-		1
Dry matter.....z	g		5.78		0.38		5
Fluoride.....zw	µg		8		-		-
Fructose.....zc	g		1.38		-		-
Gamma-tocopherol.....bz	mg		0.175		-		-
Glucose.....zc	g		1.27		-		-
Hemicellulose.....z	g		0.09		-		1
Insoluble non-starch polysaccharides.....z	g		0.67		-		1
Iodide.....z	µg		1.5		-		-
Lactose.....a	g		0		-		-
Lactose (monosacc).....p	g		0		-		-
Lead.....zl	µg		T		-		2

Lignin.....	g	0.35	-	1
..... Z				
Maltose	g	0	-	-
..... a				
Maltose (monosacc).....	g	0	-	-
..... a				
Neutral detergent fibre (Van Soest 1967).....	g	0.93	-	1
..... Z				
Soluble non-starch polysaccharides.....	g	0.55	-	1
..... Z				
Starch	g	0.04	-	1
..... Z				
Starch (monosacc).....	g	0.04	-	1
..... Z				
Sucrose.....	g	0	-	-
..... ZC				
Sucrose (monosacc).....	g	0	-	-
..... ZC				
Total available sugars	g	2.7	-	-
..... aZC				
Total available sugars (monosacc).....	g	2.65	-	1
..... Z				
Total dietary fibre (Prosky, 1984).....	g	1.2	-	1
..... a				
Total niacin equivalents.....	mg	0.6	-	-
..... C				
Total nitrogen	g	0.14	-	1
..... Z				
Carbohydrate exchange		0.27	-	-
..... C				

