Lycopene bioaccessibility and bioavailability from processed foods

Monica Anese, Giorgio Mirolo, Astrid Fabbro and Giovanna Lippe*
Department of Food Science, University of Udine, via Sondrio 2/A, 33100 Udine, Italy

Received 19 March 2013; revised 23 May 2013; accepted 28 May 2013

Lycopene is one of the most abundant carotenoids naturally occurring in red fruits and vegetables, especially tomato and its derivatives. It has potent antioxidant activity and can reduce risk of certain chronic diseases and cancers. A key limitation of lycopene use is that its intestinal absorption is far from complete and highly variable depending on food processing. Consuming fat markedly increases efficiency of lycopene absorption, while other dietary components may reduce lycopene bioavailability. Heat treatment is quite effective in improving lycopene bioaccessibility by breaking down food matrix without affecting its content. High power ultrasound treatments of tomato pulp markedly decrease lycopene bioaccessibility, possibly due to lycopene entrapment in a stronger pectin network. This study reviews lycopene bioaccessibility and bioavailability from processed foods.

Keywords: Antioxidant, Bioavailability, Carotenoid, Lycopene, Tomato

Introduction

Lycopene is a lipid soluble carotenoid synthesized by plants and microorganisms, but not by animals and is one of the most abundant pigment naturally occurring in red fruits and vegetables. Tomato (lycopene, 8.8-42 µg/g wet weight) and its derivatives represent main dietary sources of lycopene, but also watermelon, papaya, guava and pink grapes are rich sources. Lycopene is absorbed in sufficient amount by gastrointestinal tract to be detected in human plasma, where it represents the most abundant carotenoid accounting for 50% of all plasma carotenoid content. Liver, seminal vesicles and prostate are primary sites of accumulation. Studies support dietary lycopene role in health promotion, possibly through a synergy with other bioactive compounds contained in food. Regular intake of tomatoes and tomato products containing lycopene has been associated with decreased risk of malignancies, particularly prostate cancer. However, a number of dietary-based epidemiological studies have yielded less supportive results. Lycopene consumption is also reported protective against inflammatory processes and cardiovascular diseases. Lycopene supplementation is effective in reducing LDL cholesterol, inducing comparable effects of low doses of cholesterol lowering drugs statins.

In vitro studies have demonstrated that lycopene, a most potent antioxidant among carotenoids, is able to protect lipids, DNA and proteins from oxidative damage. However, evidence is accumulating for other mechanisms, most probably mediated through its derivatives formed inside cells. Mechanisms proposed for cancer-preventive activity of tomato lycopene focus on activation of antioxidant response element transcription system, inhibition of transcriptional activity of estrogens and androgens, and activity of insulin-like growth factor. Modulation of transcription factors peroxisome proliferator-activated receptor, retinoid X receptor, liver X receptor, and activating protein-1 by lycopene has been also proposed.

A key limitation of dietary-based studies is that lycopene absorption is low and highly variable depending on the source of foodstuffs. Moreover, a relatively high inter-individual variability exists in plasma level response to lycopene intake, whose nature and cause are far to be fully elucidated. Lycopene passage within the body is reported from gut lumen into plasma to be dispersed in final tissues that is denoted as lycopene bioavailability. On the other hand, lycopene bioavailability is strictly dependent on its bioaccessibility, or its release from food matrix and its transformation into a potentially absorbable form.

This study reviews lycopene bioaccessibility and bioavailability from processed foods.

Lycopene Bioavailability

Lycopene absorption in intestinal cells is mediated by bile micelles formation (Fig. 1) and occurs through
both passive diffusion and cholesterol membrane transporter SR-BI (scavenger receptor class B type I). In enterocytes, lycopene can follow two pathways: i) cleavage by BCO2 (β-carotene-9\textsubscript{\textgamma}10\textsubscript{\textgamma} oxygenase) to give rise to apo-lycopenals exported into portal blood; and ii) inclusion in lycopen-containing chylomicrons secreted via linfatic ducts into the blood. From blood, lycopene is taken up by various tissues through the action of lipoprotein lipase on chylomicrons before clearance of chylomicrons remnants by liver. From liver, lycopene is packaged into very low-density lipoprotein (VLDL) and re-exported into blood to be delivered to peripheral tissues via LDL receptor pathway.

Consuming fat with a lycopene-containing meal increases absorption efficiency, because it stimulates bile production and favours lycopene solubility\textsuperscript{18}. It is reported\textsuperscript{19} that a minimum of 5–10 g of fat in a meal is required for carotenoids absorption. Amount of fat in a typical western diet is ample to provide for optimal lycopene absorption (up to 70 mg). However, normally ingested lycopene is only few mg/day\textsuperscript{20}, indicating that intestinal absorption is far to be complete.

Implication of cholesterol membrane transporter SR-BI in lycopene transport within enterocytes has been recently reported\textsuperscript{21}. Treatment of a enterocyte cell line (Caco-2 cells) with anti SR-BI antibody and a inhibitor of SR-BI impaired up to 60% lycopene uptake, while overexpressing SR-BI in mice markedly increased plasma lycopene concentrations\textsuperscript{21}. Other studies\textsuperscript{22} demonstrate that within enterocytes lycopene is partially cleaved by BCO2, giving rise to Apo-10\textsubscript{\textgamma} lycopenal, which could be either reduced or oxidized by NADH/NAD\textsuperscript{+} system before to be released. However, identification of lycopene derivatives \textit{in vivo} is still challenging\textsuperscript{6}. Major part of lycopene contained in enterocytes is instead incorporated in chylomicrons. When a carotenoid-containing breakfast is fed to overnight fasted volunteers, a bi-modal plasma lipid response is observed with peaks at 3 and 6 h post meal, demonstrating that lycopene is temporarily stored in enterocyte from where it is rapidly released on the ingestion of a second meal\textsuperscript{17}. Through action of lipoprotein lipase on chylomicrons, lycopene is taken up by various tissues (adrenals, adipose tissue, testes and prostate) possibly by SR-BI\textsuperscript{6}. Rate of chylomicrons clearance and intestinal absorption are considered key factors in determining high degree of inter-individual variability in lycopene plasma response\textsuperscript{17,23}. Differently from chylomicrons, action of lipoprotein lipase, which metabolizes VLDL to LDL, does not favour lycopene release and 80% of plasma lycopene is associated to LDL\textsuperscript{24}, which are taken up via LDL receptor pathway. Half-life of plasma lycopene ranges from 12 to 33 days\textsuperscript{25}.
Regarding lycopene configuration upon absorption, while lycopene in fruits and vegetables occurs mostly (80-97%) in all-trans configuration, a considerable proportion of lycopene in human body is present as cis-isomers, which offer potentially improved antioxidant activity in vitro when compared with all-trans-isomers. Cis-isomers are preferentially absorbed and incorporated in chylomicrons, stimulating searching of good sources of cis-isomers, such as tangerine tomatoes, as well as optimal processing conditions for production of tomato products rich in cis-isomers. On the other hand, a intriguing study recently established that all-trans-lycopene is isomerized inside intestinal cells, while it remains almost unchanged during its passage in gastrointestinal tract, including its incorporation into mixed micelles. In addition to dietary fat, certain fibers, plant sterols, cholesterol lowering drugs and other carotenoids may affect lycopene availability possibly by interfering with its micelle incorporation. Interestingly, recent studies indicate that dietary lycopene can regulate BCO2 expression possibly by apo-106 lycopenoids formation in mammalian tissues both in vitro and in vivo.

**Lycopene Bioaccessibility**

Food processing and cooking can improve lycopene absorption, as lycopene is more bioavailable from tomato paste or puree than from fresh tomatoes, or from processed (boiled with 1% corn oil for 1 h) tomato juice. In nature, lycopene is in a semicrystalline form associated to plastid membranes, where it is present primarily in all trans-isomeric form protected from oxidation even if exposed to intense sunlight. Conversely, when protection of native environment is lost and lycopene can undergo isomerization by light and thermal energy to its cis-isomers, particularly 5-cis, although isomerization can also occur at positions 9, 13 and 15. Tomato lycopene is rather stable under conditions commonly used for food storage and thermal processing and treatment of tomato pulp induces its partial isomerization only at high temperature (140°C). However, long thermal treatment seems to significantly enrich cis-lycopene content of tomato puree, whereas dehydrated and powdered tomatoes have poor lycopene stability giving rise to cis-isomers unless hermetically sealed in an inert atmosphere for storage. In carrot homogenates, lycopene is less stable, giving rise to 9-cis-isomers upon thermal processing above 70°C, except when oil is added.

<table>
<thead>
<tr>
<th>Sonication time</th>
<th>Viscosity (Pa s) ± sd</th>
<th>Lycopene bioaccessibility (µg/g mm) ± sd</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.9±1.2</td>
<td>36.5±2.3</td>
</tr>
<tr>
<td>15</td>
<td>17.5±1.0</td>
<td>16.0±0.5</td>
</tr>
<tr>
<td>30</td>
<td>26.9±1.7</td>
<td>14.4±0.2</td>
</tr>
<tr>
<td>60</td>
<td>27.6±3.3</td>
<td>11.9±0.3</td>
</tr>
</tbody>
</table>

Heat treatment can markedly improve lycopene bioaccessibility by breaking down cell walls and weakening bonding forces between lycopene and tissue matrix. While crushing or homogenization in itself did not influence in vitro lycopene accessibility, crushing and subsequent heating markedly improved lycopene bioaccessibility, without affecting its content, that was parallel to a decrease of tomatoes consistency. Moreover, kinetics of temperature increase during tomato processing appeared essential to modulate lycopene release, being more effective a quick rise than a progressive one, even if this latter maintained active endogenous cell-wall lytic enzymes. A recent study presents effect of high power ultrasound treatments (HPU) on lycopene bioavailability in tomato pulp by a simulated digestion including both gastric and small intestinal steps. HPU is now widely used at an industrial level for food processing to generate emulsion and to change viscosity of food matrices. In this study, ultrasound treatments (105 W/cm² of wave intensity) given to tomato pulp, caused progressive increase of viscosity due to formation of a new network among ultrasonically de-esterified pectin molecules. However, ultrasound processing caused a marked decrease in lycopene bioaccessibility, due to lycopene entrapment in the stronger network of pectin, making it less accessible for digestion. Research is in progress to establish effects of the addition of a lipid matrix to ultrasonically treated tomatoes.

Lycopene diffusion from food matrix to bulk lipid emulsion or mixed bile micelles needs a hydrophobic continuum. Although presence of dietary lipids (vegetable oil, animal fat and dairy fat) markedly improves lycopene absorption, their optimal amount is still debated. A model, in which tomato juice was mixed with oil or oil/water emulsions, showed that both with low amount and with a large excess of oil, lycopene diffusion is limited, as well as interface structure in emulsions is relevant, because addition of proteins or
phospholipids decreases lycopene diffusion. These effects of lipids on lycopene bioaccessibility prompted the use of lycopene as food supplement dissolved in a lipophilic carrier, which can markedly improve lycopene bioavailability, especially if consumed with a normal fat-containing meal.

Conclusions

Many factors (cooking temperature, food processing, presence of lipids or other dietary components) can affect lycopene bioaccessibility and hence its bioavailability. Such a scenario needs multidisciplinary approaches to obtain a comprehensive mechanistic model necessary to generate recommendations towards more optimized processing strategies. Considering that consumers demand to develop lycopene-rich food, being now well established its health-promoting properties, further studies are warmly encouraged.

References


45 Chemat F, Huma Z & Khan M K, Applications of ultrasound in food technology: processing, preservation and extraction, *Ultrason Sonochem*, 18 (2011) 813-835.
