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Lycopene and β-carotene in non-blanched and blanched tomatoes

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Abstract

Tomatoes are an important agricultural commodity worldwide. Tomatoes and tomato-based food products, such as tomato paste, tomato sauce, tomato juice, and tomato soups, are considered as important sources of carotenoids in the human diet. There are many studies showing strong correlations between carotenoid consumption and a reduced risk of cancer and coronary and cardiovascular diseases. The beneficial effects of carotenoids are thought to be due to their role as antioxidants. Lycopene is the predominant carotenoid in tomatoes and exhibits the highest antioxidant activity of known carotenoids. β-carotene is also present in tomatoes, but in a much smaller amount. Lycopene is able to function as an antioxidant and has an activity that is twice as strong as β-carotene, but β-carotene is the major dietary precursor of vitamin A. The waste of tomato processing has been shown to be an excellent and inexpensive source of carotenoids because a large proportion of the carotenoids are discarded along with the peels during the processing of tomatoes into pastes or sauces. Furthermore, some studies indicate that tomato thermal processing (for example, the blanching process) increases carotenoid bioavailability. In the present study, it was established that the best source for purified lycopenes is tomato peels (a by-product of tomato juice production). Data from the present study suggest that the mean lycopene and β-carotene concentrations were higher in the blanched 'Admiro' F_1 tomatoes than in the non-blanched tomatoes. The β-carotene concentration in the blanched tomato peels was 24.7 mg/100 g, and there was over 2 times more β-carotene than that in the non-blanched tomato peels. The lycopene concentration in the non-blanched tomato peels was 62.92 mg/100 g, whereas it was 134.04 mg/100 g in the blanched tomato peels. Because a literature review has shown that hexane is the most suitable solvent for extracting carotenoids from the tomato matrix, the stability of lycopene and β-carotene in hexane extracts was evaluated. The samples were stored in the dark at +5°C (±1°C) for 23 days. The *all-trans* lycopene from the non-blanched tomato peels gradually degraded (by approximately 37% after 23 days), whereas the degradation of the *all-trans* lycopene from the blanched tomato peels was only approximately 25%. The β-carotene was stable during storage for 23 days. The color of the fresh tomato fruit and after blanching was measured with a portable MiniScan XE Plus spectrophotometer. The intensity of the color was expressed in *CIE L*a*b** color coordinates: *L** (brightness), *a** (redness) and *b** (yellowness).

Key words: Lycopene, β-carotene, tomato flesh and peel, blanching, stability, color coordinates.

Introduction

Tomatoes are an important agricultural commodity worldwide. Tomatoes and tomato-based food products, such as tomato paste, tomato sauce, tomato juice, and tomato soups, are rich in carotenoid compounds [1]. There are many studies showing strong correlations between the intake of carotenoids and a reduced risk of cancer and coronary and cardiovascular diseases [2-4], and the beneficial effects of carotenoids are thought to be due to their role as antioxidants [5]. The carotenoids that have been most studied in this regard are lycopene and β-carotene. Lycopene is the predominant carotenoid found in tomatoes; in addition to lycopene, β-carotene is present in tomato in a much smaller amount [6,7]. Lycopene is able to function as an antioxidant and exhibits an antioxidant activity that is twice as strong as β-carotene [8], but β-carotene is the major dietary precursor of vitamin A, together with other carotenoids containing unsubstituted β-ionone rings. Lycopene has no pro-vitamin A activities because it lacks the β-ionone ring structure of β-carotene [9].

The characteristic red color of tomato is produced by a combination of carotenoid pigments, the most abundant of which is lycopene, and the tomato color is determined by the pigmentation of the skin and flesh [1]. Lycopene composes as much as 85% of the total pigmentation in tomatoes [10], and tomatoes have a consistently deep-red skin because most of lycopene is accumulated in the pericarp [1]. The waste from tomato processing has been shown to be an excellent and inexpensive source of carotenoids because a large proportion of the carotenoids are removed by discarding the peels during the processing of tomatoes into pastes or sauces [11].

Food thermal processing is used to prepare tomato paste, tomato sauce, tomato juice, and tomato soups. Some studies indicate that heating can be responsible for increased carotenoids bioavailability [12]. Indeed, the composition and structure of the food have an impact on the bioavailability of lycopene and may affect the release of lycopene from the tomato tissue matrix. Food processing may improve the bioavailability of lycopene by breaking down cell walls, which weakens the bonding forces between lycopene and the tissue matrix [13]. Furthermore, the bioavailability of lycopene is also affected by the presence of other carotenoids,

such as β-carotene. Johnson and associates found that the bioavailability of lycopene was significantly higher when it was ingested along with β-carotene than when ingested alone [5].

Additionally, lycopene may be expected to undergo two changes during processing and storage: isomerization and oxidation [13]. The physical and chemical factors known to degrade carotenoids include an elevated temperature and the exposure to light and oxygen [14]. Carotenoids are sensitive to isomerization in heat, light and aerial oxidation; the chemical form of lycopene may be altered from *trans* isomers to *cis* isomers by the temperature changes involved in processing [13]. Lycopene from natural plant sources exists predominantly in an *all-trans* configuration [9], and in relation to lycopene stability, Shi and Le Maguer [15] reported that heat induces the isomerization of the *all-trans* to *cis* forms. Boileau *et al.* [16] also reported that *cis* isomers are more bioavailable than the *all-trans* lycopene.

The objectives of this study were to determine the concentration and stability of lycopene and β-carotene subjected to blanched and non-blanched tomatoes. Additionally, the color of the fresh tomato fruit was compared with blanched tomatoes.

Materials and Methods

The experiments were carried out at the Biochemistry and Technology Laboratory of the Institute of Horticulture Lithuanian Research Centre for Agriculture and Forestry. Fresh tomatoes of the 'Admiro' F_1 hybrid (grown in the greenhouses of the Institute of Horticulture) were investigated. The tomatoes were red-ripe, uniform in size, firm and undamaged.

The samples were divided into two groups: one tomato group was subjected to the blanching treatment, and another group was untreated as a non-blanching control. The blanching treatment consisted of submerging the tomatoes in water at 85°C (±2°C) for 4 min, followed by cooling under running water at room temperature.

The carotenoids content was determined spectrophotometrically [17], the absorption was measured using a Cintra 202 spectrophotometer (GBC Scientific Equipment Pty Ltd., Australia), and the results were analysed using the Cintral ver.2.2 program.

The stability of lycopene and β-carotene in hexane extracts was studied. The samples were stored in the dark at +5°C (±1°C) for 23 days.The stability of the *all-trans* lycopene and β-carotene in the extracts was analysed by the slightly modified reversed-phase HPLC method of Ishida [18] using a C_{30} column (250 mm x 4.6 mm i.d.; 3 µm particle diameter; YMC, Wilmington, NC, USA). The HPLC system used was a Waters 2695 liquid chromatograph (Water Corporation, U.S.A.) connected to a Waters 2489 (Water Corporation, U.S.A.) UV-VIS detector. The mobile phase consisted of methanol, methyl-*tert*-butyl ether and ethyl acetate at a flow rate of 1.5 ml/min. The injection volume was 10 µl. The column temperature was 28°C. The samples were filtered through a 0.45-mm syringe filter (Millipore, polypropylene, PVDF) before they were injected.

The color coordinates (*L**, *a**, and *b**) in the *CIEL*a*b** scale of the fruit surface of the non-blanched and blanched tomatoes was measured with a spectrophotometer MiniScan XE Plus (Hunter Associates Laboratory, Inc., Reston, Virginia, USA). The apparatus (45°/0° geometry, illuminant D65, 10° observer) was calibrated with a standard white tile (X = 81.3, Y = 86.2, Z = 92.7). The *L** value indicates the ratio of white to black color, the *a** value indicates the ratio of red to green color, and the *b** value indicates the ratio of yellow to blue color. The chroma ($C^* = (a^{*2} + b^{*2})^{½}$) and hue angle ($h° = \arctan[b^*/a^*]$) were also calculated [19]. The data are presented as the averages of the three measurements. The color parameters were processed with the program, "Universal Software V.4–10".

Results and Discussion

During the processing of tomatoes into pastes or sauces, a large proportion of the lycopene, as well as other carotenoids (β-carotene), is removed by discarding the peels, which are particularly rich in carotenoids [11]. The best possibility to refine lycopene is to use the discarded tomato peels left after the production of juices. In previous study, it was established that the best source for purified lycopene are tomato peels (a by-product of tomato juice production). In that study, the β-carotene amount was 5.65 mg/100 g, and the lycopene content was found to be as high as 65.15 mg/100 g in overripe tomato peels of the 'Raissa' F_1 hybrid. The lycopene concentration in the tomato pulp without the peels was only 4.224 mg/100 g, and there was 7-15 times more lycopene in the tomato peels than in the tomato flesh [20]. This result is in agreement with the present study, as 10 times more lycopene was found in the tomato peels than in the tomato flesh of the ripe fruit of the 'Admiro' F_1 cultivar (average lycopene was 62.92 mg/100 g in the non-blanched tomato peels and 6.37 mg/100 g in the non-blanched tomato flesh) (Fig. 1).

The results showed that the mean lycopene and β-carotene concentrations were higher in the blanched 'Admiro' F_1 tomatoes than in the non-blanched tomatoes. The β-carotene concentration in the tomato peels of the blanched tomatoes was 24.7 mg/100 g, and there was more than twice as much β-carotene in the non-blanched tomato peels. The concentration of lycopene in the non-blanched tomato peels was 62.92 mg/100 g, whereas it was 134.04 mg/100 g in the blanched tomato peels (Fig. 1).

Galicia *et al.*[26] found that the lycopene concentration in non-blanched tomatoes was 7.920 mg/100 g and in blanched tomatoes 7.525 mg/100 g; there was no significant difference between these values. However, our results show that the concentration of lycopene from blanched tomato peels is two times greater than that in fresh tomato skins.

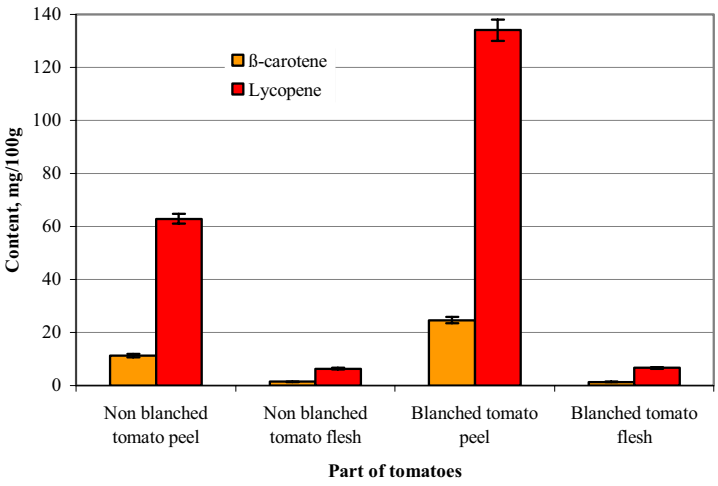

Figure 1. Content of β-carotene and lycopene in the blanched and non-blanched peels and flesh of 'Admiro' F_1 tomatoes.

Processed fruits and vegetables are usually considered less valuable than the fresh ones due to the loss of nutritional components. However, according to some studies, carotenoids from processed tomatoes are more bioavailable. In fact, heating can be responsible for increasing *in vivo* carotenoid bioavailability by promoting the degradation of carotenoid-associated proteinaceous structures [21-24]. However, Mayer-Miebach *et al.* [25] suggested that thermal processing (for example, a blanching process) generally causes some loss of lycopene in tomato-based foods because heat induces the isomerization of the *all-trans* to *cis* forms. Lycopene from natural plant sources exists predominantly in an *all-trans* configuration [9]; isomerization and degradation reduce the concentration of the *all-trans* isomer form, whereas the *cis*-isomers increase with temperature and processing time [25]. In addition, lycopene bioavailability in processed tomato products is higher than that in unprocessed fresh tomatoes [13].

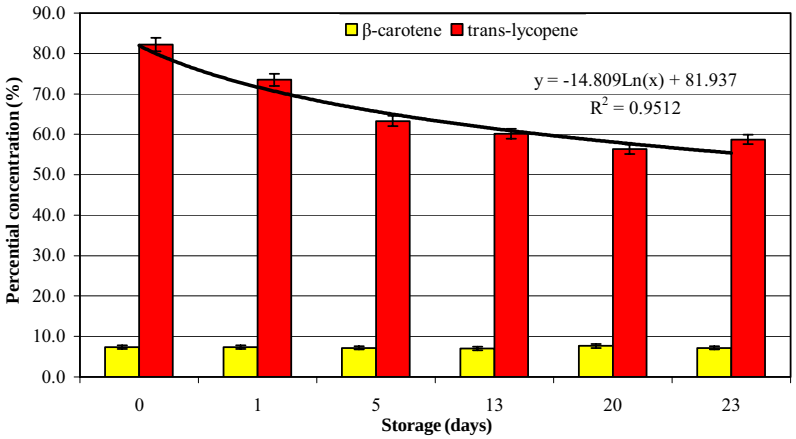

Figure 3. *Trans*-lycopene and β-carotene stability in hexane extract from blanched tomato peels.

A literature review has shown that the procedures for extracting carotenoids from fresh tomatoes involve various types of solvents, solvent combinations and techniques. Taungbodhitham *et al.* [27] showed that two solvents of low biological hazard, ethanol and hexane, are the most suitable for extracting carotenoids from the tomato matrix. Lambelet *et al.* [28] analysed the stability of lycopene during incubations in organic solvents, including n-hexane, at room temperature in the absence of light. Based on their results, the authors reported that the all-trans lycopene had gradually converted (~40% conversion after 33 days) into *cis* isomers. Lin and Chen [6] studied the stability of β-carotene in tomato juice, and their results clearly indicated that the degradation of β-carotene proceeded more rapidly under light. Only a minor change was found for β-carotene after 3 weeks of storage at 4°C in the absence of light.

Our results on the degradation of lycopene and β-carotene from blanched and non-blanched tomato peels during an incubation in n-hexane at +5°C (±1°C) in the absence of light (because light degrades carotenoids [6, 14]) are shown in Figs 2 and 3. The *all-trans* lycopene from the non-blanched tomato peels was gradually degraded (~37% after 23 days), whereas the degradation of the *all-trans* lycopene from the blanched tomato peels was only approximately 25%. The β-carotene stored for 23 days was stable.

The degradation of the *trans*-lycopene in blanched tomato peels could be best expressed by the exponential equation, $y = -14.809 \times \ln(x) + 81.937$, with a coefficient of determination of $R^2 = 0.9512$. The relationship between the *trans*-lycopene from the non-blanched tomato peels was also strong and significant, with a coefficient of determination of $R^2 = 0.9106$.

Food color is a critical objective parameter that can be used as a quality index (raw vs. processed foods). The color of a sample can be described by many color coordinate systems, such as *RGB* (red, green, blue), Hunter Lab, *CIE* (Commission Internationale de l'Eclairage) *L*a*b**, *CIE XYZ*, *CIE Yxy* and *CIE LCH*. The most used system in the food industry is the *CIEL*a*b** system [29]. In tomato products, an important reaction during thermal processing is the degradation of the red pigment, lycopene, originally in the *trans* form, due to an isomerization to the *cis* form that results in color changes [30]. Moreover, in tomato juice products stabilized by thermal processing, the changes in color can also be caused by non-enzymatic browning [31].

The color coordinate, ***L****, characterizing the lightness in fruit color, decreases during tomato fruit ripening [32]. Based on our study results, the tomato color lightness (*L**) exchange was susceptible to the blanching duration. The color lightness (L*) decreased when the tomato was blanched for 4 min. According to the study of Radzevičius *et al.* [32], during tomato ripening, the ratio of tomato color lightness decreased, as indicated by a darkening of the fruits. However, our study shows that the color lightness increased by blanching the tomato for 0.5 min (Fig. 4a).

The chroma value indicates the degree of saturation of color and is proportional to the strength of the color. A change was found in the chroma between the fresh and blanched tomato fruit; the color chroma (*C*) value also varied at the different blanching durations. The highest C value was found for the fresh (non-blanched) tomatoes (Fig. 4b).

The hue angle is another parameter often used to determine the color of tomatoes. In our study, the hue angle of the blanched tomatoes at different blanching durations was higher than that of the non-blanched tomatoes (Fig. 4c). The hue angle indicated that the

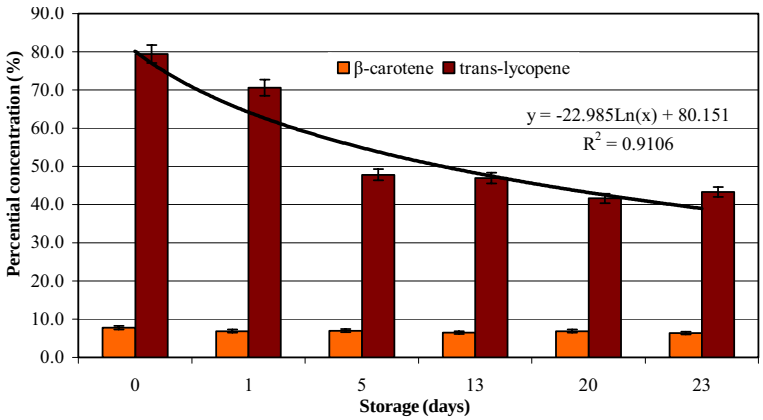

Figure 2. *Trans*-lycopene and β-carotene stability in hexane extract from non-blanched tomato peels.

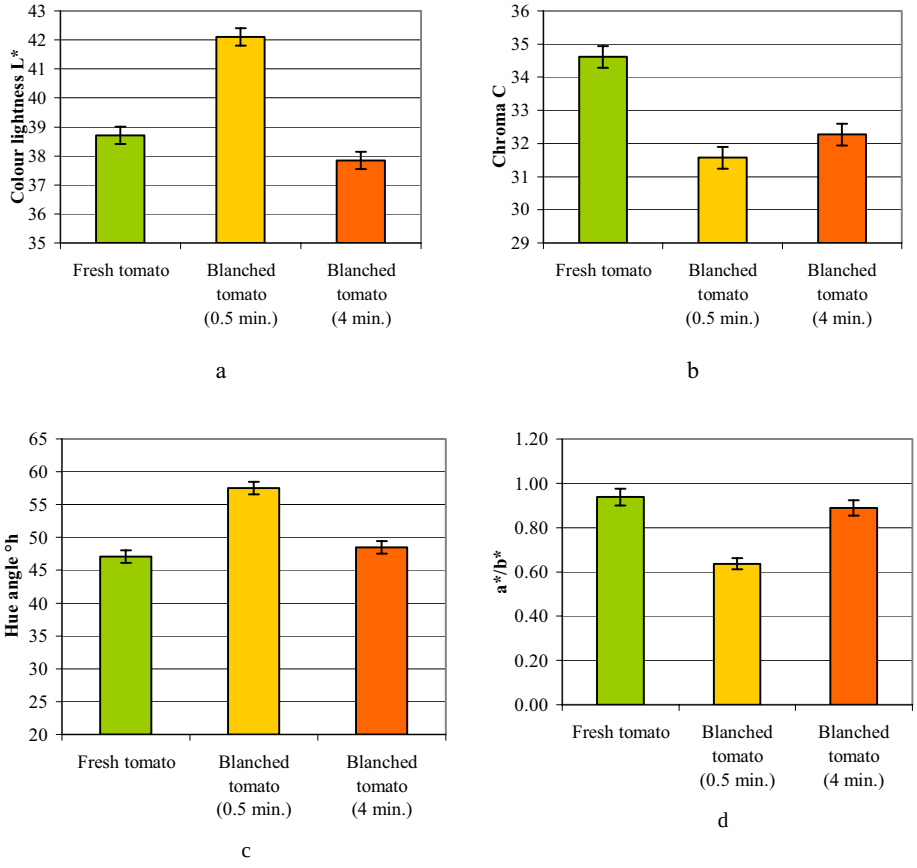

Figure 4. Color lightness (a), chroma (b), hue angle (c), and color coordinate a*/b* ratio (d) for the surface of non-blanched and blanched tomato fruit at 85°C temperature and different blanching durations (0.5 and 4 min).

blanched tomatoes (at 0.5 and 4 min) are not pure red color, whereas a hue angle of 57.52° is a reddish-yellow color (90° would mean that the tomato is yellow, and 0° indicates completely red).

The ratio of the *a** and *b** color coordinates indicate the red color development in tomatoes and is a strong positive correlation between the lycopene content and *a*/b** ratio (r = 0.86) [33]. Our results indicated that the *a*/b** ratio (Fig. 4d) decreased for the tomatoes blanched at 0.5 and 4 min, but this increase was not statistically significant. In addition, the lycopene amount was higher in the blanched tomatoes as compared with the non-blanched tomatoes. It is possible that the blanching process promotes tomato ripening, a process that also increases the lycopene content.

Conclusions

Data from this study suggest that the thermal processing of tomatoes and the application of heat treatment may represent an efficient way to promote the extractability of lycopene and β-carotene and possibly their bioavailability.

Our results indicate that the mean lycopene and β-carotene concentrations were higher in the blanched 'Admiro' F_1 tomatoes than in the non-blanched tomatoes. The β-carotene concentration in the blanched tomato peels was 24.7 mg/100 g, and there was more than twice as much β-carotene than in the non-blanched tomato peels. The concentration of lycopene in the non-blanched tomato peels was 62.92 mg/100 g, whereas it was 134.04 mg/100 g in the blanched tomato peels.

In addition, the stability of the lycopene and β-carotene was studied during incubation in n-hexane at +5°C (±1°C) in the absence of light for 23 days. The *all-trans* lycopene from the non-blanched tomato peels was gradually degraded (~37% after 23 days), whereas the degradation of the *all-trans* lycopene from the blanched tomato peels was only approximately 25%. The β-carotene stored for 23 days was stable.

The data showed that the color lightness (*L**) decreased when the tomato was blanched for 4 min, but the lightness increased in the tomato blanched for 0.5 min. A change was found in the chroma between the fresh and blanched tomato fruit, and the highest chroma (*C*) value (34.61) was in the fresh tomato.

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