Chapter

Terpenoids: Lycopene in Tomatoes

Dwi Setyorini

Abstract

Terpenoids are compounds that only contain carbon and hydrogen, or carbon, hydrogen and oxygen that are aromatic, some terpenoids contain carbon atoms whose number is a multiple of five called isoprene units. There are many terpenoids in tomatoes, one of which is a tretrapenoid. A type of tetrapenoid, the carotenoids. Lycopene is a terpenoid found in tomatoes. Lycopene is the most carotenoid group in tomatoes. Lycopene plays a very important role in maintaining human health, including its role in the risk of chronic diseases such as cancer, heart disease, and others. The lycopene content in tomatoes depends on genetic factors, in this case the tomato variety, the environment where the tomatoes grow and the fruit storage environment, and the age of the tomatoes. The genetic factor of tomato fruit that greatly affects lycopene content in tomatoes is the color of the fruit. Color is generally an accurate indicator of lycopene content, with yellow cultivars containing less lycopene than red cultivars, and two out of three red cultivars contain more than orange cultivars. Shade tomato plants can increase the lycopene content in tomatoes. Aside from the lack of light in the tomato plant environment, the humidity and air temperature around the tomato plants also greatly affect the lycopene content in the fruit.

Keywords: terpenoids, carotenoids, lycopene, genetics and environment

1. Introduction

Terpene is a group of hydrocarbons that are produced by many plants and animals. In plants, terpenes are contained in the sap and vacuoles of cells. Hydrocarbons are commonly known as terpenes and oxygen-containing compounds called terpenoids are the most important constituents of essential oils. In plants, terpene compounds and their modification, terpenoids, are secondary metabolites. These tarpenes exist in large numbers and in a variety of molecular frameworks, but can be easily recognized by the regularity of the monomers formed from isoprene [1, 2]. Apart from being a secondary metabolite, terpenes are the building blocks of a number of important compounds for living things. Humanity has used terpenes extracted from plants for various purposes, namely as fragrances and flavorings, as pharmaceutical agents and as insecticides. Despite their great commercial value, terpene products have important biological functions in plants. The terpene metabolites are not only important for plant growth and development (eg gibberellin phytochromes) but also an important tool in various plant interactions with the environment [2].

Terpenoids are plant components that have an odor and can be isolated from plant material by distillation, known as essential oils. Essential oils derived from flowers were initially known from a simple structure determination with the ratio of hydrogen atoms and carbon atoms of a terpenoid compound, which is 8: 5 and with this ratio it can be said that these compounds are in the terpenoid group.. In general, terpenoids consist of elements C and H with the general molecular formula (C5H8) n, the classification usually ranges from the value of n (**Table 1**).

Food carotenoids are generally made of the C40 tetraterpenoid of eight C5 isoprenoid units, joined in reverse order down the middle. A symmetrical linear base framework, which can be cyclically at one or both ends, has a side methyl group separated by six C atoms at the center and five C atoms elsewhere. Cyclization and other modifications, such as hydrogenation, dehydrogenation, double bond migration, shortening or expansion of chains, rearrangement, isomerization, recognition of oxygen function, or a combination of these processes, yield a myriad of structures. Its hallmark is the extensive system of conjugated double bonds, which function as a light-absorbing chromophore responsible for the yellow, orange, or red color this compound imparts to many foods. Hydrocarbon carotenoids (that is, carotenoids consisting only of carbon and hydrogen) are collectively called carotenoids; which contain oxygen are called xanthophiles. In nature, they exist mainly in the more stable all-trans isomer form, but the cis isomer appears. The first two C40 carotenoids formed in the biosynthetic pathway have a 15-cis configuration in plants. The small amount of other cis carotenoid isomers in natural sources is increasingly being reported [4].

A terpenoid compound is a compound that contains only carbon and hydrogen, or carbon, hydrogen and oxygen which are aromatic, some terpenoids contain carbon atoms which are multiples of five containing only carbon and hydrogen, or aromatic carbon, hydrogen, and oxygen, some are terpenoids containing carbon atoms whose number is multiples of five called isoprene units. Terpenoids are grouped based on the number of isoprene units that compose them, namely monoterpenoids, sesquiterpenoids, diterpenoids, triterpenoids, tetraterpenoids, and polterpenoids. Some of these terpenoid compounds are used as anti-tumor drugs because of their cytotoxic effects and some have antiviral activity. Terpenoids are commonly found in plant cells [5]. Terpenoids are chemical compounds made up of several isoprene units. Most terpenoids have a cyclic structure and have one or more functional groups. Terpenoids are generally fat soluble and present in the cytoplasm of plant cells [6].

The terpenoid compounds that contain C40H64 are Pigments and Carotene. For humans, carotenoids or carotenoids play an important role for health, carotenoids with provitamin A activity are important for vision. Other carotenoids that affect human defense function and gap junctional communication (GJC). Moreover, their antioxidant capacity is responsible for the health-promoting properties of fruits and vegetables [7]. The chemical diversity of plant terpenoids can be a reflection of their various biological activities in nature, as natural resources that are widely used

Name	Chemical Formulas	Source
Monoterpen	$C_{10}H_{16}$	Essential oil
Seskuiterpen	$C_{15}H_{24}$	Essential oil
Diterpen	$C_{20}H_{32}$	Pine Resin
Triterpen	$C_{30}H_{48}$	Saponins, Damar
Tetraterpen	$C_{40}H_{64}$	Pigment, Carotene
Politerpen	$(C_5H_8)_n$ n 8	Natural Rubber

Table 1.
Classification of terpenoids [3].

by traditional and modern humans, for example medicines, flavorings, fragrances, food supplements in the form of sweetening vitamins., and pesticides. The terpenoid plant also serves as a volume high feedstock for producing industrial materials. Due to their many different structures, plant terpenoids a group as compounds with many different physical and chemical properties. They can be lipophilic or hydrophilic, volatile or non-volatile, cyclic or acyclic, chiral or achiral. The chemical diversity of terpenoids comes from the biosynthetic pathway of complex terpenoids [8].

In classical biochemistry, it plays an important role in determining features of cellular regulation (eg, possible feedback loops involving allosterism or covalent modification) and in measuring intermediate fluxes and concentrations to provide important metabolic context. With this level of understanding, it should be possible to manipulate transgenic terpenoids directed at biosynthesis to enhance the taste and color of foodstuffs, increase yields of any commercially important compounds, and resistance to pests and pathogens. The possibilities, like the form and function of terpenoid biosynthesis, of orbit are nearly endless [9].

Terpenoids (isoprenoids) encompass more than 40,000 structures and form the largest class of all known metabolic plants. Several terpenoids with typical physiological functions are common to most of the plant species. Historically, terpenoids in particular, along with alkaloids and many phenolics, have been referred to as secondary metabolites. Literature in broad terms, conceptually and empirically, has an essential ecological function in plant biology. Due to their diverse biological activities and their various physical and chemical properties, terpenoid plant chemicals have been exploited by humans as traditional biomaterials in complex compounds or in more or less pure compound form since ancient times [8].

2. Lycopene one of the carotenoids

There are many terpenoids in tomatoes, one of which is tretrapenoid. One type of Tetrapenoid, namely Carotenoids. Carotenoids are important pigments in plant growth. It has been isolated and identified that more than 750 carotenoids have been described as biological substances. These carotenoids are synthesized by plants, algae, fungi, and bacteria, and are also present in animals that eat them [10]. Apart from being an antioxidant, it turns out that carotenoids can now also be used as bio-solar cells. Dye sensitive solar cells (DSSC), also called Graetzel cells, are a new type of solar cell. DSSC becomes more attractive because a variety of dyes including natural dyes can be used as light harvesting elements. The information currently available on the natural dyes that have been used at the DSSC is expected to provide reasonable light harvesting efficiency, sustainability, low cost and easy waste management. Promising natural compounds are carotenoids, polyphenols, and chlorophyll [11].

Carotenoids are found in photosynthetic plants and bacteria, where these compounds have two important functions, namely pigments as accessories in photosynthesis and photoprotection. The first function is as a place for photosynthesis in plant organs. The second function is a consequence of the structure of the carotenoid conjugated polyenes, which allow molecules to absorb light and deactivate single oxygen and free radicals. Humans routinely ingest a variety of different carotenoids, including those that occur naturally in foods (especially fruits and vegetables) and the addition of food coloring to other foods [12].

Several papers reported carotenoid retention of more than 100% in cooked foods calculated on the basis of dry weight. This result cannot be considered an actual improvement; it is unlikely that carotenoids will be biosynthesized during cooking. The heat treatment activates the enzymes responsible for carotenoid biosynthesis and, in fact, stimulates isomerization and oxidative degradation of carotenoids. This alleged increase could be simply due to carotenoids that are easier to extract from cooked or processed samples compared to carotenoids in fresh foods, which are physically protected or combined with other dietary components. The extraction efficiency of fresh samples must be increased to match those of cooked samples (such as immersing the sample in water or extracting solvents prior to extraction), and the extraction must be thorough. The significant increase may also be due to leaching of sizeable dissolved solids, such as carrots, which concentrate carotenoids per unit weight of food. Calculating the retention of insoluble solid bases has been proposed in this case. In addition, the enzymatic oxidation of carotenoids can substantially decrease their concentration in the raw sample, especially if the sample is left for some time after being cut or shredded [4].

Lycopene (lycopene), often referred to as α-carotene, is a bright red pigment carotenoid, found in tomatoes and other red fruits. Lycopene in nature, is in a thermodynamically stable trans form, dissolves in non-polar solvents and is found in the 446-506 nm wavelength range [13]. Lycopene is a class of carotenoid compounds, and carotenoids including terpenoids, so lycopene is also a terpenoid. Lycopene is found in fruits, giving the fruit their red color. In this study, two variables were observed, namely the ratio of sample versus solvent 1: 1 and 1: 3, and temperature variables of 30° C and 50° C. The results were variable levels of 20% and 75% lycopene. The solvent ratio results in a higher lycopene. One thing that affects the lab results is the cleanliness of the cuvette as it can cause the absorbance and transmittance readings to be wrong [14]. Lycopene is the main pigment of many red meaty fruits and vegetables, such as tomatoes, watermelon, papaya and red guava, and red or pink grapefruit. ζ- Carotene is more ubiquitous but usually present at low levels except in Brazilian passion fruit [15] and in star fruit [16] where it appears as the main pigment.

3. The role of lycopene in life

Lycopene is included in a family of carotenoid compounds found in fruits, vegetables and green plants. In plants, these compounds are part of the plant and are responsible for the yellow, orange, and red colors in fruits and vegetables. They are synthesized by plants and microorganisms [17]. Lycopene is not an essential nutrient for humans, but is found in many foods, especially from foods prepared with tomato sauce. When absorbed from the stomach, lycopene is carried in the blood by various lipoproteins and accumulates in the liver, adrenal glands, and testes. The lycopene content of the different tomato and tomato products was determined. In the following table, we present the lycopene content (mg / 100 g), of the products we studied. The lycopene content in fresh tomato samples ranged from 12 mg / 100 g. In tomato products, lycopene content has the following values: in tomato paste, approximately 16 mg / 100 g, in boiled tomato sauce approximately 4 mg / 100 g, tomato sauce 17 mg / 100 g and spaghetti sauce 16 mg/100 g [18].

Lycopene acts as an inhibiting agent, lycopene eliminates carcinogenesis from the outside (viruses, pollution, radiation, chemicals) with an antioxidant mechanism so that the oxidative stress that occurs does not cause cellular or genetic damage to DNA [19]. Serum concentrations of lycopene, a biomarker of dietary intake rich in tomatoes, may play a role in the early stages of atherogenesis and may have clinical and public health relevance [20]. Lycopene can also decrease H2O2 levels which trigger heart cell damage and decrease the activity of Caspase-3 which is a key enzyme in cell death in in-vitro testing of H9C2 cardiac cells [21]. Lycopene, a type of biological carotenoid, shows a constant physical cooling rate with the highest singlet oxygen (kq = 31 × 109 M-1 s-1). Constant physical cooling rate with β-carotene singlet oxygen (kq = 14 × 109 M-1 s-1), β-carotene singlet oxygen cooling capacity (0.5 μm in plasma), lycopene singlet oxygen cooling capacity (0.7 μm) in plasma), albumin-bound bilirubin (15 μm in plasma), and α-tocopherol (22 μm in plasma) were comparably large [22]. Lycopene has been shown in several studies to be the most powerful antioxidant, ranking as follows: lycopene> α-tocopherol> α-carotene> β-crypto-xanthin> zeaxanthin = β-carotene> lutein. Carotenoid mixtures are more effective than single compounds. This synergistic effect is most pronounced when lycopene or lutein is present. The superior mixed protection may be related to the specific position of different carotenoids on the membrane [23]. Consumption of tomatoes is usually associated with intake of lycopene and other antioxidants that have health effects. The tomatoes analyzed in this work represent a typology primarily used for fresh consumption in Mediterranean countries. They show remarkable differences in antioxidant abilities and carotenoid and glycocaloid content [24].

Several animal studies have reported a role for lycopene in cancers other than the prostate. Lycopene inhibited the growth and development of C6 glioma cells (malignant brain cells) transplanted into mice [25]. Growth inhibition is more pronounced when given prior to inoculation of glioma cells. Administration of lycopene has been shown to significantly slow down and reduce the growth and development of spontaneous breast tumors in mice [17]. This effect is associated with decreased activity of milk thymidylate synthetase and decreased levels of serum free fatty acids and prolactin, hormones known to be involved in breast cancer development by stimulating cell division. The mice given lycopene developed significantly fewer tumors, and smaller areas of the tumor than mice not given the supplement. β-Carotene has shown no protection against breast cancer development.

Lycopene is an antioxidant that can neutralize free radicals. Free radical damage is one of the main causes of diseases such as heart disease, premature aging, cancer and cataracts. Lycopene has long been used as a preventative measure to prevent prostate cancer, consumption of tomato products is often associated with a lower risk of developing prostate cancer [26]. In vitro studies, showed that lycopene can also inhibit the growth of lung cancer cells [27]. High levels of lycopene and vitamin A in women's blood serum had a 33% lower chance of developing cervical cancer [28] and lycopene was also able to reduce the development of breast cancer [29]. Lycopene can also manage and prevent osteoporosis which is common in women [30].

Lycopene has attracted a lot of attention since 1995, a 6-year study by Harvard University, nearly than 48,000 people found that those who ate at least 10 servings of foods containing tomato or tomato sauce per week, had a 45% less chance of developing cancer prostate [31]. The molecular formula for lycopene is C42H56 with the following formula (**Figure 1**).

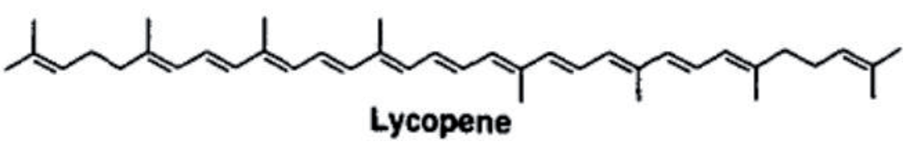

Figure 1.
Lycopene construction formula [31].

4. Effect of genetic factors on lycopene content in tomatoes

The lycopene content in tomatoes is greatly influenced by many factors. Both genetic and environmental factors. The genetic factor of tomatoes that greatly affects the content in tomatoes is the color of the fruit. Color is generally an accurate indicator of lycopene content, with yellow cultivars containing less lycopene than red cultivars, and two out of three red cultivars containing more than orange cultivars. Yellow, orange and red tomatoes can be used as indicators of lycopene and beta-carotene content in tomatoes, but this is not the case for black tomatoes, because black tomatoes "Black Cream" have a higher lycopene content than red. "Celebrity type, however, black tomatoes. "Black Tula" and "Black Plum" have lower lycopene content [24, 32].

The lycopene concentration of fruit growing in the field showed a significant difference based on fruit color. Lycopene concentrations range from 0.14 mg-g bk on Yellow Pear to 1.63 mg-g bk, in Rome, the equivalent of 1.86 mg-100 g - 1 bs in Yellow Pear to 16.30 mg –100 g - 1 bs in Rome [33]. The constructs are introduced into tomato (cv. Moneymarker) through Agrobacterium-mediated transformation and the primary transformants are brought to maturity in the greenhouse. The presence of transgene was tested on leaf DNA via PCR and chromosome complement through leaf nucleus cytometry analysis. Only PCR positive euploid plants were subjected to further research. These plants showed no significant change in growth habits or leaf color phenotypes, and produced normal fruit. Among the transformants, many exhibited a changing color phenotype of the fruit, varying from parent Moneymarker line red (MM) to bright orange. The transform shows a red color, after visual inspection, some shows a slightly darker color [32].

Fruit color is very much determined by the ratio of lycopene and beta-carotene content, where fruit with the same lycopene content but lower beta-carotene content will make the fruit look red, while fruit that has the same lycopene content with higher beta-carotene content results in fruit color appearance more orange [34]. Tomatoes with red color with a higher content of lycopene have better antioxidant activity for the heart than tomatoes with higher levels of beta-carotene and lutein, but this antioxidant activity is better in the form of fruit juice compounds than in the form of lycopene, beta-carotene and lutein pure [35].

The antioxidants in cherry tomatoes have a higher lycopene content than round or cluster tomatoes. Cherry tomatoes contain between 48.9 and 116.7 mg of lycopene per kg of wet weight. Round types ranging from 4.3–47 mg / kg wet weight. The lowest type of lycopene cluster or cluster is 12.6–35 mg / kg wet weight [24, 34]. However, the color of the fruit always gives a different content of lycopene. Red fruit will provide a higher content in yellow fruit, but this is also connected to

Figure 2.
Color Varieties Juliet (N1V1) and Golden Sweet (N1V2) of Cherry Tomatos, Golden Shine (N1V3), and Betavila (N1V4) of Round Tomato.

the ratio A and B in the fruit. So although cherry tomatoes have a higher lycopene content, if the fruit color is more yellow or orange than round tomatoes, the lycopene content in cherry tomatoes is less than that of round tomatoes [36, 37]. One example of a cherry tomato from the Golden Sweet variety which is yellow in color has a lower content of lycopene compared to the red Betavila variety, although it is not a cherry tomato (**Figure 2**).

5. Effect of environmental factors on lycopene content in tomatoes

Apart from genetic factors, there are other factors that affect lycopene levels in tomatoes. The intensity of sunlight greatly affects plant growth, as well as on tomato plants. Tomato plants treated with 25% black color gave higher antioxidant content of lycopene and beta-carotene than plants treated with 40% shade with pearl, red and yellow colors [38]. The lycopene content of tomatoes grown in greenhouses was 40% higher than those grown in open land. Shade by the foliage may be important for maximizing the lycopene content of tomato plants that grow in warm areas with high solar radiation. Partial fruit shade can be achieved by selecting cultivars with closed canopies, by changing pruning techniques to leave the upper lateral shoots, tying this ripening intact and by orienting the crop rows in a north-south direction [39].

In terms of production parameters, plants with a net shade of 40% had a higher tomato production than 50% shade and the highest production when given net shade with pearl and red colors [40]. The sensitivity to shade depends on plant genetics, the production of tomato varieties in Rempai and Bogor varieties will decrease if planted by poly-culture/intercropping, while Palupi varieties have higher production when planted intercropping [41]. The intensity of sunlight greatly affects the temperature around the plant. Research on lycopene content shows that fruit surface temperature is a more accurate predictor of fruit lycopene content than air temperature, especially in situations where the fruit is directly exposed to intense sunlight. The more direct sunlight is exposed to the fruit, the higher the surface temperature of the fruit, which leads to a lower lycopene content of the fruit [39]. This also happened in the study conducted by the author, where 25% shade gave a high enough yield on tomato production and lycopene content. The increase in tomato fruit production can reach 40% in determinate tomatoes (Betavila variety). The increase in lycopene content occurred for Juliet tomatoes, with the highest lycopene content at 50% shade and for Betavila varieties the highest lycopene content with 25% shade [42].

Other environmental factors that can affect the lycopene content of tomatoes are temperature and humidity. Air temperature below 12° C and temperature above 32° C can reduce the antioxidant content [43]. Fruit stored at 15° C and 25° C had a higher lycopene content than when stored at 7° C [44]. Tomato fruit harvested green-ripe and exposed to light for 24 hours of ripening at 25° C in a growth cabinet, had a higher concentration of lycopene than light-ripe green fruit for 8 hours [35]. Tomato plants grown in environmental conditions with a maximum average air temperature of 40.01° C, with an average maximum air humidity of 73%, have a lower lycopene content in tomatoes. Meanwhile plants grown in environmental conditions with an average maximum temperature of 34.52 and 35.85° C with an average humidity of 77.24% and 82.52% had higher lycopene content in Juliet tomatoes [42]. This happens because respiration occurs faster in environments with higher temperatures. This respiration process affects the lycopene content in the fruit. In this respiration process lycopene is degraded into terpenes so that the lycopene content is reduced. On the other hand, the water content in tomatoes will increase with each storage, because one of the results of this process is water [45].

The results of research on greenhouses in anticipation of climate change, with the application of a combined high-pressure fog system and CO_2 enrichment can be applied to reduce the internal temperature of the greenhouse. This can increase the level of CO_2 concentration, humidity, and high ambient temperature, compared to conventional climate strategies. This can increase photosynthesis and other metabolic activities, including increased carbohydrate supply, driven by changing micro-climatic conditions in the greenhouse, thereby accelerating plant growth and increasing dry matter in leaves. The new technology applied to tomato plants in greenhouses has no negative impact on the formation of fruit sets per frame. Climate change with modern greenhouses has decreased in increasing total yield and fruit size, while the occurrence of flower tip rot in tomatoes has decreased. This indicates that the quality of the fruit is better than the fruit grown in conventional climatic conditions. Furthermore, it promotes the biosynthesis of carotenoids and phenolic compounds in tomatoes which are likely to benefit human health [46].

Fruit age also greatly affects the lycopene content in tomatoes. This can be seen from the results of previous studies that at the time of harvest it affects the lycopene content in tomatoes, the fruit harvested on June 11, 2001, has a lower fruit lycopene content than fruit harvested on July 11, 2001. Fruits harvested on 13 September 2001 contain lycopene was lower than the fruit harvested August 14, 2001 and August 29 2001 [39]. Physiologically immature fruit has a lower lycopene content than physiologically ripe fruit, but physiologically overripe fruit also has a lower lycopene content. The carotenoid content, as well as the antioxidant activity of lypo-philic, was more influenced by the maturation stage than the cultivar which was determined to be less although the effect was significant. The glycolipid content depends on the cultivar stage and maturation [23].

The process of respiration affects the content of lycopene, because during storage the process of respiration occurs which makes lycopene degraded into terpenes so that the lycopene content decreases. In fact, the water content in tomatoes will increase with each storage, because one of the results of this process is water [45]. Hydrophilic anti-oxidative activity is typology-dependent, and independent of the maturation stage. Cherry tomatoes have the highest lipophilic and hydrophilic antioxidant abilities; In addition, its high carotenoids combined with low glycocaloid content. Therefore it is necessary to conduct research on the factors related to pre and post harvest conditions that must be taken into account to better understand their effects on the synthesis and accumulation of components such as carotenoids and glycocaloids as well as antioxidant abilities. All of these factors contribute to the determination of tomato quality, particularly in terms of the health-related properties of this fruit [23].

A larger proportion of water results in a decrease in lycopene content. Considerable differences can be observed between greenhouse production and open fields. In the field, climatic factors cannot be controlled and plant stands are exposed to high temperatures and rainfall. Plants grown in the field show lower lycopene content than in greenhouses. Significant differences were also observed between different varieties in terms of lycopene content. An understanding of the relationship between the factors that influence lycopene levels and the content of other compounds with antioxidant properties is necessary if the potential benefits for human health are to taken from tomato consumption [47].

The effect of using various enzyme concentrations on the maximum extraction of lycopene from all dental tumors. The results of the enzyme-assisted extraction showed an increase in lycopene yield of 96.3/g / g (144%), in the case of the cellulase-treated samples. Cellulase acts on cellulose. Lycopene extraction using cellulases and pectinases from various fractions and tomato waste showed that cellulases and pectinases were effective in increasing the yield of lycopene. For whole tomatoes, pectinase was more effective than cellulose, with an increase in lycopene yield of 108 g / g (224%). For tomato peels used as a source of lycopene, pectinase was also found to be more effective than cellulose, with an increase in lycopene yield of 1104 μg / g (206%). Fruit pulper waste showed an increase in lycopene extraction yield of 119 g / g (23%) for cellulase and 190 g / g (52%) for samples treated with pectinase. Once again, pectinase was proven to be more effective than cellulase for lycopene extraction from pulp waste. However, there was an increase in lycopene yield of 202 g / g (61%) and 156 μg/g (45%) respectively for industrial waste samples treated with cellulase and pectinase. Therefore, cellulase enzymes are more effective than pectinases for lycopene extraction from industrial waste. Of all the fractions and tomato waste studied as a source of lycopene, it turned out that tomato peels showed the highest increase in lycopene yield using the pectinase enzyme. The two enzymes used in this study were found to improve lycopene recovery from tomato waste. In conclusion, the amount of valuable lycopene pigment in tomatoes, which is lost as waste in processing, can be recovered in high yield by extraction using cellulases and pectinases [48].

Processing of tomato pulp in the presence of 5% lipids led to the following results and hypotheses. Adding lipids before processing clearly increases the bio-accessibility of lycopene. However, the type of lipid added is not very important compared to the applied process conditions. Processing can remove cellular barriers to the accessibility of lycopene in tomato-based products. However, it remains unclear which barrier (cell wall or chromoplast) is affected by which unit operation and under what conditions. Therefore, a more detailed study in this context is suggested. As a practical guideline for increasing the bio-accessibility of lycopene, intense thermal processing is recommended for large tomato particles while less intense conditions are sufficient for smaller tomato particles obtained by prior mechanical processing to damage the cellular structure. Although in vitro digestion models have proven to be valuable tools for predicting phytochemical bioavailability in foods, further (in vivo) bioavailability studies are needed to confirm the findings of this study. The results presented can be used as a guide for this in vivo experiment [49]. So the content of lycopene in fruit is not only influenced by plant genetics, environmental factors and fruit processing also greatly affect the content in tomatoes.

Author details

Dwi Setyorini[1,2]

1 Assessment Institute for Agricultural Technology, East Java, Indonesia

2 Indonesian Agency Agricultural for Research and Development, Jakarta, Indonesia

*Address all correspondence to: rinibptpjatim@gmail.com

References

[1] I. Gunawan, I. Gede Bawa, and N. Sutrisnayanti, "Isolasi dan Identifikasi Senyawa Terpenoid yang Aktif Antibakteri pada Herba Meniran(Phyllanthus niruri Linn) (Isolation and Identification of Antibacterial Active Terpenoid Compounds in Meniran Herbs (Phyllanthus niruri Linn))," *J Kim*, vol. 2, no. 1, pp. 31-39, 2008.

[2] D. Tholl, "Terpene synthases and the regulation, diversity and biological roles of terpene metabolism," *Curr Opin Plant Biol*, vol. 9, no. 3, pp. 297-304, 2006, doi: 10.1016/j.pbi.2006.03.014.

[3] S. Lenny, "Senyawa Flavonoida , Fenilpropanoida dan Alkaloida (Flavonoids, Phenylpropanoida and Alkaloida Compounds)," USU Repository, Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Sumatera Utara, 2006.

[4] D. B. Rodriguez-Amaya, *A Guide to Carotenoid Analysis in Foods*. Campinas, SP., Brasil: ILSI Press, International Life Sciences Institute, One Thomas Circle, N.W. Washington, D. C. 20005-5802, 2001.

[5] Ramadani, "Senyawa Kimia Bahan Alam Terpenoid (Natural Terpenoid Chemical Compounds)," *Tarbawi J Ilmu Pendidik*, vol. 1, no. 1, pp. 1-9, 2016.

[6] J. Graßmann, "Terpenoids as Plant Antioxidants," *Vitam Horm*, vol. 72, no. 05, pp. 505-535, 2005, doi: 10.1016/S0083-6729(05)72015-X.

[7] C. I. Keeling, "Terpenoid biomaterials," *Plant J*, vol. 54, pp. 656-669, 2008.

[8] D. J. Mcgarvey and R. Croteau, "Terpenoid Metabolism," *Plant Cell*, vol. 7, no. July, pp. 1015-1026, 1995.

[9] G. Britton, S. Liaaen-Jensen, and H. (ed.. Pfander, "Carotenoids. Handbook," in *Photosynthetica*, vol. 42, no. 2, 2004, pp. 186-186.

[10] H. Hug, M. Bader, P. Mair, and T. Glatzel, "Biophotovoltaics : Natural pigments in dye-sensitized solar cells q," *Appl Energy*, vol. 115, pp. 216-225, 2014, doi: 10.1016/j.apenergy.2013.10.055.

[11] S. T. Mayne, "Beta-carotene, carotenoids, and disease prevention in humans.," *FASEB J*, vol. 10, pp. 690-701, 1996.

[12] Hasri, "Kandungan Likopen Buah Tomat (Lycopersicum esculentum l.) terhadap Waktu dan Suhu Pemanasan (Content of Tomato Lycopene (Lycopersicum esculentum l.) On Heating Time and Temperature)," *J Ilm Kim dan Pendidik Kim*, vol. 16, no. 2, pp. 28-35, 2015.

[13] S. Apriliani, "Analisa Kadar Likopen pada Pasta Tomat Dengan Menggunakan Spektrofotometer Genesys 20 Visible (Analysis Content of Lycopen on Tomato Pasta using Genesys 20 Visible Spectrophotometer)." Universitas Diponegoro (Diponegoro University), p. 34, 2015.

[14] A. Z. Mercadante and D. B. Rodriguez-Amaya, "Effects of Ripening, Cultivar Differences, and Processing on the Carotenoid Composition of Mango," *J Agric Food Chem*, vol. 46, no. 1, pp. 128-130, 1998, doi: 10.1021/jf9702860.

[15] J. Gross, "Chlorophyll and carotenoid pigments in Ribes fruits," *Sci Hortic (Amsterdam)*, vol. 18, no. 2, pp. 131-136, 1982.

[16] A. V. Rao, M. R. Ray, and L. G. Rao, "Lycopene," *Adv Food Nutr Res*, vol. 51, no. 06, pp. 99-164, 2006, doi: 10.1016/S1043-4526(06)51002-2.

[17] L. M. Alda *et al.*, "Lycopene content of tomatoes and tomato products,"

J Agroaliment Process Technol, vol. 15, no. 4, pp. 540-542, 2009.

[18] I. Fitricia, D. Winarni, and I. B. R. Pidada, "Pengaruh Pemberian Tomat (*Solanum lycopersicum* L.) Terhadap Histologi Kelenjar Mammae Mencit Yang Diinduksi 7,12-Dimetilbenz (A)Antrasena (DMBA) (Effect of Giving Tomato (*Solanum lycopersicum* L.) on Mice Histology of Mammal Glands, Induced 7,12-Dimethylbe," *J Mat dan Ilmu Pengetah Alam*, vol. 15, no. 2, pp. 52-56, 2012.

[19] Q. P. Arnanda and R. F. Nurwarda, "Penggunaan Radiofarmaka Teknesium-99M dari Senyawa Glutation dan Senyawa Flavonoid Sebagai Deteksi Dini Radikal Bebas Pemicu Kanker (Use of Technetium-99M Radiopharmaceuticals from Glutathione Compounds and Flavonoid Compounds as Early Detection of Cancer," *J Farmaka*, vol. 17, no. 2, pp. 236-243, 2019.

[20] H. Li, Z. Deng, R. Liu, S. Loewen, and R. Tsao, "Carotenoid compositions of coloured tomato cultivars and contribution to antioxidant activities and protection against H(2)O(2)-induced cell death in H9c2," *Food Chem*, vol. 136, no. 2, pp. 878-88, Jan. 2013.

[21] P. Di Mascio, S. Kaiser, and H. Sies, "Lycopene as the most efficient biological carotenoid singlet oxygen quencher," *Arch Biochem Biophys*, vol. 274, no. 2, pp. 532-538, 1989, doi: 10.1016/0003-9861(89)90467-0.

[22] D. Heber and Q. Y. Lu, "Overview of mechanisms of action of lycopene," *Exp Biol Med*, vol. 227, no. 10, pp. 920-923, 2002.

[23] *C. leonardi et al.*, "Antioxidative Activity and Carotenoid and Tomatine Contents in Different Typologies of Fresh Consumption Tomatoes," *J Agric Food Chem*, vol. 48, pp. 4723-4727, 2000.

[24] K. Thanigai Arul, E. Manikandan, and R. Ladchumananandasivam, *Nanoarchitectonics in Biomedicine*, no. March. Bucharest, Romania: Elsevier, 2019.

[25] E. Giovannucci, "Promises and Perils of Lycopene/Tomato Supplementation and Cancer Prevention Tomato: Tomato Products, Lycopene, and Prostate Cancer: A Review of the Epidemiological Literature," *Am Soc Nutr Sci J Nutr*, vol. 135, no. Mei, pp. 2030S–2031S, 2005.

[26] P. Palozza, R. E. Simone, A. Catalano, and M. C. Mele, "Tomato lycopene and lung cancer prevention: from experimental to human studies.," *Cancers (Basel)*, vol. 3, no. 2, pp. 2333-57, Jan. 2011.

[27] Y. M. Peng *et al.*, "Concentrations of carotenoids, tocopherols, and retinol in paired plasma and cervical tissue of patients with cervical cancer, precancer, and noncancerous diseases," *Cancer Epidemiol Biomarkers Prev*, vol. 7, no. 4, pp. 347-350, 1998.

[28] S. Zhang *et al.*, "Measurement of retinoids and carotenoids in breast adipose tissue and a comparison of concentrations in breast cancer cases and control subjects," *Am J Clin Nutr*, vol. 66, no. 3, pp. 626-632, 1997.

[29] A. V. Rao and L. G. Rao, "Carotenoids and human health," *Pharmacol Res*, vol. 55, no. 3, pp. 207-216, 2007.

[30] L. Arab, S. Steck-Scott, and P. Bowen, "Participation of lycopene and beta-carotene in carcinogenesis: defenders, aggressors, or passive bystanders?," *Epidemiol Rev*, vol. 23, no. 2, pp. 211-30, Jan. 2001.

[31] Nurhayat Atasoy, "Biochemistry of lycopene," *J Annu Vet Adv*, vol. 11, no. 15, pp. 2605-2610, 2012.

[32] H. Choi and D. G. Lee, "Lycopene induces apoptosis in Candida albicans

through reactive oxygen species production and mitochondrial dysfunction," *Biochimie*, vol. 115, pp. 108-115, 2015, doi: 10.1016/j.biochi.2015.05.009.

[33] M. Stacewicz-Sapuntzakis and P. E. Bowen, "Role of lycopene and tomato products in prostate health," *Biochim Biophys Acta - Mol Basis Dis*, vol. 1740, no. 2, pp. 202-205, 2005, doi: 10.1016/j.bbadis.2005.02.004.

[34] C. Rosati et al., "Metabolic engineering of beta-carotene and lycopene content in tomato fruit," *Plant J*, vol. 24, no. 3, pp. 413-420, 2000, doi: 10.1046/j.1365-313X.2000.00880.x.

[35] S. E. Cox, C. Stushnoff, and D. A. Sampson, "Relationship of fruit color and light exposure to lycopene content and antioxidant properties of tomato," *Can J Plant Sci*, vol. 83, no. 4, pp. 913-919, 2003.

[36] H. Li, Z. Deng, R. Liu, S. Loewen, and R. Tsao, "Ultra-performance liquid chromatographic separation of geometric isomers of carotenoids and antioxidant activities of 20 tomato cultivars and breeding lines," *Food Chem*, vol. 132, no. 1, pp. 508-517, 2012, doi: 10.1016/j.foodchem.2011.10.017.

[37] J. O. Kuti and H. B. Konuru, "Effects of genotype and cultivation environment on lycopene content in red-ripe tomatoes," *J Sci Food Agric*, vol. 85, no. 12, pp. 2021-2026, 2005, doi: 10.1002/jsfa.2205.

[38] P. P. Tinyane, D. Sivakumar, and P. Soundy, "Influence of photo-selective netting on fruit quality parameters and bioactive compounds in selected tomato cultivars," *Sci Hortic (Amsterdam)*, vol. 161, pp. 340-349, 2013, doi: 10.1016/j.scienta.2013.06.024.

[39] L. Helyes, A. Lugasi, and Z. Pék, "Effect of natural light on surface temperature and lycopene content of vine ripened tomato fruit," *Can J Plant Sci*, vol. 87, no. 4, pp. 927-929, Oct. 2007.

[40] Z. S. Ilić and L. Milenković, "The Influence of Photo-selective Shade Nets on Quality of Tomatoes Grown Under Plastic Tunnels and Field Conditions," 2010.

[41] F. Khumairot, "Pertumbuhan dan Produksi Tomat (Lycopersicon esculantum Mill.) Toleran Naungan pada Pola Tanam Tumpangsari (Shade Tolerance of Tomato (Lycopersicon esculantum Mill.) Growth and Production in Tumpangsari Planting Patterns)," p. 29, 2014.

[42] D. Setyorini, Y. Sugito, N. Aini, and S. Yudho Tyasmoro, "Lycopene, beta-carotene and productivity of tomato varieties at different shade levels under medium land of Indonesia," *J Appl Hortic*, vol. 20, no. 02, pp. 92-96, 2018.

[43] Y. Dumas, M. Dadomo, G. Di Lucca, and P. Grolier, "Effects of environmental factors and agricultural techniques on antioxidant content of tomatoes," *J Sci Food Agric*, vol. 83, no. 5, pp. 369-382, 2003.

[44] R. K. Toor, G. P. Savage, and C. E. Lister, "Seasonal variations in the antioxidant composition of greenhouse grown tomatoes," *J Food Compos Anal*, vol. 19, no. 1, pp. 1-10, 2006.

[45] Bunga Ludya Fitri, "Pengaruh Varietas dan Lama Penyimpanan terhadap Kandungan Lykopen Buah Tomat (Effect of Variety and Storage Time on the Lykopen Content of Tomatoes)," Universitas Islam Negeri Malang, 2007.

[46] D. Dannehl, C. Huber, T. Rocksch, S. Huyskens-Keil, and U. Schmidt, "Interactions between changing climate conditions in a semi-closed greenhouse and plant development, fruit yield, and health-promoting plant compounds of

tomatoes," *Sci Hortic (Amsterdam)*, vol. 138, pp. 235-243, 2012.

[47] S. Brandt, A. Lugasi, É. Barna, J. Hóvári, Z. Pék, and L. Helyes, "Effects of the growing methods and conditions on the lycopene content of tomato fruits," *Acta Aliment*, vol. 32, no. 3, pp. 269-278, 2003, doi: 10.1556/AAlim.32.2003.3.6.

[48] S. M. Choudhari and L. Ananthanarayan, "Enzyme aided extraction of lycopene from tomato tissues," *Food Chem*, vol. 102, no. 1, pp. 77-81, 2007, doi: 10.1016/j.foodchem.2006.04.031.

[49] I. J. P. Colle, L. Lemmens, S. Van Buggenhout, K. Met, A. M. Van Loey, and M. E. Hendrickx, "Processing tomato pulp in the presence of lipids: The impact on lycopene bioaccessibility," *Food Res Int*, vol. 51, no. 1, pp. 32-38, 2013, doi: 10.1016/j.foodres.2012.11.024.