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Stability of carotenoids in tomato juice during storage

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Abstract

The stability of carotenoids in tomato juice during storage was studied. Tomato juice was processed by hot-breaking of tomatoes at 82 °C, screening, heating at 121 °C for 40 s and then storing in the dark or under light at 4, 25 and 35 °C for 12 weeks. Results showed that the amounts of all-*trans*-lutein and its *cis* isomers decreased with increasing storage time for all the treatments. Light enhanced the degradation and isomerization of all-*trans*-lutein, and 13-*cis*-lutein was more susceptible to formation than 9-*cis*-lutein. Similar trends were observed for β-carotene and lycopene. However, light exposure promoted the formation of di-*cis*-, 9-*cis*- and 13-*cis*-β-carotene. For lycopene, 15-*cis*-lycopene was the major isomer formed during dark storage at 4 °C, while 9-*cis*- and 13-*cis*-lycopene were favoured at 25 °C and 5-*cis*- as well as 13-*cis*-lycopene dominated at 35 °C. Under light storage, both 9-*cis*- and di-*cis*-lycopene (II) were the main isomers generated at 35 °C, whereas 13-*cis*- and 15-*cis*-lycopene were the most abundant at 4 and 25 °C.

Keywords: Carotenoid; Storage; Tomato juice; HPLC

1. Introduction

Carotenoids represent important biological compounds that are widely distributed in fruits and vegetables. Of the various carotenoids, lycopene has received considerable attention in recent years because of its possible role in the prevention of chronic diseases such as prostate cancer (Clinton, 1998; Rao & Agarwal, 1999). Epidemiological studies have also shown that the increased consumption of lycopene-rich foods, such as tomatoes and tomato-based products, is associated with a low risk of cancer (Giovannucci, 1999). In addition to lycopene, both lutein and β-carotene are also present in tomatoes in a much smaller amounts (Shi & Le Maguer, 2000).

In fresh and processed tomato juice, all-*trans*-lycopene is dominant (Lin & Chen, 2003). Also, several *cis*-isomers of lycopene, lutein and β-carotene are present (Lin & Chen, 2003). It has been well documented that *cis*-lycopene is more bioavailable than *trans*-lycopene in vitro and in vivo probably because *cis*-isomers are more soluble in bile acid micelles and may be preferentially incorporated into chylomicrons (Boileau, Merchen, Wasson, Atkinson, & Erdman, 1999). Thus, the amount and variety of lycopene isomers in tomato juice has to be determined.

In a previous study, Lin and Chen (2004) studied the effects of various processing treatments on the stability of carotenoids in tomato juice and found that the high-temperature-short-time treatment (121 °C, 40 s) resulted in the highest yield of all-*trans* plus *cis* forms of lutein and lycopene, followed by 90 °C heating for 5 min and heating in 100 °C water for 30 min. However, the stability of carotenoids during storage of tomato juice remains unknown. The objectives of this paper were to study the changes of the amount and variety of *cis*-isomers of lycopene, lutein and β-carotene in tomato juice as affected by various storage treatments.

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2. Materials and methods

2.1. Materials

All-*trans*-lycopene standard was purchased from Extrasynthese Co. (France), while all-*trans*-β-carotene and all-*trans*-lutein standards were from Sigma Co. (St. Louis, MO, USA). A YMC C30 column (250×4.6 mm ID, 5 μm) was obtained from YMC Co. (Tokyo, Japan). Chemicals, including magnesium sulfate and sodium chloride, were from J.T. Baker Co. (Phillipsburg, NJ, USA) and Riedel-de Häen Co. (Barcelona, Spain), respectively. Deionized water was obtained using a Milli-Q water purification system (Millipore Co., Bedford, MA, USA). The HPLC-grade solvents, hexane, ethanol, methylene chloride and acetonitrile were from Mallinckrodt Co. (Paris, KY, USA), whereas 1-butanol was from Riedel-de Häen Co.

A total of 1200 tomatoes (*Tau-Tai-Lan T93*) with an average weight of 141 g were obtained from a farm located in the central part of Taiwan. A total of 300 empty cans with a height of 113.0 mm and internal diameter 74.0 mm each were purchased from Ming-Hsing Canning Co. (Taiwan).

2.2. Instrumentation

The HPLC instrument consisted of a DP-4010 degasser (Sanwa Tsusho Co., Tokyo, Japan), a Rheodyne 7161 injector (Rheodyne Co., CA, USA), a Jasco MD-915 photodiode-array detector (Jasco Co., Tokyo, Japan), and two Jasco PU-980 pumps. The plate-type heat exchanger was from Alfa-Laval Co. (Switzerland). The double seamer (S-C17V) was from Hsin-Yi Co. (Taipei, Taiwan). The pulper finisher (FYH P205) was from Ke-Seng Co. (Taipei, Taiwan). The double kettle (SF-1) was from An-Jon Co. (Taipei, Taiwan). The steam-exhausting machine was from Ke-Seng Co. (Taipei, Taiwan).

2.3. Processing of tomato juice

All the tomatoes were washed with running water to remove dirt and each was cut into eight pieces, which were then subjected to grinding in a blender for 1 min and the tomato pulps were obtained. Tomato pulps were poured into a double kettle and crushed under steam with a temperature at 82 °C for 2 min (Kuo & Cheng, 1991). After crushing, the tomato pulps were filtered through a pulper finisher with two pore diameters, 1 mm and 0.35 mm, to remove peel, seed and waste. Hundred and twenty six litres of tomato juice were obtained and then heated using a plate-type heat exchanger (HTST treatment). In the first section, tomato juice was preheated to 95 °C, then heated at 121 °C for 40 s in the middle section, and cooled to 93 °C for filling in the last section. After further cooling to room temperature with running water, a total of 300 cans (113.0×74.0 mm ID each) was obtained with a juice content of about 360 ml each. Three cans were randomly selected and the juice mixed, and a 8 g sample was collected for carotenoid analysis in duplicate by HPLC.

2.4. Storage of tomato juice

Three litre of processed tomato juice were collected, and a portion (720 ml) was poured into 72 20 ml transparent glass vials, with a juice content of 10 ml each, for illumination treatment. Likewise, the other portion of tomato juice (720 ml) was also poured into 72 20 ml vials wrapped with aluminium foil for control treatment. In addition, 72 cans of processed tomato juice were also used for storage experiments. All the vials or cans were placed in 3 incubators separately, with 24 in each, and the incubator temperatures were maintained at 4, 25 and 35 °C with a storage period of 12 weeks. Six 10 W fluorescent tubes with a length of 40 cm each were placed at the bottom of the incubator in which a total of 24 vials were attached to a rotating disc driven by a motor, with the disc hooked to the top of the incubator. This device irradiated all the sample vials exposed to the light more uniformly. The distance between sample vials and fluorescent tubes was 30 cm with the light intensity 2500 lx. Two samples were collected for each treatment every week for analysis of carotenoids, and a total of 144 sample vials and 72 cans were used.

2.5. HPLC analysis of carotenoids

A method developed by Lin and Chen (2003) was used for analysis of carotenoids. A 8 g juice sample was poured into a 60 ml vial and mixed with ethanol–hexane (4:3, v/v) and 0.2 g magnesium carbonate. The solution was shaken for 30 min, after which the upper layer was collected and poured into a 500 ml flask. The lower layer was further extracted with 32 ml ethanol–hexane (4:3, v/v) and shaken for 30 min. Again, the upper layer was collected and poured into the same flask. The lower layer was repeatedly extracted with 15 ml hexane and shaken for 20 min, followed by addition of 5 ml hexane and the solution was homogenized at 12 000 rpm for 5 min. The mixture was filtered through Whatman No.1 filter paper, and the filtrates were combined and poured into the same flask. Then, 150 ml distilled water and 100 ml NaCl solution (10%) were added to the filtrate for partition, and the upper phase was also collected. The lower layer was again extracted with 20 ml hexane. All the filtrates were pooled and evaporated to dryness in a flask under vacuum, with the residue dissolved in 1 ml methylene chloride and filtered through a 0.2 μm membrane filter for HPLC analysis. The injection volume was 20 μl. A gradient mobile phase of 1-butanol/acetonitrile (30:70, v/v) (A) and methylene

chloride (B) was used: 99% A and 1% B initially, increased to 4% B in 20 min, 10% B in 50 min and returned to 1% B in 55 min. The detection wavelength was 476 nm and the flow rate was 2.0 ml/min, with sensitivity at 0.005 AUFS. The identification and quantification of carotenoids and their *cis* isomers in tomato juice were described in a previous study by Lin and Chen (2003). All the data were subjected to analysis of variance and Duncan's multiple range test using SAS (2000).

3. Results and discussion

3.1. Concentrations of lutein and its cis isomers in tomato juice during dark storage

Fig. 1 shows the contents of lutein and its *cis* isomers in tomato juice during storage in the dark. The contents of all-*trans* plus *cis* forms of lutein were found to decrease following the increase of storage temperature, implying that degradation may still proceed even in the absence of light. All-*trans*-lutein was not detected after storage at 4 and 25 °C for 5 weeks, however, the same phenomenon occurred after a 4 week storage at 35 °C. This result showed that the higher the storage temperature, the faster was the degradation of all-*trans*-lutein. Similar trends also applied to 9-*cis*- and 13-*cis*-lutein, with the latter being more susceptible to degradation loss than the former at 25 and 35 °C. Theoretically, both 9-*cis*- and 13-*cis*-lutein can be formed from all-*trans*-lutein during heating or storage (Chen, Peng, & Chen, 1995, 1996). The large decline of 9-*cis*- and 13-*cis*-lutein during dark storage indicates that the presence of oxygen may be important for degradation to proceed. Chen et al. (1996) pointed out that 13-*cis*-lutein was more readily formed than 9-*cis*-lutein during storage of carrot juice, probably because the activation energy required for isomerization of the former was lower. Nevertheless, 13-*cis*-lutein may undergo faster degradation than 9-*cis*-lutein as soon as it is formed from all-*trans*-lutein.

Fig. 2 shows the concentrations of lutein and its *cis* isomers in tomato juice during storage under light. Likewise, a decreased trend was found for all-*trans* plus *cis* forms of lutein during light storage. After storage for 1 week at 4, 25 and 35 °C, the amounts of all-*trans*-lutein decreased by 0.29, 0.26 and 0.39 μg/g, respectively. However, no all-*trans*-lutein was detected at 4, 25 and 35 °C, respectively, over a storage period of 4, 3 and 3 weeks. This result indicated that a more pronounced degradation of all-*trans*-lutein occurred during light storage than during dark storage. 9-*Cis*-lutein, decreased by 0.24, 0.39 and 0.37 μg/g, respectively, after a 2-week storage at 4, 25 and 35 °C. Higher losses were shown for 13-*cis*-lutein for the same storage period and temperatures, which amounted to 0.84, 0.92 and 1.20 μg/g, respectively. Obviously 13-*cis*-lutein was more prone to undergo illumination loss than 9-*cis*-lutein. Nevertheless, no 13-*cis*-lutein was detected after storage time reached 4 weeks at 4 and 25 °C, revealing that the formation of 13-*cis*-lutein may proceed faster than 9-*cis*-lutein, which was completely degraded in three weeks. By comparison, both 9-*cis*- and 13-*cis*-lutein also showed a greater loss under light storage than under dark storage. This outcome

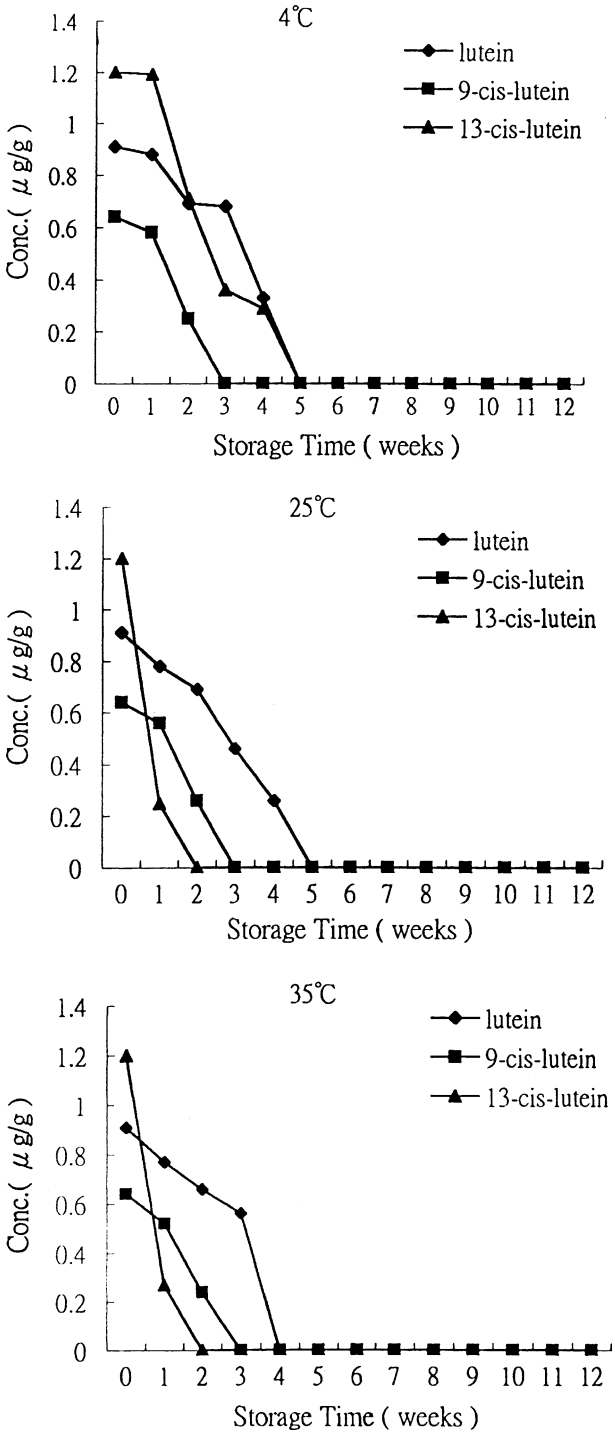

Fig. 1. Concentration changes of lutein and its *cis* isomers in tomato juice during storage in the dark.

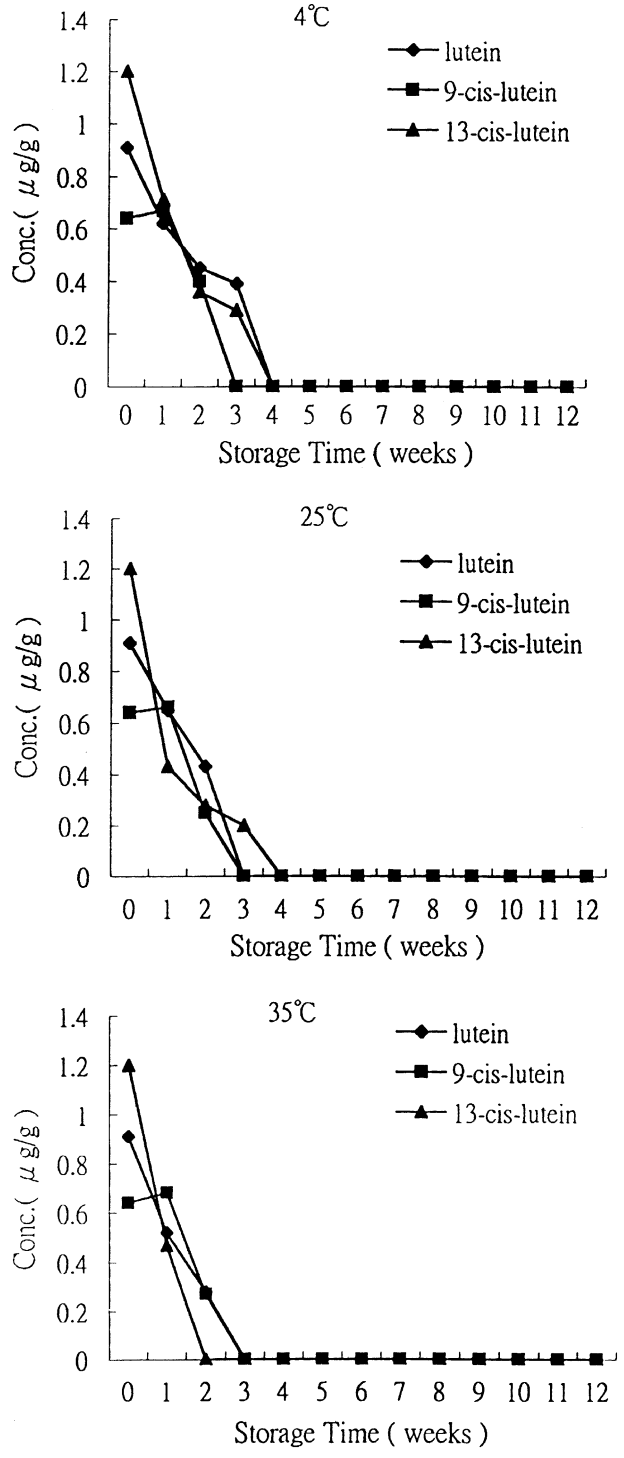

Fig. 2. Concentration changes of lutein and its *cis* isomers in tomato juice during storage under light.

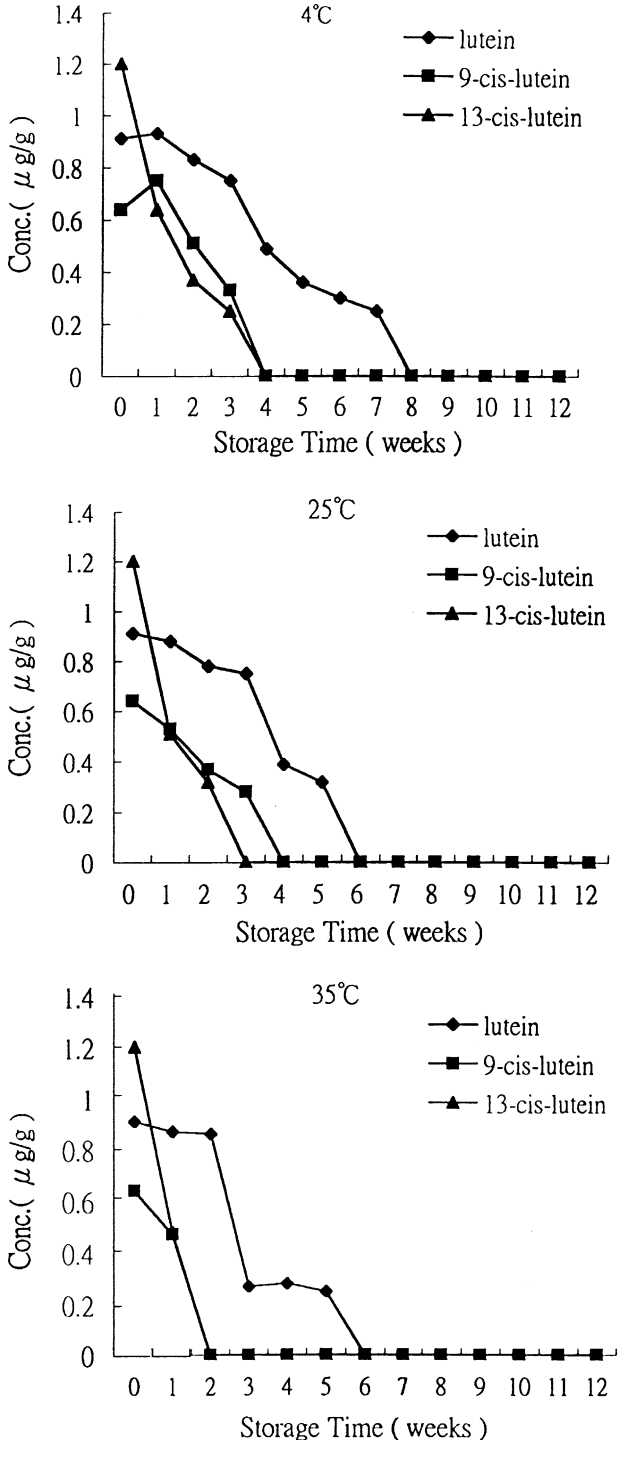

Fig. 3. Concentration changes of lutein and its *cis* isomers in canned tomato juice during storage.

was also reported by Chen et al. (1996), who studied the carotenoid stability during storage of carrot juice.

Fig. 3 shows the concentrations of lutein and its *cis* isomers in canned tomato juice during storage. The contents of all-*trans* plus *cis* forms of lutein declined with increasing storage temperature. All-*trans*-lutein was completely degraded after storage for 8, 6 and 6 weeks at 4, 25 and 35 °C, respectively. This is probably because of oxidative degradation caused by the presence of residual oxygen in canned tomato juice. The same phenomenon also applied to 9-*cis*- and 13-*cis*-lutein. However, no 9-*cis*-lutein was detected in 4, 4 and 3 weeks at 4, 25 and

35 °C, respectively. For 13-*cis*-lutein, the time periods required for complete loss at 4, 25 and 35 °C were 4, 3 and 2 weeks, respectively. Apparently, 13-*cis*-lutein undergoes a faster degradation than 9-*cis*-lutein in canned tomato juice during storage. Compared to dark storage and light storage, the degradation of all-*trans* plus *cis* forms of lutein proceeded move slowly mainly because canned tomato juice is in a dark environment and the exposure of juice to atmospheric oxygen is excluded. Sharma and Le Magure (1996) also reported that carotenoids, such as lycopene, undergo more degradation in air than under vacuum. It was also found that, during storage at 4, 25 and 35 °C, all-*trans*-lutein in canned tomato juice was not detected after 8, 6 and 6 weeks, respectively. 9-*Cis*- and 13-*cis*-lutein were both not detected after 4 weeks at 4 or 25 °C, while, at 35 °C, the storage period for complete loss was 3 weeks. Nevertheless, a higher degradation loss was found for 13-*cis*-lutein than for 9-*cis*-lutein. As explained before, 13-*cis*-lutein should be more readily formed than 9-*cis*-lutein during storage, however, the presence of residual oxygen in canned juice may result in degradation and isomerization of the former proceeding faster than the latter. By comparison, it was clearly revealed that storage under light or high temperature possessed a destructive effect on all-*trans* plus *cis* forms of lutein in tomato juice, and a smaller loss of lutein was found in canned tomato juice.

Fig. 4 shows the concentrations of β-carotene and its *cis* isomers in tomato juice during storage in the dark. Following the increase of storage temperature, all-*trans* plus *cis* forms of β-carotene exhibited a declining tendency. After storage for 12 weeks at 4, 25 and 35 °C, the levels of β-carotene decreased by 4.69, 4.87 and 5.71 μg/g, respectively. However, a reversed trend was found for 9-*cis*-, *cis*- and 13-*cis*-β-carotene, all of which increased in the first 2 weeks at 4 °C and began to decline thereafter. In contrast, both 15-*cis*- and di-*cis*-β-carotene decreased with increasing storage time, and a complete loss was found after 12 weeks for the former and 4 weeks for the latter. At 25 °C, no 13-*cis*-, or *cis*- and di-*cis*-β-carotene were detected in 3 weeks, whereas 9-*cis*- and 15-*cis*-β-carotene were not present at 7 and 12 weeks, respectively. Interestingly, the formation of *cis*-, 9-*cis*- and 13-*cis*-β-carotene occurred after 4, 9 and 10 weeks, respectively, and then declined afterwards. A similar outcome was shown at 35 °C, i. e., the complete degradation times required for *cis*-, 13-*cis*-, 15-*cis*- and di-*cis*-β-carotene were 5, 6, 7 and 3 weeks, respectively. Surprisingly, 13-*cis*-β-carotene was generated again in 10 weeks and then dropped sharply. This result further demonstrated that both isomerization and degradation of β-carotene may proceed simultaneously, which may lead to inconsistent change of concentration. This phenomenon was also observed by Pesek, Warthesen, and Taoukis (1990) and Chen, Chen, and Chien (1994),

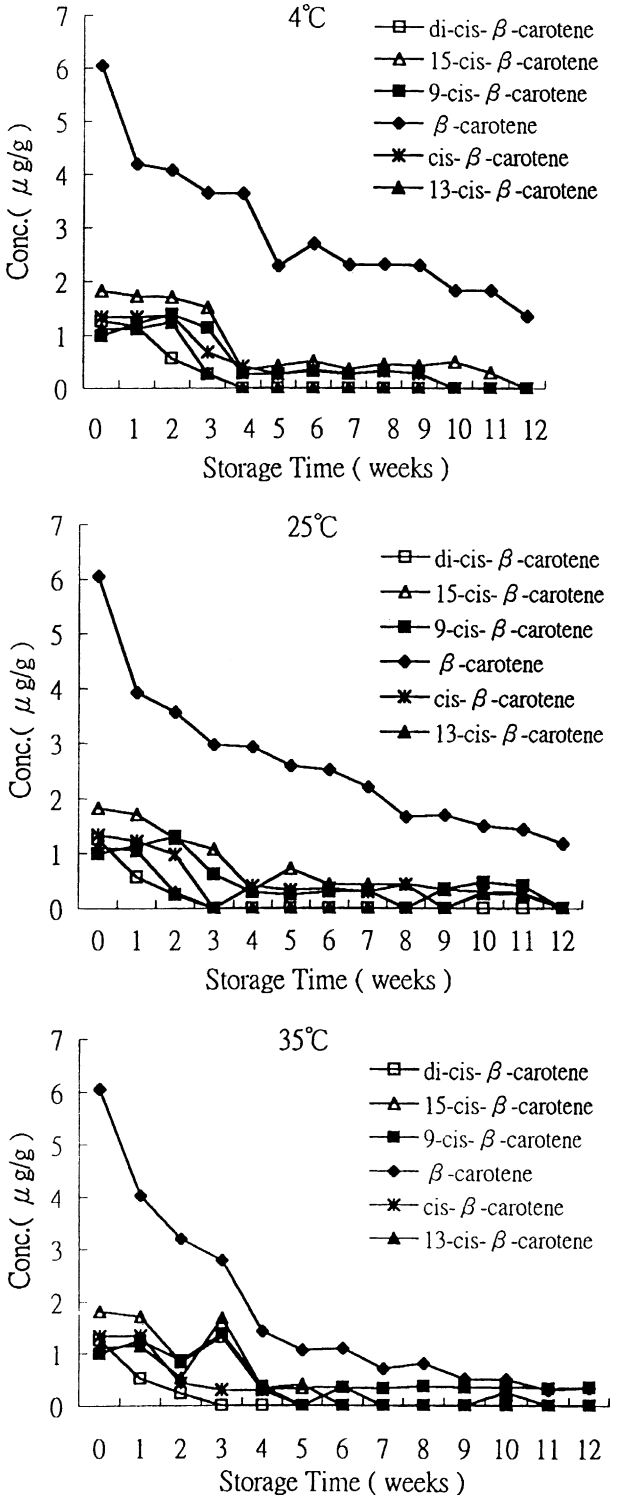

Fig. 4. Concentration changes of β-carotene and its *cis* isomers in tomato juice during storage in the dark.

who reported that the dominant reaction, isomerization or degradation, may be dependent on many factors, such as temperature, illumination intensity and storage environment. In addition, it was found that a higher storage temperature could be destructive to all-*trans*-β-

carotene and its *cis* isomers and, in most cases, the degradation of *cis* isomers proceeded faster than the formation.

Fig. 5 shows the concentrations of β-carotene and its *cis* isomers in tomato juice during storage under light. Compared to dark storage, a pronounced degradation of all-*trans* plus *cis* forms of β-carotene was shown. At

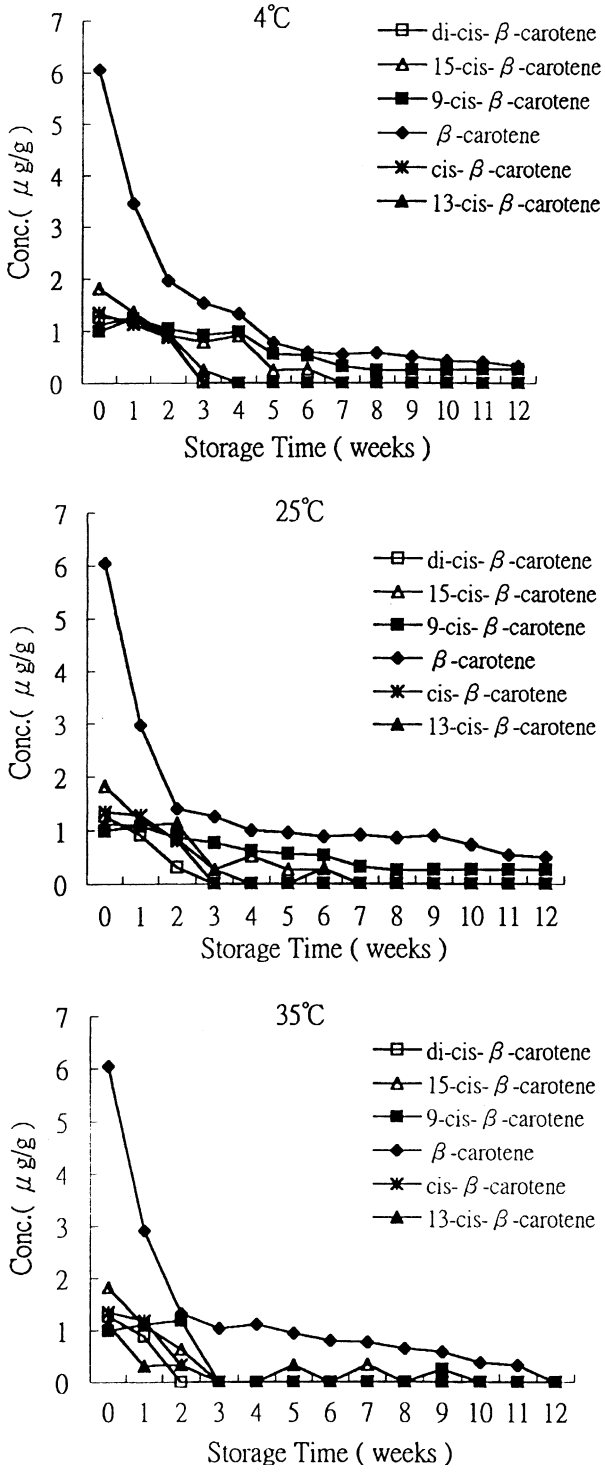

Fig. 5. Concentration changes of β-carotene and its *cis* isomers in tomato juice during storage under light.

4 °C and in the first 6 weeks, the level of all-*trans*-β-carotene decreased by 5.46 μg/g and slight change followed, while at 25 and 35 °C, further declines of 4.80 and 5.02 μg/g occurred for all-*trans*-β-carotene in the first 3 weeks. After prolonged storage for 12 weeks, all-*trans*-β-carotene was not detected at 35 °C and great losses, (94.7 and 91.7%) were found at 4 and 25 °C, respectively. For *cis* isomers, the levels of 9-*cis*-β-carotene climbed in the first 2 weeks and then dropped afterwards at 4 °C under light. Conversely, the other *cis* isomers showed a declining tendency, and complete degradations of 13-*cis*-, 15-*cis*-, *cis*- and di-*cis*-β-carotene occurred after storage for 4, 7, 3 and 3 weeks, respectively. Similar results were shown at 25 and 35 °C, and most *cis* isomers were completely degraded at 35 °C after 3 weeks. This result clearly indicated that the degradation of all-*trans* plus *cis* forms of β-carotene proceeded faster than isomerization under light storage at high temperature. Both illumination and high-temperature-storage treatments could facilitate formation of 9-*cis*-, 13-*cis*- and di-*cis*-β-carotene, however, a complete loss was found for most *cis* isomers after 4-weeks of storage. Obviously illumination has a greater influence on isomerization and degradation of *cis*-isomers of β-carotene than temperature. The formation of di-*cis*-β-carotene is probably due to conversion of mono-*cis*-β-carotene as reported by Chen et al. (1994).

Fig. 6 shows the concentrations of β-carotene and its *cis* isomers in canned tomato juice during storage. After storage at 4, 25 and 35 °C for 12 weeks, the amounts of all-*trans*-β-carotene decreased by 3.36, 3.48 and 4.16 μg/g, respectively. Likewise, during storage at 4 °C, only a minor change was found for *cis*-isomers of β-carotene in the beginning. However, with higher storage temperature, a faster degradation proceeded. With the exception of 15-*cis*-β-carotene, a complete loss was observed for di-*cis*, 9-*cis*, *cis*- and 13-*cis*-β-carotene after a 25 °C storage for 4, 6, 10 and 5 weeks, respectively. Meanwhile, the time periods for complete loss can be shortened to 3, 4, 10 and 3 weeks at 35 °C. Apparently 15-*cis*-β-carotene showed the highest stability when compared to the other *cis* isomers, probably because the formation of this isomer from all-*trans*-β-carotene is faster than the other *cis* isomers (Chen et al., 1994). Compared to dark storage, most *cis*-isomers of β-carotene were at lower levels in canned tomato juice, which can be due to the fact that the canned juice is in a dark environment and the exposure to air is excluded.

By comparison, the illumination treatment resulted in the highest loss of all-*trans* plus *cis* forms of β-carotene, followed by dark storage and canned juice. However, under certain conditions, the levels of all-*trans*-β-carotene showed a slightly higher increase at 25 and 35 °C than at 4 °C after 6-week storage. This is probably due to conversion between all-*trans* and *cis* forms of β-carotene. It has been well established that the mono-

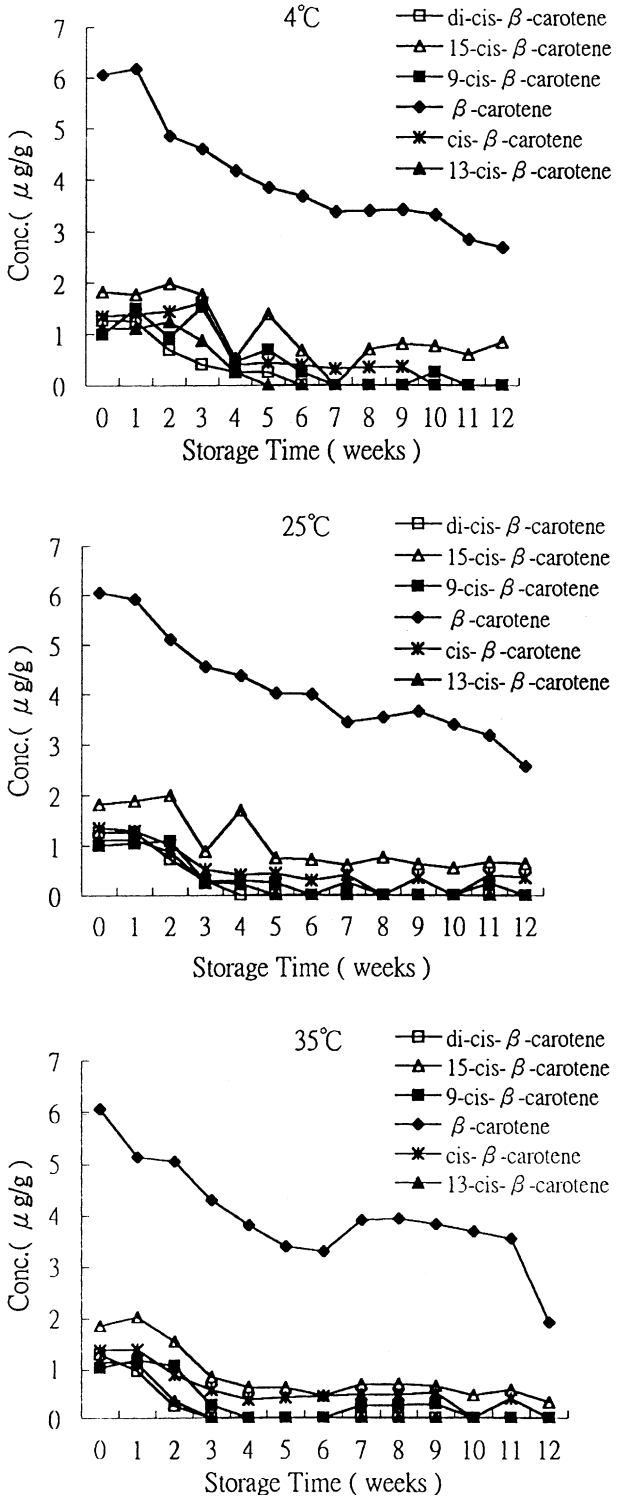

Fig. 6. Concentration changes of β-carotene and its *cis* isomers in canned tomato juice during storage.

cis forms of β-carotene, such as 9-*cis*-β-carotene, can be converted to 13-*cis*- or 15-*cis*-β-carotene only through the intermediate all-*trans*-β-carotene (Chen et al., 1994; Pesek et al., 1990), and the *cis* isomers may continue to degrade as soon as they are formed. Meanwhile, the mono-*cis* forms of β-carotene could be further converted to di-*cis*-β-carotenes, such as 13,15-di-*cis*-β-carotene (Chen et al., 1994). Thus, this phenomenon could explain the inconsistent concentration change of several β-carotene isomers as affected by various storage treatments.

Fig. 7 shows the concentrations of lycopene and its *cis* isomers in tomato juice during storage in the dark at 4, 25 and 35 °C. After storage for 12 weeks at 4, 25 and 35 °C, the contents of all-*trans*-lycopene decreased by 68.1 (80.1%), 71.0 (83.5%) and 78.3 (92.1%) μg/g, respectively. Similar to the results for all-*trans*-lutein and all-*trans*-β-carotene, the higher storage temperature could facilitate destruction of all-*trans*-lycopene. Also, all-*trans*-lycopene undergoes a higher loss than all-*trans*-lutein and all-*trans*-β-carotene. This can be attributed to the coplanarity structure of all-*trans*-lycopene, in which 11 conjugated double bonds are present and should be more reactive than all-*trans*-lutein and all-*trans*-β-carotene. Sharma and Le Magure (1996) demonstrated that the reaction rate of lycopene during storage of tomato puree at 25 °C was 2.7 times greater than at 5 °C. In a study dealing with storage of dried tomatoes (10% H_2O) at 37 °C, a high loss of 50% was found after a 30-day storage and 70% after 90 days (Zanoni, Peri, Nani, & Lavelli, 1999).

Cis isomers of lycopene, mostly decreased with increasing storage time and temperature. Di-*cis*-lycopene (I) was formed in the first 2 weeks and completely degraded thereafter at 4 °C while, at 25 and 35 °C, no di-*cis*-lycopene (I) was detected. Instead, di-*cis*-lycopene (II) was generated at 25 and 35 °C and then completely degraded after prolonged storage at 35 °C for 11 weeks. This result showed that di-*cis*-lycopene was more susceptible to degradation than the other mono-*cis* isomers. After 12-weeks of storage, 13-*cis*-lycopene showed the lowest loss, followed by 5-*cis*-, 9-*cis*-, 15-*cis*-, di-*cis*-(I) and di-*cis*-lycopene (II). Nevertheless, 13-*cis*-lycopene may undergo further degradation or convert to the other mono-*cis* isomers as soon as it is produced from all-*trans*-lycopene. This phenomenon also applied to 15-*cis*-lycopene. Theoretically, when compared to the other *cis* isomers, the activation energy required for formation of 15-*cis*-lycopene should be lower because of the symmetrical nature of its structure. At 25 °C, the losses of 15-*cis*-, 13-*cis*-, di-*cis*-(II), 9-*cis*- and 5-*cis*-lycopene were 34.7, 27.4, 36.3, 31.2 and 34.4%, respectively, after a 3-week storage. For the same storage period at 35 °C, the losses were 43.0, 30.1, 40.6, 40.7 and 38.5%, respectively. This result indicated that, in addition to 15-*cis*-lycopene, both 9-*cis*- and 13-*cis*-lycopene were the major isomers formed at 25 °C, while 5-*cis*-lycopene dominated at 35 °C. Lee and Chen (2002) reported that all-*trans*-lycopene could be converted to 5-*cis*-, 9-*cis*- or 13-*cis*-lycopene, depending on heating condition. A 50% loss of all-*trans*-lycopene was found when tomato powder

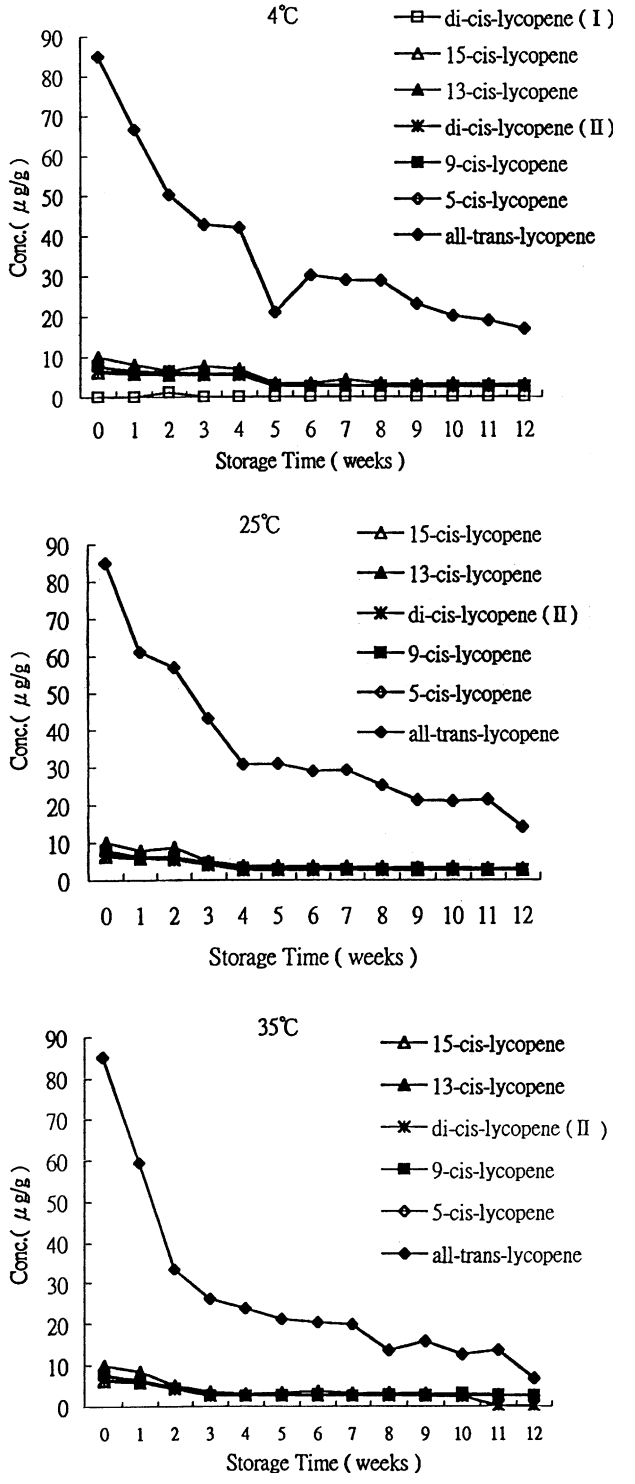

Fig. 7. Concentration changes of lycopene and its *cis* isomers in tomato juice during storage in the dark.

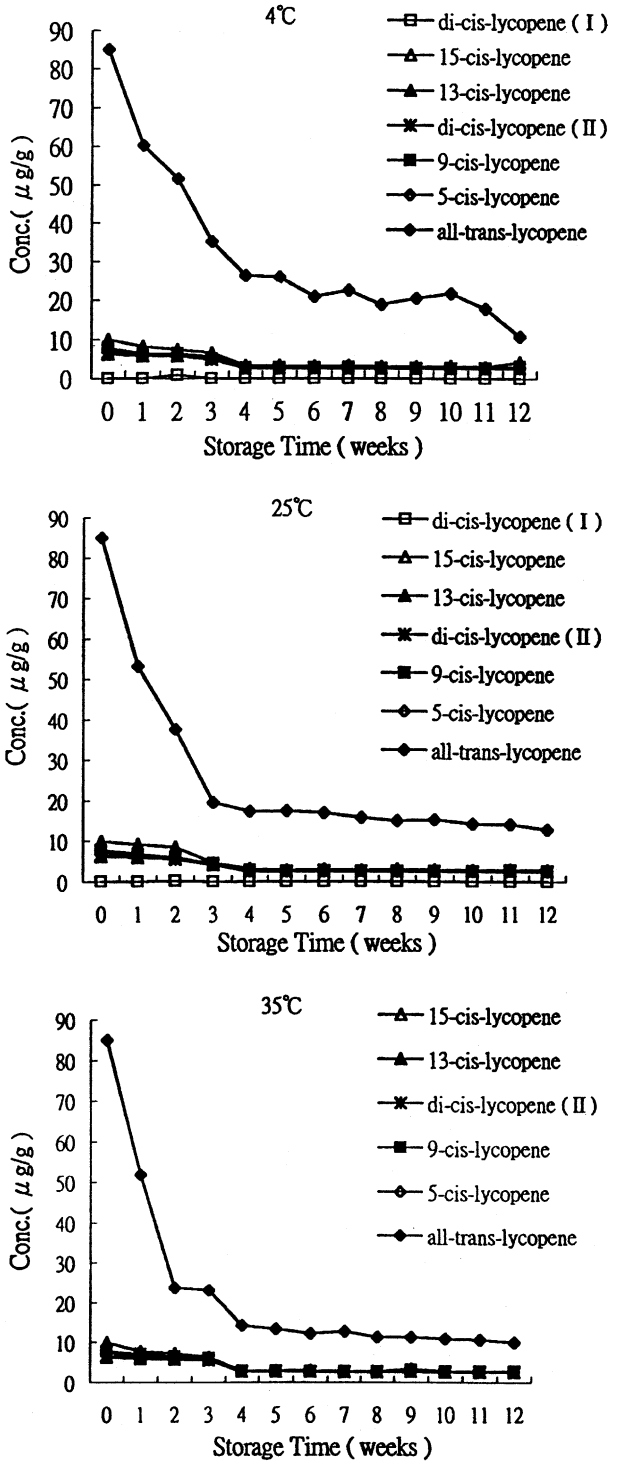

Fig. 8. Concentration changes of lycopene and its *cis* isomers in tomato juice during storage under light.

was stored at 45 °C for 6 weeks (Anguelova & Warthesen, 2000). These results further demonstrated that, in addition to isomerization, oxidative degradation is a major factor causing lycopene loss during storage of tomato juice. Interestingly, Anguelova and Warthesen (2000) also observed that all-*trans*-lycopene increased slightly during storage of tomato powder at 6 °C for 4–6 weeks. As stated previously, this phenomenon may be due to conversion of mono-*cis*-lycopene (Lee & Chen, 2002).

Fig. 8 shows the concentrations of lycopene and its *cis* isomers during storage under light. Decreases of 74.3, 72.2 and 75.1 μg/g were found for all-*trans*-lycopene after 12-weeks of storage at 4, 25 and 35 °C, respectively. Sharma and Le Magure (1996) reported that illumination could enhance the reaction rate of lycopene in the presence of air, and the degradation of all-*trans*-lycopene could be accompanied by the isomerization. However, there was no significant change of *cis* isomers over a 4-week period, and a further decline occurred thereafter. After storage at 4 °C for 12 weeks, lower contents of 3.5, 5.8, 4.0, 4.7 and 4.6 μg/g was shown for 15-*cis*-, 13-*cis*-, di-*cis*-, 9-*cis*- and 5-*cis*-lycopene, respectively. Similar trends were also found at 25 and 35 °C, however, the latter showed a greater loss. 13-*Cis*- and 15-*cis*-lycopene were the isomers favoured at 4 °C while, at 25 and 35 °C, 5-*cis*-, 9-*cis*-, 15-*cis*- and di-*cis*-lycopene were the most abundant. Moreover, the high storage temperature (35 °C) may promote generation of di-*cis*-lycopene. In a study dealing with illumination of lycopene standard at 25 °C for 144 h with a light intensity 200–300 lx. Lee and Chen (2002) concluded that both formation and degradation of mono-*cis*-lycopene could proceed simultaneously, with mono-*cis*-lycopene being further converted to di-*cis*-lycopene after prolonged exposure to light.

Fig. 9 shows the concentrations of lycopene and its *cis* isomers in canned tomato juice during storage. The contents of all-*trans*-lycopene decreased by 54.5, 57.3 and 54.7 μg/g, respectively, after storage at 4, 25 and 35 °C for 12 weeks. However, a slight rise was shown for all-*trans*-lycopene after 9 weeks, probably because of conversion from mono-*cis*-lycopene (Lee & Chen, 2002). For *cis* isomers, a small amount of di-*cis*-lycopene was produced initially and then degraded. After 12-weeks of storage at 4 °C, the levels of 15-*cis*-, 13-*cis*-, di-*cis*-(II), 9-*cis*- and 5-*cis*-lycopene decreased by 3.5, 6.5, 3.8, 4.9 and 4.4 μg/g, respectively. Likewise, a higher loss was found at 25 and 35 °C for each *cis* isomer. Compared to the other *cis* isomers, the degradations of 15-*cis*-, di-*cis*-(II) and 5-*cis*-lycopene were slower at 4 and 25 °C. However, at 35 °C, both 5-*cis*- and di-*cis*-lycopene (II) undergo a faster degradation. This result seemed to be different from tomato juice stored under light or in the dark, which showed a higher yield of 5-*cis*- and di-*cis*-lycopene (II). As described previously, the formation of di-*cis*-lycopene (II) may be due to conversion of mono-*cis*-lycopene, while the formation of mono-*cis*-lycopene may be due to conversion of all-*trans*-lycopene. Therefore, the dominant reaction, formation or degradation, of *cis* isomers of lycopene is an extremely complicated phenomenon and can vary, depending on storage conditions. Several authors have proved that the amounts of all-*trans*-β-carotene and all-*trans*-lycopene decrease with increasing illumination time (Chen et al., 1994; Lee & Chen, 2002). Conversely,

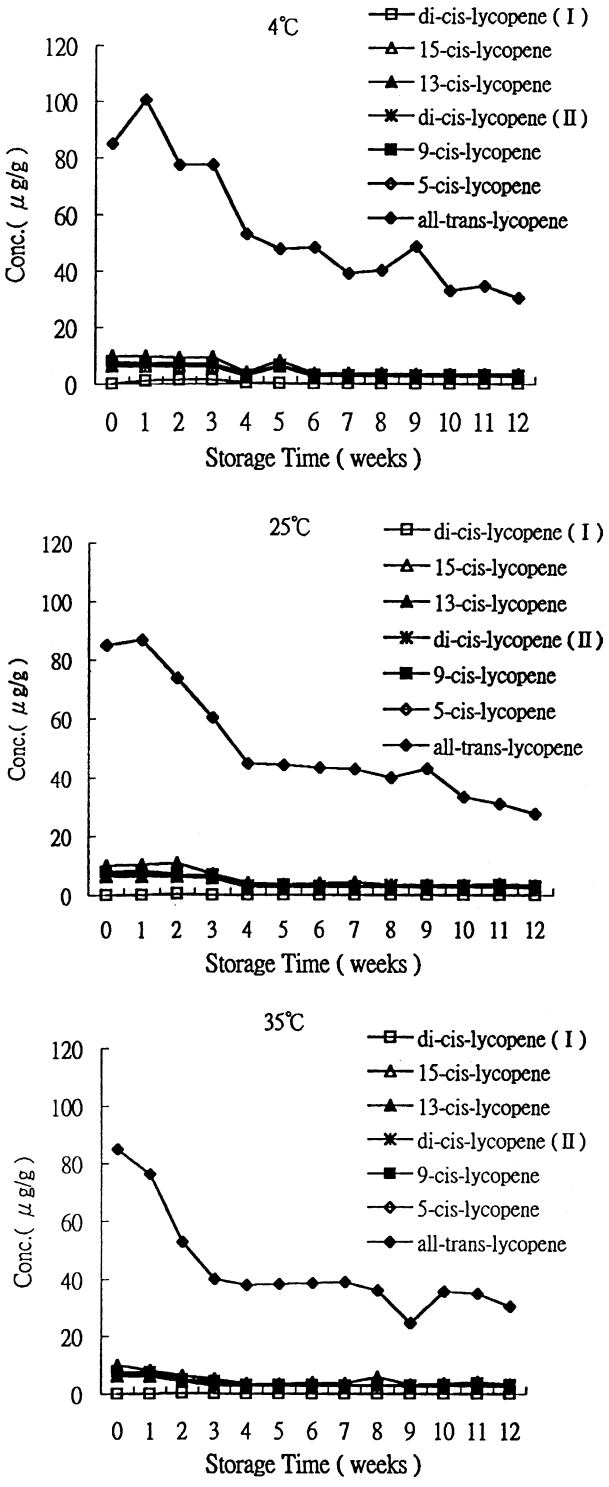

Fig. 9. Concentration changes of lycopene and its *cis* isomers in canned tomato juice during storage.

Anguelova and Warthesen (2000) reported that the amount of all-*trans*-lycopene in tomato powder was not affected during illumination. This difference can be due to variety of system, i.e., food system or model system.

In conclusion, the higher the storage temperature, the greater are the losses of all-*trans* plus *cis* forms of lutein, β-carotene and lycopene during illumination. All-*trans*-lycopene showed the highest degradation loss, followed by all-*trans*-β-carotene and all-*trans*-lutein. More *cis*-isomers of lycopene than lutein or β-carotene were generated during storage. However, the type of major isomers formed may be inconsistent, depending on storage conditions.

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