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*Review Article*

# Influence of Thermal Treatments, Extraction Methods, and Storage Conditions on Lycopene Content of Foods

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Lycopene is one of the main carotenoids in our daily diet. Fruit variety, environmental conditions, and maturity stage are the factors affecting the content of lycopene. Various processing techniques and extraction methods may also affect the level of lycopene in different food products, consequently changing the biological role of lycopene. The biological role of lycopene is to defend the tissues of tomatoes (conjugate bonds) and attract predators (red colour). Moreover, storage conditions also impact the lycopene content of fruits, vegetables, and their products. Efficient and novel technological interventions are required for stabilizing lycopene content during postharvest procedures, such as refrigeration, heating, extraction, and transportation. Therefore, the study of different crucial factors concerning the change in lycopene content is required. The present review explores the lycopene content of different food commodities and the effect of postharvest operations and processing techniques on lycopene content. It also highlights the storage impact on the concentration of lycopene which may be useful for future studies.

## 1. Introduction

Lycopene is a natural pigment that falls under the carotenoid family. Lycopene is a fat soluble, red-coloured pigment, found in various fruits and vegetables, such as tomato, papaya, rosehip, pink grapefruit, watermelon, and gac fruit. However, the highest level of lycopene has been determined in fresh tomatoes (0.77–20) and the lowest in apricots (0.01–0.05) in mg/100 g fresh weight [1–3]. The amount of lycopene in fresh fruits depends on the variety, maturity level, and climatic conditions. Tomatoes (specifically deep red-coloured fruits) contain a higher amount of lycopene (80–90%) and a negligible concentration of other carotenoids such as lutein, $\alpha$-carotene, $\beta$-carotene, and $\beta$-cryptoxanthin. Therefore, vast research is carried out on tomato and tomato products than on any other commodity due to their lycopene content [4–6]. The lycopene content of some selected foods is presented in Figure 1.

As per the research, a sufficient amount of lycopene consumption may impart protection against many cardiovascular diseases, cancer, loss of brain function, and macular degradation[9]. Moreover, epidemiological studies revealed that lycopene protects against lung, prostate, breast, cervix, and skin cancer and lowers the blood cholesterol level and serum lipid oxidation [10, 11]. In addition to this, lycopene possesses higher antioxidant power than vitamin E to inactivate reactive oxygen species (ROS) for preventing cell damage related to the risk of chronic diseases [7, 8].

During various processing methods, lycopene undergoes isomerization and gets degraded or oxidized, which consequently impacts on sensory quality of food and health gains [12]. Lycopene degradation affects the colour of final products and sensory quality as well [13]. Therefore, it is crucial to study the effect of different food processing methods on the concentration and stability of lycopene content.

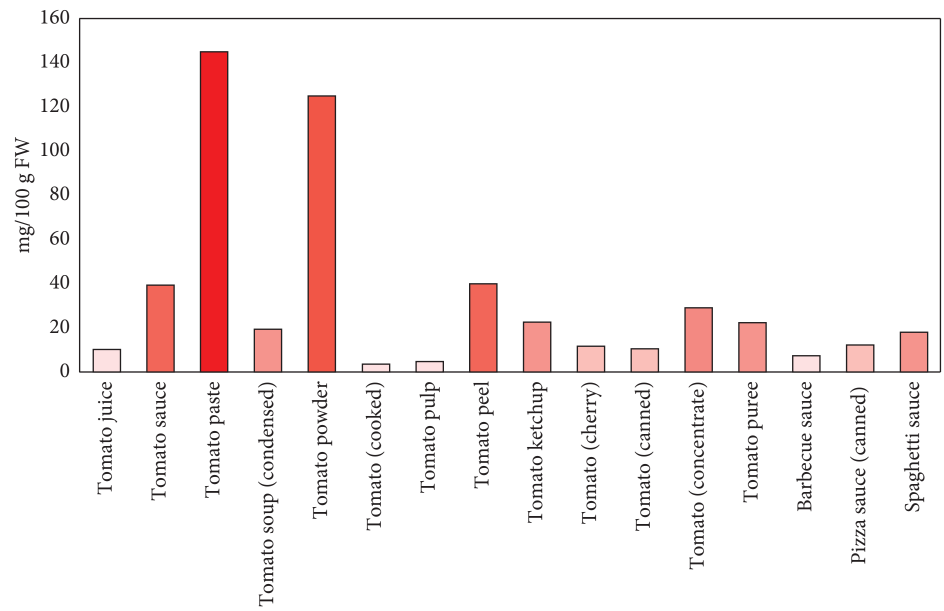


Figure 1: Lycopene content of some food products. Sources: [5–8].

## 2. Effect of Postharvest Operations on Lycopene Content

Postharvest operations mainly include cleaning, sorting, packaging, storage, and transportation [14]. Such operations may influence the level of lycopene in fruits and vegetables, such as tomato, cucurbits, citrus fruits, grapefruit, and their products [15–18]. Hence, cost-effective, innovative, and efficient postharvest procedures must be utilized for the retention of lycopene in food products.

*2.1. Effect of Transportation and Packaging Conditions.* The chemical changes of fresh vegetables may be accelerated during longer-distance transportation. The temperature during storage has an impact on the quality of fresh products as well [15]. A study was conducted to investigate the influence of transportation conditions (distance: 100, 154, and 205 km; temp: 10 and 20; time required: 75, 120, and 180 min) on lycopene content of tomato fruit (Miral variety). Results showed that the tomato group that travelled a long way (205 km) and kept at 22°C on day 12 had the highest level of lycopene, i.e., 1.21 mg/100 g FW [15]. Likewise, Munhuewyi [19] disclosed that the lycopene growth in tomatoes is significantly influenced by the ambient storage condition, i.e., 22–25°C. It can be concluded that that long transport distances can accelerate ripening, which increases the development of the red colour as well as the amount of lycopene and carotenoids in the produce. For instance, a change in fruit firmness, moisture content, colour, and carotenoids of watermelon, tomatoes, and strawberries was identified as the distance increases during the transportation [20].

Controlled atmosphere (CA) and modified atmosphere packaging (MAP) are very useful storage technologies to enhance the shelf life of fresh produce. In order to control the amounts of $O_2$ and $CO_2$, MAP involves changing the gaseous environment through respiration (passive MAP) or by adding and removing gases from food packages (active MAP). Such packaging methods lower ethylene production, delay textural softening, reduce ripening, delay respiration, and slow down compositional changes related to ripening, which results in an extended shelf life of the commodity [21]. A study on tomatoes was carried out in the CA atmosphere (20% of $CO_2$ and 30% of $O_2$) that showed an inhibition of lycopene accumulation, while an increment in the lycopene content was observed when tomatoes were kept in the ambient condition [22]. Cherry tomatoes (cv. "Josefina") were packed in a plastic bag, and 5% $O_2$ + 5% $CO_2$ + 90% $N_2$ were injected, followed by the storage for 25 days at 5°C. A reduction in lycopene concentration was found in MAP samples, i.e., 39 g/L compared to the control (53 g/L) [21]. Likewise, MAP of watermelon varieties in 10 kPa $O_2$ showed a minor decline in lycopene concentration for 7 or 10 days at 2°C [23].

*2.2. Effect of Storage Conditions on Lycopene.* Lycopene increases with ripening and accumulates effectively during storage [24]. The harvesting stage plays an important role in affecting lycopene content. Fruits were found to have more lycopene when harvested at the breaker stage than at the green stage [25]. Oxygen and light have likewise effects on lycopene content in processing. The temperature has also a crucial role in lycopene loss during storage.

Canned tomato juice was stored at 25°C and 37°C for the period of 1 year, but no lycopene loss was obtained [26]. Lavelli and Giovanelli [27] stored commercial tomato paste, puree, and pulp at 30, 40, and 50°C for up to 90 days and examined no significant change in lycopene concentration. The added preservatives during manufacturing could be a reason for this. As per the study of frozenly stored foods, watermelon had decreased levels of lycopene (about 40%)

when stored between −20°C and −80°C temperature for 1 year [28]. In addition to this, a study revealed that the lycopene degradation was higher in tomato ingredients of frozen pizza than in frozenly stored tomato puree and diced [29]. Inversely, when diced tomatoes were stored at −20°C and −30°C, no change in lycopene content was observed throughout 1 year [30]. Lycopene degradation becomes lower due to the exclusion of oxygen when tomato products are frozenly stored [31].

A slower accumulation of lycopene was observed when conventionally grown tomatoes cultivars, i.e., "Monika," "Delfine," "Marlyn," "Fanny," "Linda," etc. were stored at a low temperature (4°C) whereas lycopene increased up to 70% in hydroponically grown tomatoes. The reason is unknown for this increment [9]. In a study, greenhouse tomatoes of salad cv. "Tradiro" were stored for 10 days at different temperatures, i.e., 7, 15, and 25°C. Temperatures of 15 and 25°C showed two fold more lycopene concentration in tomatoes (7.5 mg/100 g) than at 7°C (3.2 mg/100 g) [3]. Gil et al.[32] stored minimally processed watermelon (fresh cut) for up to 9 days at 5°C and found a slight decrease in lycopene content. Application of ethylene after harvesting also triggers fruit ripening and accumulation of lycopene, while lycopene synthesis was inhibited by lycopene inhibitors [32].

Oxidation and isomerization are the main factors of lycopene loss during dried tomato storage. Oxidation rises with respect to the increased temperature of storage; however, isomerization goes higher with increased storage time under lightening conditions [7]. According to Sharma and Le Maguer [33], oven-dried and freeze-dried tomato pulp lost their lycopene content up to 79% and 97%, respectively, between temperature ranges of 25–75°C under the storage of 4 months. The freeze-dried pulp had more volume and fluffy texture compared to oven-dried samples with thin crust sheets. This incidence revealed that light and air exposure to freeze-dried fibers was the cause of a higher loss of lycopene content. Lovrić et al. [34] carried out a storage study of foam-mat-dried tomato powder in the presence of oxygen for comparison with samples stored in air and $N_2$ and found that oxygen plays an important role in lycopene retention throughout storage. Moreover, Lavelli and Giovanelli [27] checked tomato paste (in aluminium tubes), pulp (in cans), and puree (in glass bottles) for 3 months at 25°C, 30°C, and 40°C temperatures, and they observed that the lycopene content was stable in all the samples. The packaging materials might have played an important role in the stability of lycopene levels.

Li et al. [35] conducted research on tomato hot pot sauce at different storage temperatures (0, 25, and 37°C) for 120 days with two types of packaging materials. They concluded that there was no specific difference in the lycopene content of both the packaging materials at 0°C up to 120 days, but at 25°C and 37°C temperatures, lycopene content decreased in both kinds of packaging samples. Similarly, tomato ketchup was stored at 30°C for up to 8 months, but no difference in lycopene concentration was obtained [36]. Patanè et al. [37] packaged fresh-cut tomatoes and stored them at 4°C for 12 days and reported about a 45% drop in lycopene content, which was 100–110 mg/kg. In reverse to this, Odriozola-Serrano et al. [38] observed a slight increment in lycopene concentration of sliced (fresh-cut) tomatoes at 4°C up to 21 days of storage than a decline in lycopene content. The effect of storage temperature and duration is given in Table 1 for various commodities.

## 3. Effect of Different Processing Factors on Lycopene Content

Various common foods contain lycopene, which comprises our daily diet. Only tomato and tomato products provide ~85% of lycopene intake [47, 48]. As per the FAO (Food and Agriculture Organization) data, China is the top producer (6,75,38,340 tonnes) of tomato followed by India (2,11,81,000 tonnes), and the United States of America (1,04,75,265) [49]. In terms of processing, the USA processed more than 95% of tomatoes in California alone, which makes up 40% of global production [48]. Besides the USA, Italy, China, Spain, and Turkey are the top tomato-processing countries [50].

Approximately 80% of tomatoes produced are consumed in the processed form of tomato paste, puree, ketchup, juice, salsa, and sauce. Lycopene content changes during processing in the industry or home. Thermal processing (cooking, pasteurization, blanching, drying, and frying) can decrease lycopene content but on the other hand, it may increase the lycopene availability by disrupting the cell wall and liberating the bound molecules for better solubilization [51–54]. Processed foods get converted from cis to trans form due to the unstability of the cis isomer in comparison to the trans isomer [5, 55].

*3.1. Impact of Temperature and Other Processing Techniques.* Usually, tomato juice is concentrated through vacuum evaporation and steam coils for the production of different tomato products such as puree, paste, pulp, and ketchup. Sliced or whole tomatoes are retarded for canned tomatoes, and dehydration is carried out for the production of tomato powder and dried slices. The thermal processes applied for such products may affect their lycopene content. The lycopene content of processed tomato products is considered lower than exact because of processing. Isomerization and oxidation are the main causes of lycopene degradation during processing [56].

In tomato processing, oxidation is a composite process and depends on various components such as temperature, moisture, and processing conditions. Miki and Akatsu [57] heated tomato juice at 90°C and 100°C temperatures and observed a 1.1% and 1.7% decrease in lycopene content, respectively. As the temperature rose to 130°C, lycopene degraded by 17%. Dewanto et al. [58] conducted research on raw tomatoes and found a 1.6-fold elevated level of lycopene by heating, at 88°C for 2 minutes compared to nonheated fruits. Jabbari et al. [13] heated tomato juice at 30°C for 30 seconds with a 4% nanofluid heating medium and observed 60% lycopene retention. In a prolonged heating study of tomato pulp at 100°C for 2 h, partial degradation (18%) of lycopene content was observed [33]. The experimental

Table 1: Effect of storage duration and temperature on lycopene content.

| Storage temperature | Storage duration | Commodity | Effect on lycopene | References |
|---|---|---|---|---|
| <0°C | 12 months | Tomato pulp: prepared from "Micra RS" tomatoes and frozen followed by storage at −20°C | Decreased 48% | [30] |
| | 50 days | Tomato puree: puree was prepared in hot oil followed by packaging and storage at −18°C | Decreased 18.5% | [29] |
| | 12 days | Pizza: pizza topped with tomato puree (prepared in oil) was packaged in low $O_2$ barrier packaging and storage at −18°C | Decreased 72% | [31] |
| | 12 months | Watermelon: "Sangria" cultivar was cut into 3 $cm^3$ chunks and packed 10 g of it a plastic bag and stored at −20°C | Decreased 30–40% | [28] |
| | 12 months | Tomatoes (diced): cubes (12 × 12 × 12 mm) were cut followed by filling in plastic boxes 500 g and frozen at −40°C | No change | [30] |
| | 12 days | Tomato: "BOS 3155" variety (conventionally grown) was homogenized (1500 g) and stored at −20°C | Decrease 9–28% | [39] |
| 0–10°C | 12 days | Tomato fruits: hydroponically grown and stored at 4°C | Increased 70% | [9] |
| | 9 days | Watermelon: two central rings were cut into 4 cm cubes and stored at 5°C | Decreased 7780.4 ± 346.6 ug/100 g | [40] |
| | 9 days | Mango: fruit was sliced (2 × 2 × 2 cm) into cubes after peeling and stored at 5°C | Increased 2789.6 ± 125.6 ug/100 g | [40] |
| | 9 days | Kiwifruit: five 7 mm thick slices were stored at 5°C | Decreased 232.7 ± 12.8 ug/100 g | [40] |
| | 9 days | Strawberry: out of 3 kg, 150 g fresh-cut fruit (4 pieces) was stored at 5°C after making | Increased 98.5 ± 11.5 ug/100 g | [40] |
| | 10 days | Watermelon: "sugar shack" variety (seedless) was cut into cubes (5 cm) and stored at 2°C | Decreased 7% | [23] |
| | 120 days | Tomato hot pot sauce: commercial tomato paste was mixed with soybean oil (25%), spice mixture, sucrose (14%), salt (2.5%), soy sauce (1%), and chicken essence (3%) at 160°C followed by storing at 0°C | No change | [35] |
| | 12 days | Tomato: Cv. "locale di vulcano" was cut into halves (longitudinally) and packed (~100 g) into conventional package followed by storage at 4°C | Decreased 45% | [37] |
| | 21 days | Tomato: cvs. "bola," "bodar," "cencara," "durinta," "rambo," and "pitenza," were cut into slices (7 mm) and packed into polypropylene trays and stored in modified atmosphere at 4°C | Increased 29.3 mg/kgfw | [38] |
| | 15 days | Cherry tomatoes: cv. "Punjab red cherry" was coated with pectin-based bionanocomposite films and packed in LDPE film followed by storage at 10°C with 90% RH (relative humidity) | Increased 7.4 ± 0.07 mg/100 g | [41] |
| | 56 days | Carrot: *Daucus carota* var. Kintoki was sliced after blanching (15 min at 70°C) and packed (250 g) to be stored at 1°C | Decreased 60% | [42] |
| | 12 days | Tomato: "Miral" variety was stored in a store house at 10°C with 95% RH | Increased from 0.12 to 0.42 mg/100 g | [15] |

Table 1: Continued.

| Storage temperature | Storage duration | Commodity | Effect on lycopene | References |
|---|---|---|---|---|
| >10°C | 1 year | Tomato juice: juice was extracted from cv. "FG99–218" by hot break process at 91°C followed by immediate cooling at 20°C and vacuum packaging (50 g juice) for storage at 36°C | Decreased 27% | [43] |
| | 90 days | Tomato products: commercial paste in (aluminium tubes, 130 g), puree (glass bottle, 700 g), and pulp (cans, 450 g) were stored in thermostatic condition (40°C) with their original packages | No effect | [27] |
| | 10 days | Tomato: hydroponically harvested cv. "Tradiro" tomatoes were placed in cardboard boxes and stored at 15°C in the dark | Increased 3-fold of 3.6–9.0 mg/100 g | [3] |
| | 4 months | Tomato pulp: fresh raw fruits cv. "H-9035" chopped and ground into pulp followed by heating (100 g) at 100°C, centrifugation, and freeze-drying and its fiber fraction was stored at 25°C in air and light conditions | Decreased 73.3–78.9% | [33] |
| | 4 months | Tomato pulp: fresh raw fruits cv. "H-9035" chopped and ground into pulp followed by heating (100 g) at 100°C, centrifugation, and oven-drying and its fiber fraction was stored at 50°C in air and light conditions | Decreased 97% | [33] |
| | 120 days | Tomato hot pot sauce: commercial tomato paste was mixed with soybean oil (25%), spice mixture, sucrose (14%), salt (2.5%), soy sauce (1%), and chicken essence (3%) at 160°C followed by storing at 37°C | Decreased 83 mg/kg | [35] |
| | 8 months | Tomato ketchup: ketchup was prepared using tomato paste (72%, 32° brix), salt (1%), sugar (5%), soybean fiber (3%), and water (19%) followed by preheating at 55°C, homogenization (20 MPa), sterilization (90°C, 15 min), and cooling (RT) and stored at 30°C | No change | [36] |
| | 42 days | Tomato powder: commercial spray-dried powder (0.2 g portion) was packed into glass vials (crimped cap: 20 ml) and stored at 45°C | Decreased 60% | [44] |
| | 6 days | Gac fruit: medium ripen fruit was stored at 26°C with 24% RH | Increased 50.11 ± 1.59 mg/100 g FW | [45] |
| | 8 days | Cherry tomatoes: cv. "Punjab Red Cherry" was coated with pectin-based bionanocomposite films and packed in LDPE film followed by storage at 30°C with 61.2% RH | Increased 7.6 ± 0.42 mg/100 g | [41] |
| | 180 days | Tomato: fresh tomato (var. "Punjab Ratta") was sliced (5–8 mm) followed by blanching (100°C, 15 s), dipping in citric: ascorbic acid (1 : 1) solution for 10 min, and dried using convection dryer (hot air cabinet: 60°C, 1.5 m/s velocity) to obtain fine powder. Then, stored at RT (28°C) | Increased 131.11 ± 0.04 mg/100 $g_{db}$ | [46] |

parameters such as time, pressure, temperature, and cultivar variety are the crucial points that influence lycopene levels. For instance, a trend of lycopene loss (up to 85.30%) was observed when tomato slurries of 8 different cultivars were cooked for 3 h [59]. Moreover, 10.5–20.5% lycopene loss was observed in three tomato cultivars when dried at 42°C for 18 h [3]. In addition to this, the lycopene content was decreased by 12–28% when tomatoes were processed into tomato paste [60]. Similarly, when tomato was processed into a paste, the lycopene was lost up to 32% [61]. It was observed that thermal treatments such as frying, blanching, steaming, and microwaving tomato fruits have a positive impact on lycopene levels [62, 63]. Khachik et al. [64] reported that lycopene concentration increased up to 12% in ripe tomatoes during stewing and approximately 8-fold during paste production. Homogenization of tomato juice degraded the lycopene content [65]. In an experiment, baking and boiling of tomatoes resulted in a slight effect on lycopene, while a decline was observed in frying tomatoes [66]. Graziani et al. [67] observed increased lycopene concentration when tomatoes were heated for 2 h at 100°C in an oil bath. Apart from this, Re et al. [68] explored that tomato pulp processing for paste production under different temperatures enhanced lycopene concentration, but when tomato puree was pasteurized at 60–85°C, no effect on lycopene was reported [69]. Besides tomato and its products, other food commodities have also shown changes in their lycopene content during processing. For instance, lycopene-containing oil-in-water emulsions were incubated at 5 to 90°C while being kept oxygen-free. The initial 9-cis-lycopene concentration of the emulsions increased to 150% during 7 hours of incubation at 90 C, but only 50% of the 13-cis-lycopene was destroyed [70]. Similarly, the heating of guava juice resulted in a 5-fold increment of lycopene content due to trans-cis isomerization [71]. When Kintoki carrots were blanched at 90°C for 15 minutes, lycopene content was enhanced by 15% [53]. It may be due to the variation in processing conditions and commodities.

Tomato concentrate was processed through four different techniques, such as conventional hot break, waring blender with steam, steam injection, and high temperature with shear (HTS), and the highest lycopene increment was found with HTS (32.28 mg/100 g) [72]. Further, Oberoi and Sogi [73] sprayed/freeze-dried watermelon juice adding maltodextrin (3%–10%) and found an increase in lycopene concentration of freeze-dried powder (62.3 mg/100 g) and spray-dried powder (54.6 mg/100 g) compared to fresh juice (6.53 mg/100 g). They concluded that the maltodextrin improved the yield and retained the sensory attributes of the samples. During the ultrasound processing of guava juice, a decrease was observed in lycopene content from 29.4 $\mu$g/g to 15.18 $\mu$g/g after 9 minutes [74]. Likewise, Rawson et al. [75] reported a decline in lycopene content in watermelon juice when subjected to ultrasound processing. Inversely, no change was observed in the lycopene concentration of guava juice and tomato puree under ultrasound treatment [76, 77]. The change in lycopene content was due to oxidation and heat; however, lycopene is found to be more sensitive to direct heat as compare to ultrasound. In a study by González-Casado et al. [78], the pulse electric field technique enhanced 150% lycopene accumulation in tomatoes during storage at 12°C for 5 days. When the ultrafiltration process was applied to papaya juice with a PS 100 membrane and 1 bar pressure at 6 m/s tangential velocity, 90% retention of lycopene was reported [79]. Jayathunge et al. [80] studied the combined effect of an ultrasonic, high-intensity pulse electric field and blanching processed for lycopene bioaccessibility in tomato fruit and achieved higher (9.6%) lycopene bioaccessibility. Novel techniques were found to retain or increase the lycopene content in foods because of their efficiency and customized operation. Similarly, Oliveira et al. [81] investigated the combined effect of microfiltration, reverse osmosis, and diafiltration processed on the lycopene content of watermelon juice. They observed a 17-fold increment in lycopene concentration. Further, when highly hydrostatically treated (50–400 MPa and 3–60 min) fresh-cut papaya fruit was stored at 4°C temperature, lycopene content increased by 11-fold compared to nontreated fruit [82]. The effect of various processing methods on lycopene content is consolidated in Table 2.

*3.2. Effect of Extraction Methods on Lycopene Content.* The extraction process is one of the important factors in achieving a higher amount of lycopene. The level of applied pressure, cell disintegration, and temperature impart better retrieval of lycopene [12]. Therefore, the pretreatment step is crucial for the disruption of physical barriers (cell wall and cell membrane) by thermal or chemical methods [95]. Cooking was observed as the most suitable method for obtaining higher lycopene content than milling and dehydration [42, 85]. There are various extraction techniques used for lycopene extraction such as liquid extraction with Soxhlet, microwave-assisted extraction, maceration, ultrasound-assisted extraction, solvent extraction later developed as pressurized liquid extraction, supercritical fluid extraction, and enzyme-assisted extraction [95, 96]. The microemulsion technique with surfactants was also reported as a useful method for lycopene extraction [97]. These conventional and innovative extraction methods are utilized to extract lycopene from different food commodities. Such techniques may vary according to their setup, conditions, and operations; therefore, the extraction yield of lycopene may also differ. It has been noticed that innovative techniques provide a better recovery of lycopene from the food matrix without any chemical residues and harm to the environment [98].

Pól et al. [99] optimized the supercritical fluid extraction (SC-$CO_2$) method (400 bar pressure, 90°C temperature, and 1.5 ml/min $CO_2$ flow rate) and recovered 100% lycopene content (in 35 min) in grapefruit, tomato, guava, tomato paste, watermelon, and rosehip paste. Apart from this, byproducts of dried tomato peel were undergone SC-$CO_2$ extraction at 90°C temperature, 40 MPa pressure, and 1.05 mm particle size, yielding 56% lycopene recovery [100]. Likewise, Perretti et al. [101] employed the SC-$CO_2$ extraction technique on tomato pomace powder at 30 MPa pressure and 15 kg/h $CO_2$ flow rate and obtained maximum

Table 2: Processing techniques and their impact on lycopene concentration.

| Processing methods | Product | Conditions | Effect on lycopene | Reference |
|---|---|---|---|---|
| Heating | Tomato | Heating at 75–95°C for 2 min | Decreased 19.46 ± 0.86 mg/100 g | [60] |
| | Guava juice | Heating at 60°C for 2 h | Increased 5-fold | [71] |
| | Pomelo | Heating at 100–120°C, for 0–5 h | Decreased 50% | [56] |
| | Tomato paste | Hot break at 90°C and concentrated at 90°C | Increased 4.50 g/100 g | [83] |
| | Tomato | Multistep heat-treatment-canning, sterilization by steam, scalding, and homogenization | No effect | [26] |
| | Tomato (paste) | Hot-break for 5–10 min at 90°C, boil at 70–80°C, and kept for 4 hours at 60–70°C under vacuum for evaporation | Increased 47.3 μg/g | [39] |
| Cooking and boiling | Rustic tomato sauce | Boiling for 30 min in olive oil | Increased 319.2 ± 13.4 μg/g | [84] |
| | Strained tomato sauce | Boiling for 30 min in olive oil | Increased 343.3 ± 27.7 μg/g | [84] |
| | Sofrito (with onion) | Heating at 100 ± 1°C (home cooking method) | Increased 122.6 μg/g | [85] |
| | Carrot (nutri red) | Cooking without oil, heating at 100°C | Increased 126 ± 3 $mg/kg_{w.b}$ | [86] |
| | Tomato (slurry) | Cooking in water bath for 1 hour at 100°C | Decreased 48.41–78.97 μg/g | [59] |
| | Tomato (pulp) | At 25°C, oven dried the pulp and stored at room temperature | Decreased 117.3 mg/100 g TS | [33] |
| | Tomato (juice) | Multistep heat treatment, canning, sterilization by steam, scalding, and homogenization | No effect | [26] |
| | Sweet potato (orange fleshed) | Boiling with 500 ml water for 15 min | Decreased 38–96% | [87] |
| | Tomato | Cooked for 15 min in 500 ml of boiling water | Decreased by 35.5 ± 21 | [66] |
| | Watermelon | Cooking into boiling water for 15 min | Decreased 41% | [88] |
| Drying | Tomato (paste) | Spray-dried at inlet temperatures 110–140°C, drying air flow rates of 17.50–22.75 $m^3/h$ (±0.18 $m^3/h$) and atomizing agent flow rate 500–8000 I/h. Pressure at 5 ± 0.1 bar, feed temperature 32.0 ± 0.5°C, and feed rate at 1.75 ± 0.05 g/ | Decreased 8.07–20.93% | [89] |
| | Tomato | Hot-air-dried for 2 h at 80°C then kept for 6 h at 60°C | Increased 8.90 ± 0.3 mg/100 g | [62, 63] |
| | Tomato | Homogenized with 80% acetone, then mixed at 5–7°C for 4 hours in a rotary mixer | Increased 9.0 mg/g | [3] |
| | Carrot (nutri red) | Hot air drying below 70°C | No effect | [90] |
| | Gac aril oil | Hot air drying at 50°C with 1.5 m/s air velocity | Increased 0.82 mg/g | [91] |
| | Watermelon juice | Freeze-drying with maltodextrin at −20°C | Increased 2.3 mg/100 g | [73] |
| | | Spray-drying with 3 g/min feed rate, 4 ml/min pump speed, 6.5 $m^3/min$ aspiration rate, 0.25 $kg/cm^2$ air pressure, 70°C outlet temperature, and 25°C inlet temperature | Increased 56.4 mg/100 g | |
| Stewing and frying | Tomato (ripen) | Stewing without addition of water in a covered pan for 8 min | Increased 4.40 ± 0.30 mg/100 g | [64] |
| | Tomato paste (Aranca) | Soaked into vinegar | Increased 49.8 ± 2.0 mg/100 g | [66] |
| | Tomato | Frying for 30 minutes | Increased 24.2 to 32.9% | [92] |
| Other methods: canning | Tomato pulp | Heating at 90–110°C | Increased 5.20 ± 0.25 mg/100 g | [76] |
| Blanching | Carrot (Kintoki) | Blanching between 50–90°C for 15 min | No effect | [42] |
| Homogenization | Tomato juice | Homogenized at 70 bar, feed rate 62.5 kg/h | Decreased 6.70 ± 0.22 mg/100 ml | [58, 65] |
| Pulse light processing | Tomato (fresh-cut) | Exposed to the highest pulse light fluence 8 $J \cdot cm^{-2}$ | Increased 57.25 mg/kg | [93] |
| UV-B radiation | Tomato | Irradiate for 1 h, 6.08 $kJ/m^2$ d | Increased 40% 59.91 ± 1.47 | [94] |

Table 2: Continued.

| Processing methods | Product | Conditions | Effect on lycopene | Reference |
| --- | --- | --- | --- | --- |
| Ultrasound processing | Guava juice | Power: 1000 W, frequency: 20 kHz using a 1.26 $cm^2$ titanium tip. Intensity power −15 $W/cm^2$ and volumetric power-121 W/L | Decreased 15.18 $\mu g/g \pm 3.58$ | [74] |
| | Tomato puree | Power density: from 55 to 5000 W/L and temperature: 23°C (ambient) to 60°C | No effect | [77] |
| High hydrostatic pressure treatment | Papaya (fresh-cut) | Treated at 50–400 MPa for 3–60 min | Increased $17.95 \pm 0.6$ mg/100 g | [82] |
| Microfiltration | Watermelon juice | Microfiltration at permeate flux 69.6 $kg/h/m^{-2}$ | Increased $229.77 \pm 6.86$ $\mu g/g$ | [81] |

lycopene recovery. Moreover, by-products of tomato peel were subjected to SC-$CO_2$ at 80°C, 4 g/min $CO_2$ flow rate, and 400 bar pressure, yielding 60.85% lycopene content [102]. It has been observed that the integrated methods showed better recovery of lycopene.

In the enzyme-assisted extraction (EAE) method, 10-fold higher content of lycopene was obtained from tomato waste when treated with pectinase and cellulase (122.5 and 70 U/g, respectively) [103]. In addition, when pectinase (2%) and cellulose (3%) (w/w) enzymes were used on tomato, tomato peel, and fruit pulp waste, a higher lycopene recovery was achieved [104]. Moreover, 8–18 fold more lycopene yield was reported when tomato-processing waste was extracted using cellulytic (Cellulyve 50LC) and pectinolytic (Peclyve PR) enzymes at 30°C with a 1.6% (w/w) enzyme load for 3.18 h [105]. As per Ranveer et al. [6], tomato processing waste treated with a tri-mixture of ethanol, hexane, and acetone (1 : 1 : 2) provided the highest lycopene yield. Cellulase was less effective than pectinase (3%). When pectinolytic enzyme pretreatment with surfactant-assisted extraction method was employed on tomato peel residue for 20 min at 6-7 surfactant molecules per lycopene, lycopene recovery was up to 25–50% [106].

In ultrasound-assisted extraction (UAE), maximum lycopene yield was observed when tomato pomace (dry) was treated at 50 kPa external pressure and 94 $\mu$m vibration amplitude [107]. Tomato pomace was treated with cellulytic and pectinolytic enzymes, surfactant (saponin), and glycerol under ultrasound and enzyme-assisted extraction method, and a maximum (409.68 $\mu$g/g) lycopene yield was achieved [97]. Enzymes enable the diffusion of solvents into the sample for a better elution of its metabolites that consequently increases the concentration of final product. In addition to this, tomato industrial waste was treated under ultrasound and enzyme-assisted extraction techniques (particle size of 400–545 $\mu$m, surfactant: cosurfactant ratio 1 : 1, and lycopene: surfactant (saponin) ratio 1 : 20) provided the highest lycopene yield [108].

The solvent extraction method (SEM) with different ratios of acetone and hexane (1 : 3, 2 : 2, and 3 : 1 v/v) at a 30–50°C range of temperature was used for tomato-processing waste, and maximum lycopene recovery (65.22–75.75%) was reported at 30°C with 1 : 3 ratio [109]. In another experiment, Phinney et al. [110] utilized commercial tomato waste first with acetone or ethanol, second with acetone/hexane, or ethanol with hexane, providing the highest extraction rate of lycopene. Studies revealed that the lycopene extracted through hexane had a higher rate of stability in comparison with other solvents, such as methanol, ethanol, dichloromethane, and acetone [6, 108, 111]. In addition, hexane can be evaporated from the extract using a vacuum drier or dehydrated by $CaCO_3$ [108].

Ho et al. [112] analyzed tomato peel (1 g) utilizing the microwave-assisted extraction (MAE) method with 400 W power and 1 : 20 (w/v) solid-to-liquid ratio for 6 seconds and obtained 13.592/100 g content of all trans-lycopene, while in the conventional method (1 : 1 mixture of ethyl acetate and hexane; heated in a water bath for 15 sec at 45°C), a total of 7.325/100 g lycopene was yielded. The discussed results reveal that the extraction yield of lycopene may vary as per the types of commodities, extraction time, solvent, enzyme, and the utilized techniques.

## 4. Conclusion

Fruits, vegetables, and other processed products having red pigment contain lycopene but in different concentrations. Lycopene plays a significant role in our diet. The present review highlighted the influence of different postharvest operations and processing methods on lycopene content of various food products. The postharvest operations, including packaging, transportation, and storage influence the content of lycopene in foods. It has been found that ripening triggers the increment of lycopene in stored commodities if the temperature is not maintained at $8 \pm 2$°C. Moreover, the packaging helps retain lycopene levels if kept in a proper storage condition. A right time and temperature are required for the retention of lycopene and a better shelf life of the products. In processing industries, various thermal treatments such as steaming, boiling, cooking, frying, cutting, dicing, blanching, canning, and pasteurization are performed which have shown different effects on the level of lycopene. High-temperature heating decreases the lycopene content, while steaming, stewing, boiling, and canning are shown to increase it. The extraction methods have also an impact on the lycopene content. The combinations of various extraction methods like solvent extraction, enzyme-assisted extraction, supercritical fluid extraction, ultrasound-assisted extraction, and so forth are employed for higher yield of lycopene. This review not only provides a comparative view for the change in lycopene content in fruits and vegetables but also gives insights about the lycopene content of processed products.

## Data Availability

The data used to support the findings of this study are available in the article.

## Conflicts of Interest

The authors declare that there are no conflicts of interest.

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