

Effect of microwave treatment on bioactive compounds and color in tamarillo (*Solanum betaceum* Cav.) red variety

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Research Article

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Abstract

The main aim of the present study was to determine the effect of microwave blanching bioactive compounds, and color in tamarillo (*Solanum betaceum* Cav.) red variety. Results that showed peroxidase enzyme inactivation based on microwave time and power, microwave blanching at 900 W for 45 seconds reduced residual peroxidase activity under 10% compared to control treatment. In microwave blanching, the content of vitamin C, total phenols, carotenoids, antioxidant activity, luminosity, chroma and yellowness index did not show a significant difference $p > 0.05$ compared to the conventional and fresh methods. On the other hand, vitamins B1, B3, B5, B6, tone and color change did present significant differences. Based on these findings, it is possible to suggest the use of microwave energy as an alternative to conventional blanching, in order to preserve nutritional and color characteristics in this fruit.

1. Introduction

The tamarillo (*Solanum betaceum* Cav.), is native to subtropical areas and its growing popularity among consumers and researchers is due to its diversity of flavors and bioactive compounds [1]. The high presence of antioxidant compounds, such as polyphenols, anthocyanins, carotenoids and vitamins A, C, B and E, makes it stand out from other fruits [2]. Although, this fruit is mainly consumed in fresh salads and desserts, also it used in processed foods like jams, hot sauces, smoothies, alcoholic beverages, yogurt, ice cream and juices [3]. The food and beverage industry have responded to the consumer demands, increasing the ingest of fruit juice from 38,473 millions liters on 2015 to 45,400 millions liters on 2018 [4]. It is expected that this sector reaches around 50,600 millions liters for 2024 [4]. Furthermore, between 2014 and 2021, the prevalence of severe food insecurity in the world increased from 7.7% (564 million people) to 11.7% (923 million people) [5]. Data indicates that the planet is far from meeting United Nations goals 2 and 3 of eradicating hunger and promoting health and well-being [6]. Globally, it is estimated that 233 million people suffer from malnutrition [5]. Which indicates that there are still problems regarding the availability and access to sufficient and nutritious food for the population. The above has led to the search for strategies that can improve the state of food security in the world.

For this reason, allocating technological and scientific resources to guarantee that bioactive compounds are preserved in equal quantities in processed foods as in fresh foods, could be an alternative that would contribute significantly to the reduction of malnutrition and the prevention of some non-communicable diseases that affect the human population [7]. Different agroindustrial operations are involved in the transformation of raw materials of biological origin, including blanching, which is a method that contributes to the inactivation of enzymes, decreases microbial load, stabilization of texture, color, flavor, nutritional value and increase of moisture loss efficiency [8]. Currently, the most commonly adopted blanching technologies in the food industry are water and steam blanching due to their simplicity and ease of implementation [9]. However, the use of these techniques presents several disadvantages, such as the loss of water-soluble nutrients, high energy and water requirements, as well as the need to dispose of wastewater generated during the process [10]. In order to solve the limitations mentioned above, various innovative technologies have been proposed for this process, such as microwave blanching. This

method uses electromagnetic energy found in the frequency range of 300 to 300 MHz and volumetrically penetrates the surface of the food, propagating inside it, resulting in a faster and deeper generation of internal heat than the conventional heating with water or hot air [11]. At the same time, this technique has an important impact on the nutritional quality of the resulting product.

The microwaves are other available alternative to implement bleaching processes and they have the previously cited advantages. In this methodology the heat transfer occurs due to the dielectric materials alignment to the oscillating electromagnetic field, allowing the transfer of the energy along all the material volume. This may reduce the treatment time and the conservation of thermolabile compounds [12]. Recent research study the effects of microwave bleaching on fruit and vegetables enzymes. [13], studied mango fruit applying microwave treatment during 5 minutes at 120 W and 12 minutes at 100 W, which resulted in a high percentage of inactivation of the ascorbic acid oxidase and larger retention of vitamin C, when samples were compared with those exposed to conventional bleaching with hot water. Different authors have reported the increase in bioactive compounds after blanching processes. [14] optimized the microwave blanching process in currant (*Phyllanthus emblica*) and found that, at 294 W for 70 s, the sample contained 3 and 6% more total phenolic content than when blanched with water and fresh, respectively. [15] showed a loss of total phenolic and vitamin C content in soursop (*Annona muricata* L.) blanched with water, microwaves and steam compared to fresh. Also, [11] found that when blanching Irish potatoes (*Solanum tuberosum*, L.) by different methods and thicknesses (4 and 8 mm), vitamin C losses were 60.8–77.1% (blanched with water), 22.2–40.6%. (microwave blanching) and 23.6–42.6% (infrared blanching). [16] blanched asparagus (*Asparagus officinalis* L.) with microwaves at a power of 300 W for times of 2, 4, 6 and 8 minutes and reported a reduction of 16.7, 27.5, 40.1 and 46.6% in the total phenol content respectively. Despite these investigations on microwave blanching, to date, to the best of our knowledge, no report is available in the current literature on the effects on bioactive compounds after thermal inactivation by microwave blanching of the peroxidase enzyme in tamarillo (*Solanum betaceum* Cav.) red variety. For this reason, the objective of the present study was to determine the effect of blanching with microwave treatment on bioactive compounds, and color in tamarillo (*Solanum betaceum* Cav.) red variety.

2. Materials and methods

2.1 Raw Material

The tamarillo fruits (*Solanum betaceum* Cav.), red variety, were obtained from a local market in the city of Palmira, Valle del Cauca, Colombia and were selected taking into account that they were free from mechanical and microbiological damage, in a state of consumption maturity, choosing only fruits on scale 5 and 6 in accordance with the NTC 4105 standard [17]. The collected material was immediately taken to the Fruit and Vegetable Technology laboratory of the Universidad Nacional in Palmira for further analysis.

2.2 Blanching treatments

The fruits were washed with running water, then they were disinfected with sodium hypochlorite at 100 ppm for 10 min, the peduncle and pericarp were removed, subsequently slices 0.70 cm thick and 4.20 cm in diameter were obtained, which were subjected to blanching. Slices of fruit (100 g) were taken and each of them was placed on the glass container. These were subjected to blanching in a domestic turntable microwave with internal dimensions of 240mm x 354mm x 358mm, an internal capacity of 30 L (Whirlpool Model WMCSG141XD; China) at 2450 MHz at a power of 300, 600, 900 and 1200 W for 15, 30, 45 y seconds. In the case of blanching in water, fruit slices (100 g) were taken and each of them was immersed in a thermostatically controlled water bath (PolyScience Model WB10A11B; USA) with total dimensions (Length x Width x Height) (cm) 39.3 x 43.2 x 30.5. Subsequently, the plant material was subjected to blanching temperatures of 70, 75, 80, 85 and 90°C for 1, 2, 3, 4, 5 y 6 minutes. The blanching water-fruit slices ratio was 4:1 (v/p) in accordance with what was established by [18]. After each experiment, each sample was subjected to cooling for 1 minute in an ice-water bath at a temperature below 4°C and subsequently taken to the juice extractor. Each experiment was performed in triplicate.

2.3 Determination of the peroxidase activity

The peroxidase extraction and activity was done using the protocol described by [19] with modifications. A 0.1 M pH 6.5 potassium phosphate buffer solution (ABC Laboratories, Bogotá Colombia) was added to the samples in a 1:2 (m/v) ratio. Samples were homogenized with an Ultra-Turrax T25 (IKA-Werke GmbH & Co, Staufen, Alemania) for one minute at 15000 rpm while they were kept/hold in ice. Then, the suspensions were centrifuged at 15000 rpm for 10 minutes at room temperature in a Beckman centrifuge (Beckman instruments Inc, J2-21 model. Palo Alto, CA, EE.UU). The supernatant was collected and used as enzyme extract for the peroxidase assay. 0.02 mL of enzyme extract were added to a 3.48 mL substrate solution (daily prepared), containing 99.8 mL of potassium phosphate 0.1 M pH 6.5 buffer solution, 0.1 mL 99.5% guaiacol (Sigma Aldrich, Milan Italy) and 0.1 mL 30% hydrogen peroxide (Sigma Aldrich, Milan Italy). Absorbance increases at 470 nm were registered for one minute, using the spectrophotometer (Biobase BK-UV1000, Jinan, Shandong, China). Then, the constant speed reaction was determined with the slope of the relationship absorbance vs time and used to determine the substrate - product transformation rate. The 26.6 mM⁻¹ cm⁻¹ molar extinction coefficient of tetraguaiacol at 470 nm was considered in the calculation [20]. The peroxidase activity was calculated as IU/g fw and the residual activity expressed as percentage compared to the initial value. Each enzyme extracts were analyzed three times and values corrected with the value obtained with a blank sample.

2.4 *Determination of the concentration of carotenoids and provitamin A*

The extraction and quantification of carotenoids and provitamin A were carried out according to the protocol described by [21]. The absorbance of each solution in the hexane phase was read at 450, 444, 451, and 472 nm, respectively, against hexane as blank using a spectrophotometer (Biobase BK-UV1000, Jinan, Shandong, China). The concentration of carotenoids (mg/100 g) was calculated using the extinction coefficients ($E_{1cm}^{\%}$) in hexane: 2560, 2800, 2460, 2480 and 3450 for β-carotene, α-carotene, β-

cryptoxanthin, zeaxanthin and lycopene published by [22]. "Retinol activity equivalents (RAE) were calculated using a conversion factor of 12 for β -carotene and 24 for the other provitamins A (α -carotene and β -cryptoxanthin) for 1 retinol and expressed in μg RAE/ g [21].

2.5 Determination of vitamin C

Vitamin C in the samples was determined following the protocol proposed by [23] with some modifications. 2 g of the sample was mixed in a test tube with 0.8 mL of a 10% (w/v) trichloroacetic acid solution, which were placed in an ice bath for 5 min. Then, 0.5 mL of the solution was taken and diluted with 2 mL of ultrapure water and 200 μL of a 1:10 dilution of the Folin-Ciocalteu reagent. The solution was allowed to stand for 10 min at room temperature. Subsequently, the absorbance at 760 nm was read against the respective blank using a spectrophotometer (Biobase BK-UV1000, Jinan, Shandong, China). The concentration of vitamin C (mg of ascorbic acid/100 g of fresh fruit) in the samples was calculated from a calibration line prepared with a standard solution of ascorbic acid (3.7–18.5 μg mL⁻¹, $R^2 = 0.9983$) .

2.6 Determination of total phenolic compounds

This evaluation was carried out using the Folin-Ciocalteu method, according to [24] with some modifications. Approximately 3 g of sample was weighed into a test tube lined with aluminum foil. Then, 20 mL of ethanol and water were added in a ratio (80:20% v/v) and mixed on a stirring plate for 3 min. Subsequently, the mixture was subjected to sonification at 42 kHz and input power of 240 W (ultrasonic cleaner HB-S49DHT, China) for 20 min at 25°C. After this time, the sample was filtered and 0.5 mL of the filtrate was mixed with 5 mL of distilled water and 0.5 mL of Folin-Ciocalteu reagent. The mixture was allowed to react for 3 min at room temperature. After this time, 1 mL of 20% anhydride sodium carbonate was added and the tubes were placed in a thermal bath programmed at 45°C for 15 min. Finally, the absorbance at 765 nm was read against the respective blank using a spectrophotometer (Biobase BK-UV1000, Jinan, Shandong, China). The concentration of total phenols (mg gallic acid/100 g fresh fruit) in the samples was calculated from a calibration line prepared with a standard solution of gallic acid (2.9–14.3 μg mL⁻¹, $R^2 = 0.9951$) .

2.7 Determination of B complex vitamins

The % of vitamins B1, B3, B5 and B6 was determined based on the method described by [25]. 1 g of fruit was macerated and mixed with 6 mL of distilled water and homogenized for 2 min using an Ultra-Turrax T25 (IKA-Werke GmbH & Co, Staufen, Germany). Vitamins were extracted by adding 0.25 M sulfuric acid (1 mL) to the sample, which was heated for 30 min in a water bath (70°C). After cooling in an ice bath, the pH was adjusted to 4.5 using a 0.5 M sodium hydroxide solution and the sample was centrifuged at 15000 rpm in a Beckman centrifuge (Model J2-21. Beckman Instruments Inc., Palo Alto, CA, USA) for 10 min. The supernatant was collected and analyzed in a spectrophotometer (Biobase BK-UV1000, Jinan, Shandong, China) at 215 (Vitamin B5), 254 (Vitamin B1), 265 (Vitamin B3) and 716 (Vitamin B6) nm using distilled water as blank. The results were recorded in retention percentage following the Eq. 1

reported by [25], where the absorbance after treatment (Abs) and the sample without treatment ($Abs_{fresh\ fruit}$) are related, respectively.

$$\%Retention = \left(\frac{Abs}{Abs_{freshfruit}} \right) \times 100 \text{ Eq. 1}$$

2.8 Determination of antioxidant activity (% DPPH)

The antioxidant activity expressed as percentage of inhibition of the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical was carried out by the method described by [24]. To 0.5 g of tamarillo pulp, 50 mL of methanol is added and stirred for 1 minute on a griddle. Then, 1 mL of the extract obtained was mixed with 2 mL of the freshly prepared 0.1 mM DPPH. A control was prepared, which consisted of 1 mL of methanol and 2 mL of freshly prepared 0.1 mM DPPH. Finally, after leaving the samples to rest for 1 h in the dark, the absorbance readings were carried out in a spectrophotometer (Biobase BK-UV1000, Jinan, Shandong, China) at 517 nm using methanol as a blank.

According to [24], the percentage of AA antioxidant activity (%) in terms of DPPH radical inhibition were calculated using the Eq. 2

$$AA (\%) = \frac{A_{517Control} - A_{517Muestra}}{A_{517Control}} \times 100 \text{ Eq. 2}$$

Where:

A_{517} : absorbance reading at 517 (nm)

2.9 Determination of superficial color CIEL*a*b

The protocol described by [21]. The surface color of the tamarillo samples was determined using a Konica Minolta CR-400 Colorimeter (Tokyo Japan), in CIEL*a*b* coordinates (L^* , a^* and b^*). A standard D65 illuminant was used and the observer angle at 2° . The instrument was standardized with a black and a white calibration plate with the following calibration parameters: $Y = 89.50$, $x = 0.3176$, $y = 0.3347$. The values of chromaticity (C), tone (h°), color change (ΔE) and yellowness index (IA) were calculated using the following Eqs. 3–6

$$C = \sqrt{a^{*2} + b^{*2}} \text{ Eq. 3}$$

$$h^0 = \tan^{-1} \left(\frac{b^*}{a^*} \right) \text{ Eq. 4}$$

$$\Delta E = \sqrt{\Delta a^{*2} + \Delta b^{*2} + \Delta L^{*2}} \text{ Eq. 5}$$

$$\frac{\varvec{I}}{\varvec{A}} = \frac{142.86 \frac{\varvec{b}}{\varvec{L}}}{\frac{\varvec{L}}{\varvec{A}}} \text{ Eq. 6}$$

2.10 Statistical Analysis

The results of residual enzyme activity in the tamarillo fruit were presented as mean values $\pm$ standard error. The effect of power treatment at 300, 600, 900 and 1200 W for 15, 30, 45 and 60 seconds, was compared to 10% threshold, which indicates the inhibition of the target enzyme, responsible of changes like undesirable color and texture and nutrients decomposition. Regarding the effect of blanching treatments, were reported as mean values $\pm$ standard error. A simple randomized design of three treatments was carried out (fresh, blanching with water (85°C for 180 seconds) and blanching with microwaves (900 W for 45 seconds). Each treatment had three repetitions. An ANOVA analysis was carried out and $p < 0.05$ was applied to determine the level of significance. The comparison of means was carried out using the Tukey test at the 95% confidence level ($p < 0.05$). Data processing was evaluated with the R program (R core team, 2016).

3. Results and discusi3n

3.1 Peroxidase enzyme inactivation in tamarillo

Figures 1 and 2 show the peroxidase enzyme inactivation for each microwave and control treatment (water blanching). Microwave blanching reduces the enzymatic activity depending on the time and power of the treatment. It is observed that only the 900 and 1200 W treatments reach enzymatic activities of less than 10% after 45 seconds (Fig. 1). For reasons of energy consumption, it has been decided to select the power-time combination for microwave blanching (900 W for 45 seconds). In the control treatment, better inactivation rates of the peroxidase enzyme ($< 10\%$) are evident at temperatures greater than 85°C after 180 seconds (Fig. 2).

Figura 1. Means and variation (standard error) of the peroxidase residual activity in tamarillo fruit exposed to different powers and times of microwave blanching.

The present result is comparable to the results reported by [11], which implemented similar bleaching methods in potato (*Solanum tuberosum* L) and string bean (*Phaseolus vulgaris* L), finding peroxidase inactivation was achieved in shorter time when samples were exposed to microwave.

Also,[26] found that in apple juice the thermostable fraction of the peroxidase was inactivated more efficiently by microwave heating than conventional heating. This was explained by the increases of the distance between the hemo group and the tryptophan residue or the loss of the calcium cofactor in the enzyme. However, [27], observed that when bleaching methods were compared, the time to inactivate the peroxidase of melon, carrot and pepper was shorter using conventional method than microwave; since chemical composition, geometry shape, size, thickness and dielectric properties might be determinant for temperature distribution and the electromagnetic energy absorbed by these foods.

The advantage of microwave treatment over conventional treatment is that in the latter, theoretically the temperature increases are slower, because this depends on the thermal conductivity of the material; Through heat transfer it flows from the surface of the product to the internal section, while in the

microwave the waves heat the food volumetrically through ionic polarization and bipolar rotation of the molecules [19].

This triggers a rapid disruption between hydrogen bonds and the Vander Waals and London forces, inducing structural changes in the polypeptide chains and reducing the catalytic activity of the enzyme [28]. By increasing the irradiation power in the microwave treatment, the residual activity of the enzyme decreases, due to the acceleration of the proportion or energy absorbed from the food.

This results in increased polarity of the molecules, generating higher temperatures caused by increases in vibration and friction of the molecules [15, 29]. The present results agree with [27] and [30] research, who present an inverse relation between the power level and residual enzymatic activity of the peroxidase when microwaves were applied to lettuce (*Lactuca sativa*), broccoli (cv. Brigadiere), string beans (cv. Hilea) and asparagus (cv. Sweet purple). However, the power excesses may contribute to the uninformed distribution of the temperature, since heating could be fast avoiding the effectiveness of the thermal conductivity in the heat transfer to other parts of the product.

Besides, the variations in power intensity may produce inner hot spots due to stationary waves inside the food, which are produced by the interaction between the reflected waves and transmitted ones (based on the thickness and dielectric properties of the food) [27].

In addition, it is important to stand out that even when the residual activity of the enzyme is reduced with high or low decreases of energy and time, the thermal stability of the peroxidase is a determinant factor. Basically, because the presence of several cysteine residues of the polypeptide chain generates disulfide bounds, which have covalent bonds, that require high energy for its cleavage [31].

Also, it must be considered that after reducing the activity of the enzyme, the peroxidase reactivation may occur due to the folding ability of the proteic group [26]. Finally, the variation of the results of the present research compared to others, may be caused by the extraction protocol, the conditions of the enzymatic assessment, the fruit type, the fruit developmental stage, the enzymatic variants along the developmental stages and other environmental/agri-climate parameters [32].

3.2 Effect of microwave blanching on bioactive compounds and color in tamarillo

In Figs. 3 and 4, it is observed that there was no significant difference in the content of vitamin C, total phenols, carotenoids (β -carotene, α -carotene, β -cryptoxanthin, zeaxanthin, lycopene and provitamin A) and antioxidant activity in the tamarillo blanched with a microwave (900 W for 45 seconds) compared to that treated with water (85°C for 180 seconds) and fresh.

Figura 3. Effect of blanching on the bioactive compounds present in tamarillo (n = 3). Response variables were reported as mean values $\pm$ standard error. Control (no treatment); MB (microwave blanching at 900W for 45 seconds); WB (blanching with water at 85°C for 180 seconds).

Figura 4. Effect of blanching on carotenoids present in tamarillos (n = 3). Response variables were reported as mean values ± standard error. Control (no treatment); MB (microwave blanching at 900W for 45 seconds); WB (blanching with water at 85°C for 180 seconds).

The percentage of retention of B complex vitamins (B1, B3, B5 and B6) was higher in blanching with water than in microwave compared to fresh (Table 1).

Tabla 1. Effect of blanching on the retention percentage of B complex vitamins present in tamarillos (n = 3). Response variables were reported as a percentage. Control (no treatment); MB (microwave blanching at 900W for 45 seconds); WB (scalding with water at 85°C for 180 seconds).

Treatment	Vitamin B1	Vitamin B3	Vitamin B5	Vitamin B6
Control	100	100	100	100
MB	0	0	0	0
WB	118.37 ± 18.37	118.9 ± 18.9	100	67.1 ± 11.75

Figure 3 shows an increase (although not significant with respect to fresh) of 13 and 12% of this compound respectively. This may be due to the fact that, by decreasing the residual enzymatic activity of peroxidase, it is guaranteed that enzymes such as polyphenoloxidase, pectinmethylesterase and ascorbate oxidase are not present, since the former has a much higher heat resistance than the others [33], which reduces the possibility of enzymatic oxidation of this compound occurring. Also, thermal blanching can destroy the cell wall of vegetables and, therefore, facilitate the elimination of water, which can lead to the concentration and release of antioxidants [34].

The retention of total phenolics during microwave, this result may be due to the fact that the energy provided in blanching by microwaves and water can cause a rupture of the cell walls, facilitating the release of phenolics linked to pectin, cellulose, hemicellulose and traces of lignin from the cell wall, which can cause a higher extraction rate compared to the degradation of phenols in the fruit [21]. On the other hand, by inhibiting the peroxidase enzyme it was possible to prevent the oxidation of monophenolic compounds from being catalyzed to o-diphenol and o-dihydroxy to o-quinones [15]. These findings are consistent with the results of previous research conducted by [14] and [15], which found that in comparison with untreated samples of gooseberry (*Phyllanthus emblica*) and soursop (*Annona muricata* L.), the total phenol content for the first case increased (6%) and for the second they were maintained after blanching with microwave.

Figure 3, it can be seen that both the methanolic extract obtained from the microwave blanched tamarillo (81.23%), as well as that from the control heat treatment (73.1%) and the fresh sample (89.03%) exhibit an important DPPH radical scavenging activity. This may be related to the content of total phenols [35], a statement that agrees with the results obtained in this study where it is evident that as the concentration

of these compounds increases, the concentration of DPPH radicals decreases. [36] recorded a higher antioxidant activity (DPPH) in ripe tamarillos (higher content of phenolic compounds) than in unripe ones (lower content of phenolic compounds). [37] used different solvents (ethanol, ethyl acetate, butanol and water) for the extraction of phenolic compounds from tamarillo and found a strong DPPH inhibitory activity as the content of these compounds increased. Another study conducted on microwave blanched asparagus (*Asparagus officinalis* L.) also found that there is a positive correlation between phenolic content and antioxidant activity [16]. This phenomenon occurs because phenolic compounds obtained from plants have significant antioxidant properties due to their ability to accept electrons in the Michael reaction [37].

The retention of carotenoids may be due to the inactivation of lipoxygenase since it is more sensitive to heat than peroxidase [38]. On the other hand, the decrease in carotenoids is related to oxidation, isomerization and degradation in response to oxygen, heat and light [23]. In the study carried out by [39], the production of esters of 13-cis- β -carotene, 5,6-epoxy- β -cryptoxanthin and zeaxanthin was evident when β -carotene, β -cryptoxanthin and zeaxanthin were degraded, respectively, in tomato tree nectar that had been subjected to heat treatment at temperatures of 80 and 90°C. Temperature can act as a catalyst for the isomerization and oxidation of carotenoid compounds, and its impact depends on both the intensity of the heat treatment and the structure of the carotenoid pigments in question; Furthermore, temperature can trigger chemical reactions that lead to the formation of structures such as cis-carotenoids, epoxycarotenoids, apocarotenoids and low molecular weight structures [23]. Although in the treatments applied in this study there was no significant difference in the content of carotenoids evaluated, it was observed that β -cryptoxanthin, zeaxanthin and lycopene presented the highest level of thermoresistance and β -carotene and α -carotene the lowest; which agrees with the results obtained by [23] for this same fruit, but in the yellow variety. These differences can be determined by various factors such as the variety/cultivation used, the time of harvest, the climate, the geographical location of production, the season in which it was produced, the part of the plant that is used, the conditions during agricultural production, post-harvest handling, processing, storage conditions, differences in the polarity of the chosen solvents and quantification techniques [36].

In table 1, the B vitamin content of this fresh fruit was used as a reference (100%) to evaluate the effect of blanching on the retention of these compounds. It is observed that in the sample blanched with microwaves, the retention of B complex vitamins (B1, B3, B5 and B6) was not achieved, which may be related to the direct interaction that electromagnetic radiation achieves with the molecules of the material, generating a destructive effect in these water-soluble compounds [40]. On the other hand, the sample blanched with water showed a positive effect on vitamins B1 and B3, presenting 18% more than the untreated sample, B5 behaved stable and B6 was retained 67.1%. Vitamin B1 (thiamine) can be phosphorylated, while B3 is usually linked to nucleotides, B5 to coenzyme A and B6 to an apoenzyme, however, conventional heat treatment could have caused the breaking or dissociation of these bonds, giving as a result, a greater amount of the free form of these vitamins causing an increase in their availability [41]. For vitamin B6, although it has low sensitivity to heat, it is considered sensitive to light, and its decrease is also attributed to the transformation of pyridoxal into pyridoxamine and the creation

of bis-4-pyridoxal disulfide [40]. Similar results were reported by [41] in retention of vitamins B1, B3 and B5 in samples of mango (*Mangifera indica* L.) and cherry tomato (*Solanum lycopersicum* var. cerasiforme) respectively. As an example, a lack of vitamin B1 can cause chemical damage to the brain known as Wernicke's encephalopathy, while a lack of vitamins B6 and B12 can lead to the development of anemia [42].

In Fig. 5, it can be seen that the color parameters (L^* , C, YI) did not present significant changes after the blanching treatments with respect to the fresh material, while in h° and ΔE there were significant increases ($p < 0.05$).

Figura 5. Effect of blanching on color parameters in tamarillo (n = 3). Response variables were reported as mean values $\pm$ standard error. Control (no treatment); MB (microwave blanching at 900W for 45 seconds); WB (blanching with water at 85°C for 180 seconds).

This chromatic change may be related to the decrease in phenolic compounds present in the control blanched sample (110.2 mg/100 g of fresh fruit) compared to the fresh one (116.1 mg/100 g of fresh fruit), since some of these, having one, two or three OH groups in their aglyconated structure, cause the maximum absorption to shift towards higher wavelengths [43], which can cause a change in the area of the visible spectrum of the samples analyzed, from red-yellow to yellow, thus reducing the hue of the red color and increasing the yellowing index (although not significantly) in the tamarillo after heat treatment. In addition, this could also cause the sample blanched with microwaves to present color differences compared to the fresh one treated by the conventional method ($p < 0.05$) as in both cases it presented a ΔE greater than 2 [21], although the one that differs the least is that of microwave treatment.

The opposite was observed in the research carried out by [21] where the increase in the content of total phenols (increase in OH groups) caused the cape gooseberry juice subjected to ultrasound pasteurization to change the area of the visible spectrum of the samples from yellow to yellow-red, thus reducing the intensity of the yellow color. Another aspect associated differently with phenols is the transformation of carotenoids through isomerization, which produces a hypochromatic change and a hypochromic effect, which is commonly manifested by an additional absorption band in the range of 320 to 360 nm [21]. In this study, the values of lightness, chromaticity and tone adjust to those obtained by [1] ($L^*=48.82-55.87$, $C^*=29.68-48.26$, $h^\circ=67.63-77.89$) who reported the results in puree (with and without oil) obtained from the red variety of tamarillo subjected at different temperatures (100, 121, 150, 175 and 200°C) and times (2, 4 and 6 min). On the other hand, the colorimetric studies carried out by [43] to solutions of anthocyanin extracts obtained from the gelatinous part of the tamarillo seeds, are adjusted in values ($L^*=40.50-66.10$ and $C^*=28.70-67.4$), but lower in tone ($h^\circ=32.1-64.9$) and present greater differences in color perception ($\Delta E=11.5-30.3$). Similar findings in color change (ΔE) were reported in Indian gooseberry (*Phyllanthus emblica*) [14], in papaya, kiwi and strawberry purees [44] and in pulp of soursop [15].

4. Conclusions

The results of the present study showed that microwave power augmentation had a significant effect on the decreases of time to inactivate the peroxidase residual activity of tamarillo fruit. Microwave blanching inactivated more than 90% of the residual activity of the enzyme in shorter time (900 W for 45 seconds) than conventional blanching.

In this study, the effect of microwave blanching on the bioactive compounds present in the red variety of tamarillo was evaluated. This heat treatment did not significantly affect the content of vitamin C, total phenols, carotenoids and antioxidant activity compared to the fresh sample and the conventional treatment, but it degraded the water-soluble vitamins of the B complex (B1, B3, B5 and B6). Changes in red-yellow to yellow color in tamarillo were also observed in samples subjected to microwave blanching. Therefore, the use of microwave energy offers a good alternative to conventional blanching given its simplicity, rapid application and no use of water. This research can be useful for the optimal industrial design of products from tamarillos.

Declarations

CRedit authorship contribution statement

Jaime Andres Tigreros: Investigation, Methodology, Software, Formal analysis, Validation, Writing – original draft. **Jader Martinez-Giron:** Validation, Investigation, Methodology, Writing – review & editing. **Luis Eduardo Ordoñez-Santos:** Conceptualization, Investigation, Methodology, Writing – review & editing.

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Data Availability All data generated or analyzed for this study are included in this published article (and its Supplementary Information fle).

Declaration of Competing Interest

The authors declare that there is no personal or financial conflict of interest that will affect the work presented in this article.

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Figures

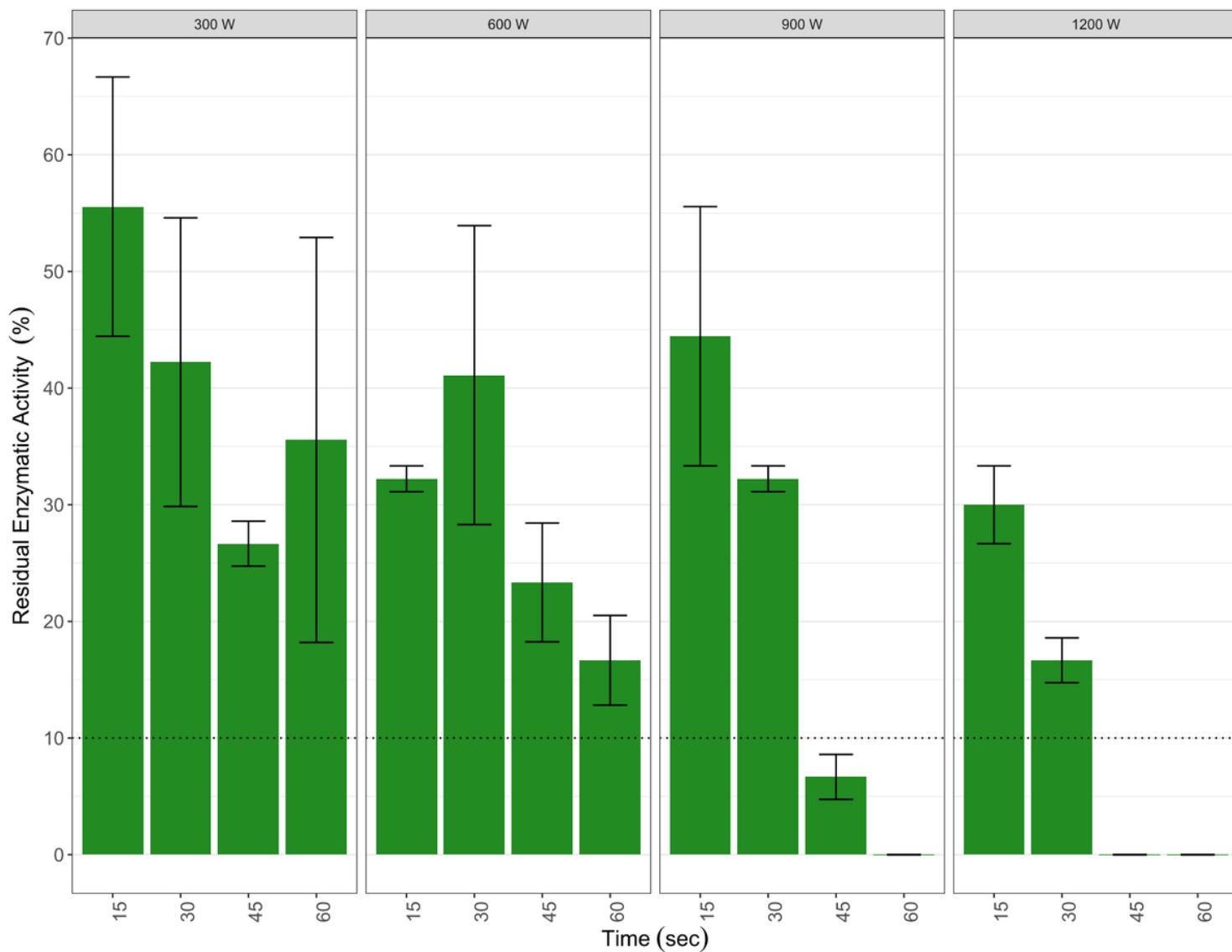


Figure 1

Means and variation (standard error) of the peroxidase residual activity in tamarillo fruit exposed to different powers and times of microwave blanching.

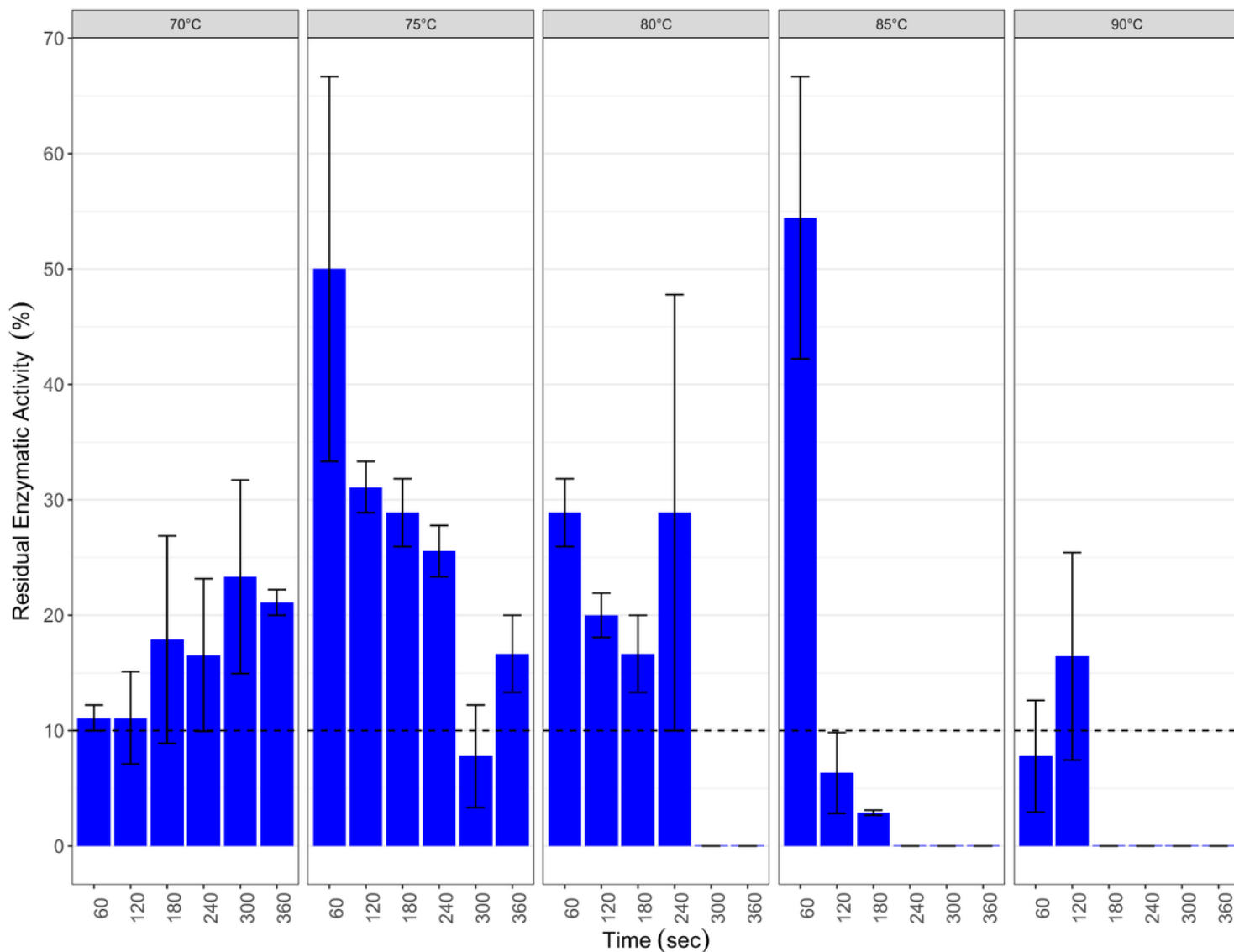


Figure 2

Means and variation (standard error) of the peroxidase residual activity in tamarillo fruit exposed to different temperatures and times of water blanching

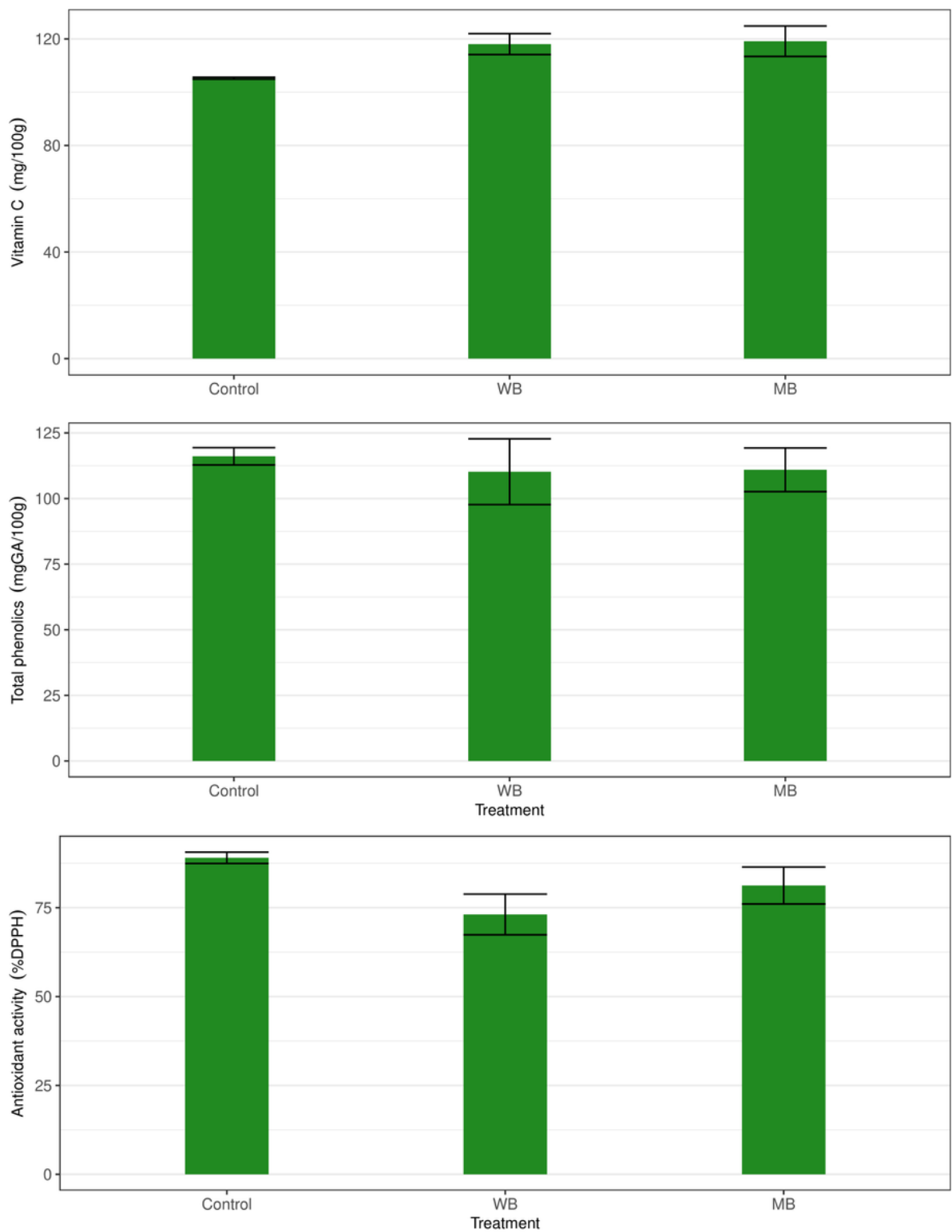


Figure 3

Effect of blanching on the bioactive compounds present in tamarillo (n=3). Response variables were reported as mean values $\pm$ standard error. Control (no treatment); MB (microwave blanching at 900W for 45 seconds); WB (blanching with water at 85°C for 180 seconds).

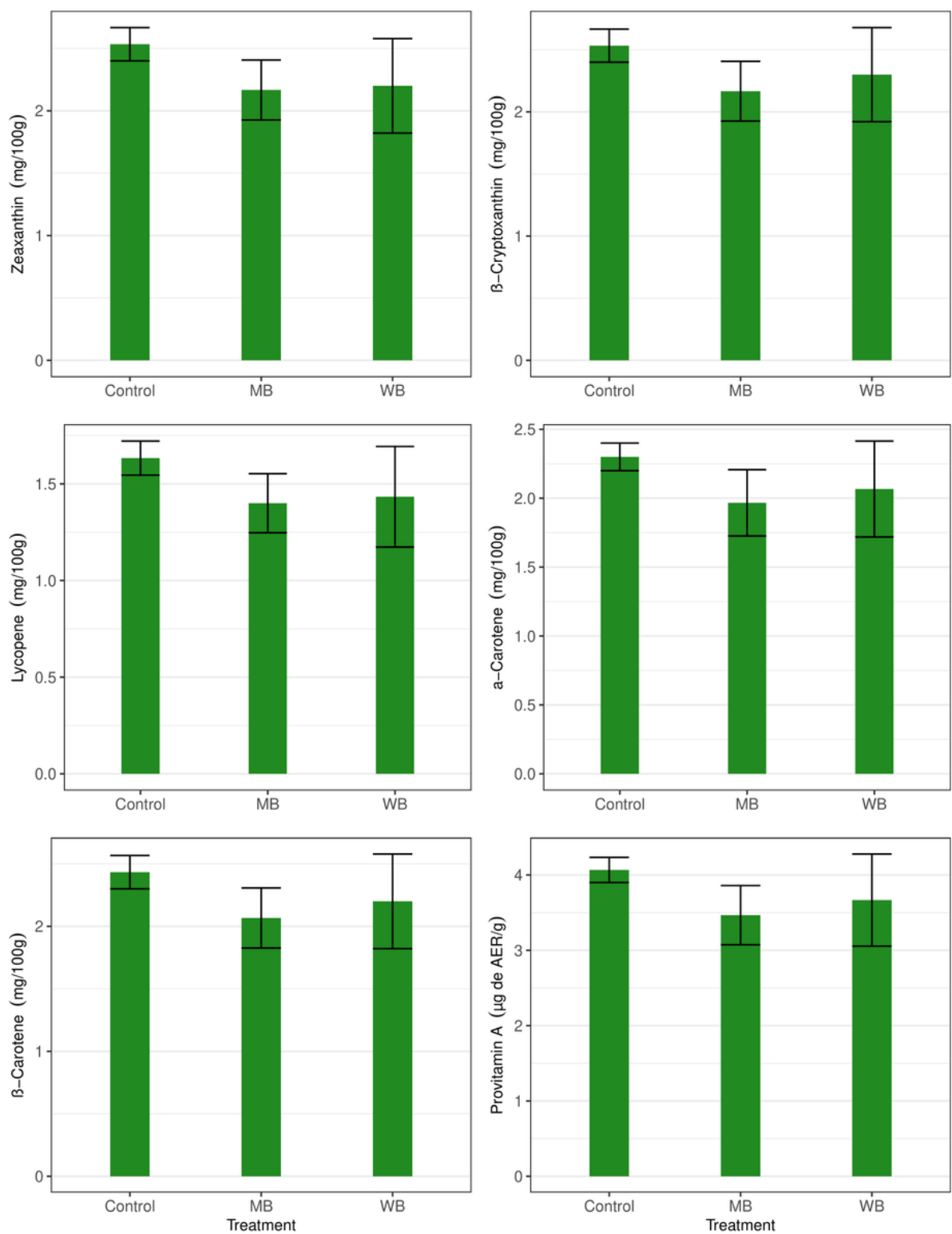


Figure 4

Effect of blanching on carotenoids present in tamarillos (n=3). Response variables were reported as mean values $\pm$ standard error. Control (no treatment); MB (microwave blanching at 900W for 45 seconds); WB (blanching with water at 85°C for 180 seconds).

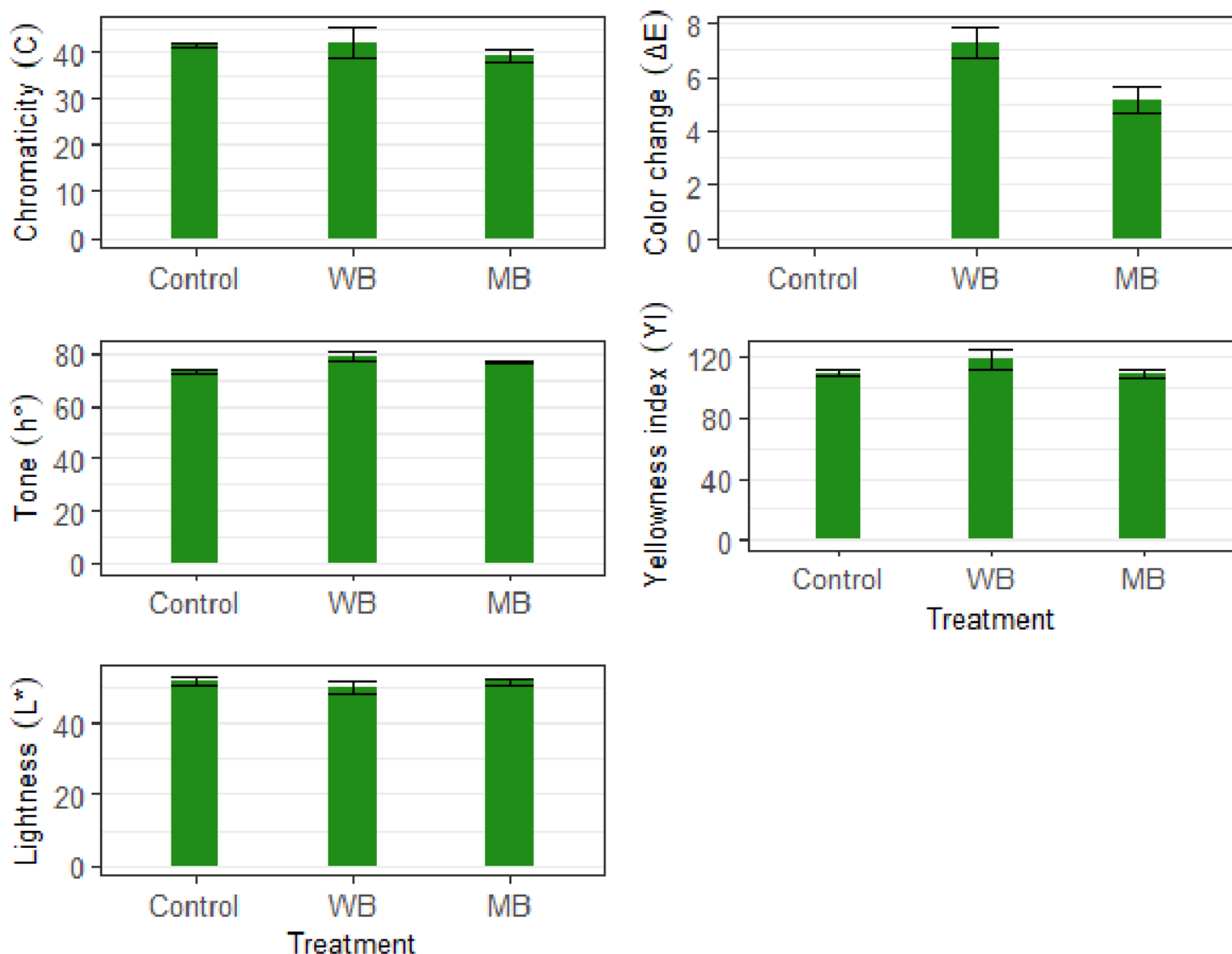


Figure 5

Effect of blanching on color parameters in tamarillo (n=3). Response variables were reported as mean values $\pm$ standard error. Control (no treatment); MB (microwave blanching at 900W for 45 seconds); WB (blanching with water at 85°C for 180 seconds).

Supplementary Files

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