Investigating the variations of sour orange juice color during the ohmic heating process

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Abstract: In this research, an ohmic heating system was constructed and applied to the heating process in three input voltage gradients (8.33, 10.83, 13.33 V cm^{-1}) and three weight loss percentages (10%, 20% and 30%) compared to the total weight. Following the heating process, color changes were performed using Image j software that measured factors L*, a*, b *, brown index, chroma, total color difference. All experiments were performed in three replications using factorial analysis and a completely randomized design. The results were analyzed using SAS software, showing that voltage gradient had a meaningful effect on all factors except a*; as for weight loss percentage, all factors were significant, and by increasing the voltage gradient of L*, a* was reduced and the amount of b*, brown index, chroma and total color difference increased during the heating process. The highest value for the color properties of L* is equal to 68.5 and for a* was 6.5 which was obtained at a voltage of 8.33 V. For browning index and b* value, the highest values were 125.4 and 45.2, respectively, which were observed at 13.33 V. For the chroma index and total color difference, the highest values were obtained at exactly the same voltage, which were equal to 43.2 and 19.8. Altogether, the thermal process significantly reduces the brightness and redness of sour orange juice, increasing the amount of yellowness.

Keywords: sour orange juice, ohmic heating, color changes, statistical analysis

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1 Introduction

Southwest Asia, and it has a rounded and acidic fruit known as bitter sour orange, sour orange or Seville Sour orange (Citrus aurantium L.) synonymous with the name "C. bigaradia Duh, C. Vulgalis" is native to names (Amiri and Niakousari, 2008). Among sour orange varieties, mention can be made of sour orange juice, spring jam, sour orange concentrate, cherry juice and sour orange juice. Sour orange juice contains citric acid, sugar, gum, minerals and vitamins, especially vitamin c. Due to the high levels of vitamin C during the maintenance period, factors affecting such qualities as color are strongly influenced by environmental conditions and have a meaningful effect on this customer-friendly product (Montazer and Niakousari, 2012).

It is also necessary to process food products, one of which methods is the thermal processes based on heat transfer mechanism via conduction, convection and radiation. The resistance of products against heat

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conduction leads to the significant loss of their quality, hence the importance of alternative technologies considered for this problem over the recent decades; ohmic heating is a method for food processing operations where the heat in the food is generated by the flow of electricity (Vahedi Torshizi et al., 2020a, 2020b). Thermal and non-thermal processing technologies, based on physical techniques for preserving food, have the potential to meet consumer demands and deliver high-quality products with a long lifespan and are free of extras and subject to high temperature treatments. Research and developments in non-thermal techniques are mainly aimed at preventing non-allergenic microorganisms, allergens and enzymes from disrupting the nutritional and allergenic properties of the heat treatment (Azadbakht et al., 2019, 2017). Product quality includes three main areas: nutritional value, acceptance and safety. Acceptance includes an extensive set of features such as visual appearance, flavor, smell and texture (Sharifian et al., 2013). The first qualitative judgment of a consumer on food is its appearance. Color is one of the most important features associated with the appearance of food because it affects consumer acceptance. The abnormal color of food might lead to its rejection by the consumer. Therefore, many food manufacturers use psychological effects to boost their sales. On the other hand, heat treatment must be optimized to obtain high quality products. Regarding quality, color is a key attribute that embraces primary food intake (Vadivambal and Jayas, 2007).

The research on ohmic heating and its impact on discoloration:

Abhilasha. (2018) conducted an experiment on the effect of ohmic heating process on cane sugar. Their results showed that cane sugar juice became significantly darker than the control sample when it was heated (Abhilasha and Pal, 2018).

Bhat et al. (2017) compared the conventional thermal processes and ohmic heating; the experiment was performed on bottle gourd juice and the results showed that the browning index and overall color variations during the ohmic process were less than the conventional heating process (Bhat et al., 2017).

Ishita and Athmaselvi. (2017) conducted an experiment on the color variations of watermelon juice during the heating process, where the voltage gradient had a meaningful effect on the amount of color variation; moreover, with the increase in voltage gradient, clarity watermelon juice decreased during the heating process (Ishita and Athmaselvi, 2017).

Makroo et al. (2017) carried out experiments on the effect of pretreatment on the amount of water color changes in the watermelon using the heat treatment process and hot water; their results showed that the overall color variations were fewer than hot water via heat treatment process, and the chromium content of hot water treatment was more than that in ohmic heating (Makroo et al., 2017).

Saxena et al. (2017) investigated effect of ohmic heating on polyphenol oxidase (PPO) inactivation and color change in sugarcane juice the result showed, color change was inversely proportional to treatment temperatures at 24 V cm^{-1} and directly proportional at 32 and 48 V cm^{-1}. The kinetics for L, a, b values was best described by first order model while colour change was best explained by the combined model (Saxena et al., 2017).

Brochier et al. (2019) conducted effect of moderate electric field on peroxidase activity, phenolic compounds and color during ohmic heating of sugarcane juice. The result showed the color of the juice was modified using low frequency (possibly due to electrochemical reactions) and different waveforms. Overall, OH is suitable for POD inactivation at 80°C with the usual process parameters (sine wave and 60 Hz) or higher frequencies (Brochier et al., 2019).

Sabancı and Icier (2019) conducted effects of vacuum ohmic evaporation on some quality properties of sour cherry juice concentrates. Vacuum ohmic evaporation process preserved the color properties of juice concentrates better compared to the vacuum evaporation process. It was concluded that vacuum ohmic evaporation method could be an alternative fast evaporation method to obtain high-quality fruit juice concentrates (Sabancı and Icier, 2019). Given the fact that the most common method for sour juice health is a heat treatment method, one should be able to create a method that, in addition to maintaining the product's qualitative characteristics, has the least color variation, hence the objective of the present study to investigate the effect of voltage and weight loss percentage on the color changes of sour orange juice during the heating process, which is important to specifying how much of sour orange juice color is changed during the heating process and using the aforementioned factors.

2 Materials and methods

2.1 Sample preparation

The sour oranges were purchased from a garden located in the city of Gorgan, Golestan province. Immediately after purchasing, the prepared sour oranges were washed and split into two halves in the middle (the digestion was carried out manually). The samples were prepared during the ohmic process with voltage gradients and different weight loss percentages to examine the changes in L *, a *, b *, chroma and browning index, and TCD.

2.2 The experiment method

In order to carry out this process, a reservoir (made of thermoset plastics) was considered, into which the samples were poured between the two electrodes; next, their initial temperature was recorded after stability, the voltage was applied to the set and the samples were heated. Three heating voltage gradients of 8.33, 10.83 and 13.33 V cm^{-1} were selected for the heating process. By using 10 (from 90 g to 81 g), 20 (from 90 g to 72 g) and 30 (from 90 g to 63 g) voltage gradients, the percentage of the total weight of the sour water samples poured into the cell during the warm-up process was determined. All samples with a weight of 90 g were selected. Figure 1 shows a schematic diagram of the heating process and system components. The experiments were carried out in a residential heating system comprised of a compact and transparent plastic cell (6 cm length, 6 cm width, 3 cm height, 0.3 cm cell wall thickness), stainless steel electrodes (thickness 0.1 cm) with a distance of 6 cm, a Variable Transformer, responsible for generating different voltages (3 kW, 0-300 V, 50 Hz, MST-3, Toyo, Japan), Power Analyzer (Lutron DW-6090), responsible for monitoring and controlling the energy of the system via a thermocouple, and a computer used to store data with specifications. A scale of 0.01 g was used to measure the cell weight and its contents during the subcellular process. All experiments were carried out in the Bio-System Mechanics Department of Gorgan University of Agricultural Sciences and Natural Resources.

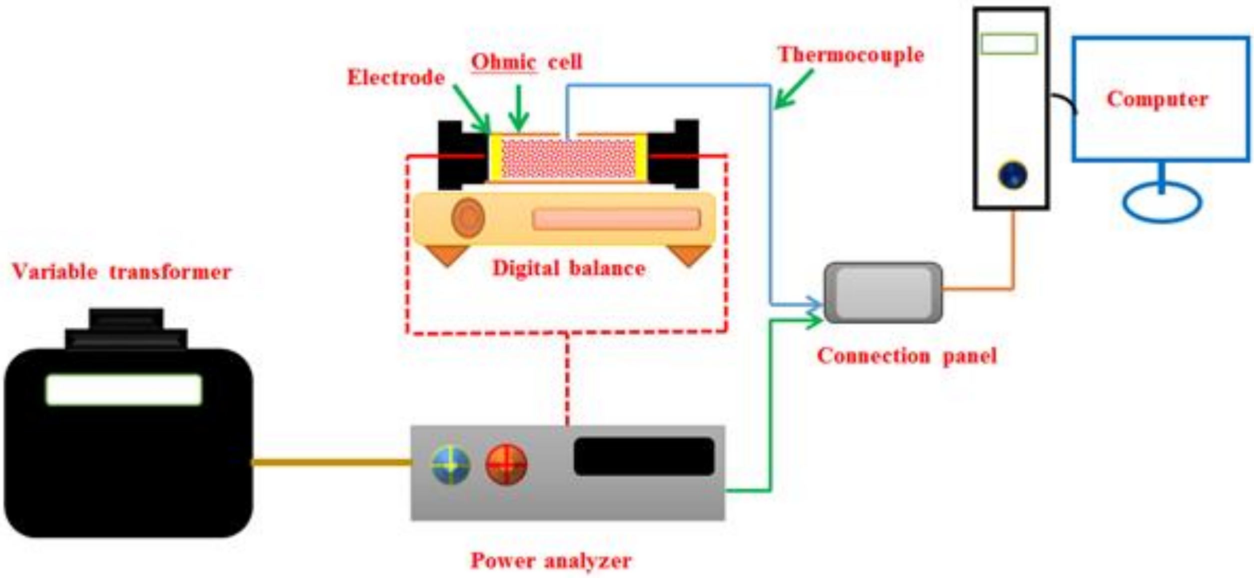


Figure 1 Schematic of the equipment used for the ohmic heating process

2.3 Color analysis

In this analysis, L*, a* and b* values were used owing to the independence of this analysis from the device and the fact that it covers a wider range compared with RGB and CMYK. Image J software was used to analyze images and obtain color values with the help of built-in plug-ins (Azadbakht et al., 2016). Primarily, the images were improved and unnecessary components were removed in the image for all pre-processing images. In the process of throwing a picture, the general purpose was to identify features of the image that can be used for the desired application. The images were converted from RGB to XYZ and then to L *, a * and b * using two steps. Using Eq. 1, used by San and colleagues, images can be converted from the RGB color space to the XYZ color space.

Moreover, using equations 1 to 4, the following XYZ images can be used in the next step: L*, a * and b * using these equations (Cheng et al., 2001).

$$\begin{bmatrix} \bar{X} \\ \hat{Y} \\ \hat{Z} \end{bmatrix} = \begin{pmatrix} 0412456 & 0.257580 & 0.180423 \\ 01212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119194 & 0.950227 \end{pmatrix} \begin{bmatrix} \bar{R} \\ \hat{G} \\ \hat{B} \end{bmatrix} \quad (1)$$

$$\hat{L} = \begin{bmatrix} 116 \times \left(\frac{\hat{Y}}{Y'}\right)^{\frac{1}{3}} - 16 \\ 903.3 \times \left(\frac{\hat{Y}}{Y'}\right)^{\frac{1}{3}} ELSE \end{bmatrix} \quad (2)$$

$$\hat{a} = 500 \times [\left(\frac{\hat{X}}{X'}\right)^{\frac{1}{3}} - \left(\frac{\hat{Y}}{Y'}\right)^{\frac{1}{3}}] \quad (3)$$

$$\hat{b} = 200 \times [\left(\frac{\hat{Z}}{Z'}\right)^{\frac{1}{3}} - \left(\frac{\hat{Y}}{Y'}\right)^{\frac{1}{3}}] \quad (4)$$

Where X ', Y' and Z 'are XYZ values for the D65 standard.

$$\begin{bmatrix} \bar{X} \\ \hat{Y} \\ \hat{Z} \end{bmatrix} = \begin{pmatrix} 95.047 \\ 100 \\ 108.883 \end{pmatrix} \quad (5)$$

The browning index was also obtained based on the color components and was calculated using criteria 7 and 8 (Moreno et al., 2016):

$$x = \frac{a^* + 1.75 \times L^*}{5.645L^* + a^* - 3.012b} \quad (6)$$

$$BI = \frac{[100(X - 0.33)]}{0.17} \quad (7)$$

Equations 8 and 9 show the measurement of chroma indices and total color differences to describe color variations during heating of sour orange juice under different process conditions (Jafarzadeh et al., 2022).

The zero indexes of the values read from the sample are not associated with fresh sour orange juice.

$$C = \sqrt{a^{*2} + b^{*2}} \quad (8)$$

$$TCD = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \quad (9)$$

2.4 Statistical analysis

The samples were tested at three voltage gradients of 8.33, 10.83, and 13.33 V cm^{-1} to reduce 10%, 20% and 30% of the total weight, an experiment performed in three replications. L*, a*, b*, BI, C, and TCD factors were measured and the results were analyzed using a factorial experiment in a completely randomized design with SAS statistical software.

3 Results and discussion

Table 1 shows the results of analysis of variance related to the effects of voltage gradient and weight loss percentage on factors such as L*, a*, b*, Browning index (BI), (C) chroma index, total color difference (TCD), and hue and whiteness Index. Concerning L*, chroma index, and total color difference, the voltage gradient was significant at 1% level; as for b*, chroma index and hue and whiteness index, a statistically significant difference of 5% was observed; a* factor did not significantly affect the voltage gradient. Also, the effect of weight loss percentage on L*, a*, b*, BI, C, TCD and hue and whiteness index were found to be significant at 1% level; regarding the interaction between the voltage gradient and the weight loss percentage, none of the factors, except for L*, were significant.

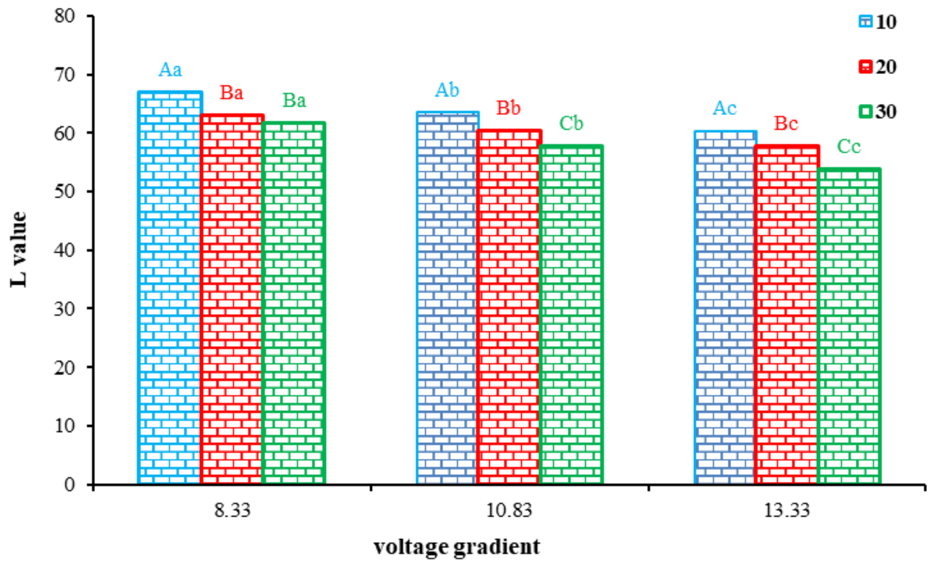
3.1 L* value

According to Figure 2a, by increasing the voltage gradient, the weight loss percentage of L* value was reduced. Furthermore, according to the amount shown in the figure at a constant voltage gradient, the increase in weight loss percentage reduced the amount of L*. The highest value was observed at the gradient of 8.33 V cm^{-1} and weight loss percentage of 10% and the lowest was found at the voltage gradient of 13.33 V cm^{-1} and weight loss percentage of 30%. Regarding the figure on 8.33 V cm^{-1} voltage gradient, no significant difference was found between 20% and 30% weight loss; for the other two gradients, however, there was a significant difference among all three percentages of the weight loss. There was also a statistically significant difference between different voltage gradients regarding the percentage of weight loss. Given the fact that L* indicates brightness or darkness in a sample, positive values above L* indicate the brightness of most samples and lower values of L* indicate less brightness or more darkness. The results of color variations may have been due to non-enzymatic browning activities and the changes in the viscosity of the sour orange juice samples. The decrease in brightness is mainly due to the fact that the enzymes used for the formation of dark color are activated in the heating process, which also reduces the brightness. These results are similar to that of Abhilasha and Pal (2018) on cane sugar juice (Abhilasha and Pal, 2018) and Chakraborty and Athmaselvi(2014) on Guava's fruit using ohmic method (Chakraborty and Athmaselvi, 2014).

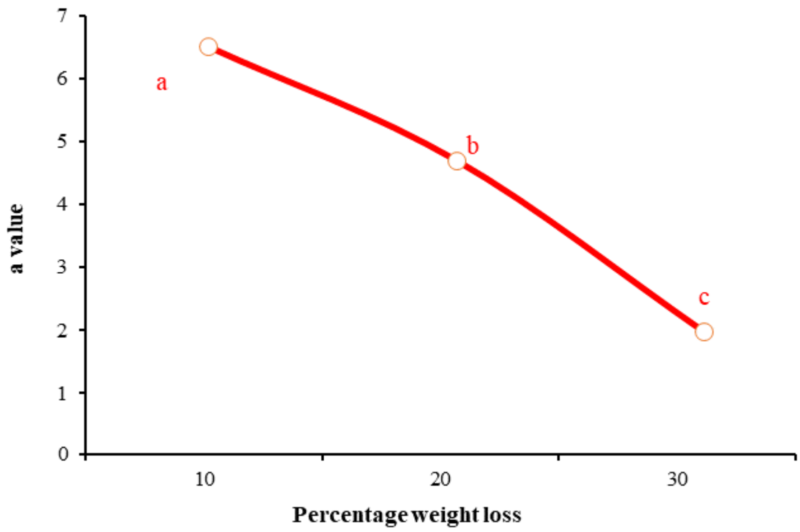
Table 1 Analysis of variance of the effects of voltage gradient and weight loss percentage factors for factors L*, a*, b*, BI, C, TCD, Hue and Wi

	L*		a*		b*	
	MS	**F value**	**MS**	**F value**	**MS**	**F value**
Voltage gradient	95.590	234.53^{**}	5.629	2.20^{ns}	131.42	4.66^{*}
Percentage of weight loss	78.06	191.52^{**}	46.683	18.22^{**}	251.910	8.94^{**}
Voltage gradient× Percentage of weight loss	1.342	3.29^{*}	0.748	0.29^{ns}	4.304	0.15^{ns}
Error	0.407		2.562		28.185	
	Brown index		**chroma index**		**Total Color Difference**	
Voltage gradient	5051.788	17.40^{**}	123.535	4.44^{*}	162.021	23.177^{**}
Percentage of weight loss	6087.26	20.97^{**}	226.469	8.14^{**}	255.135	36.49^{**}
Voltage gradient× Percentage of weight loss	635.547	2.19^{ns}	4.547	0.16^{ns}	9.04^{ns}	1.29^{ns}
Error	290.322		27.83		6.992	
	Hue			**Wi**		
Voltage gradient	0.0095	4.31*		122.65	4.54*	
Percentage of weight loss	0.0494	22.23**		223.410	8.27**	
Voltage gradient× Percentage of weight loss	0.00046	021ns		4.509	0.17ns	
Error	0.0022			27.004		

Note: ** indicates significant at 1% level, * meaningful at 5% level and ns indicates insignificance



(a) Interaction



(b) Comparison of mean

Figure 2 The results of statistical analysis on the value of a*

a: Interaction effect of voltage gradient and weight loss percentage on L*

b: Comparison of mean a* by weight loss percentage

The capital letters are similar to the insignificant sign in a fixed voltage gradient

The lower case is the same as an insignificant indication of a constant percentage weight loss

3.2 a * value

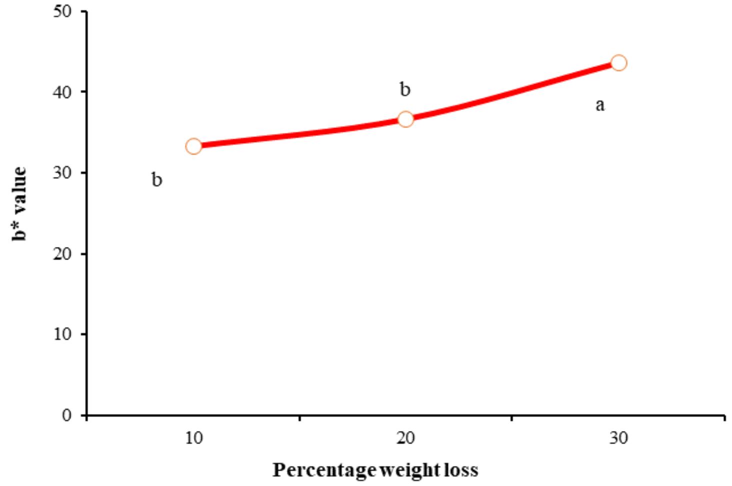
In Figure 2b, the comparison of mean results for a* are shown in terms of weight loss percentage. With 10% to 20% weight loss, a* was reduced, meaning that the color of the sour orange juice became green. Moreover, there was a significant difference between all three weight loss percentages. The highest percentage of weight loss was 10% (6.497) and the lowest was 30% (1.97). According to the results, the amount became green and its redness was reduced. Similar to Makroo et al. (2017), the results on watermelon juice during the ohmic heating process concluded that the amount of a * was reduced (Makroo et al., 2017).

3.3 b * value

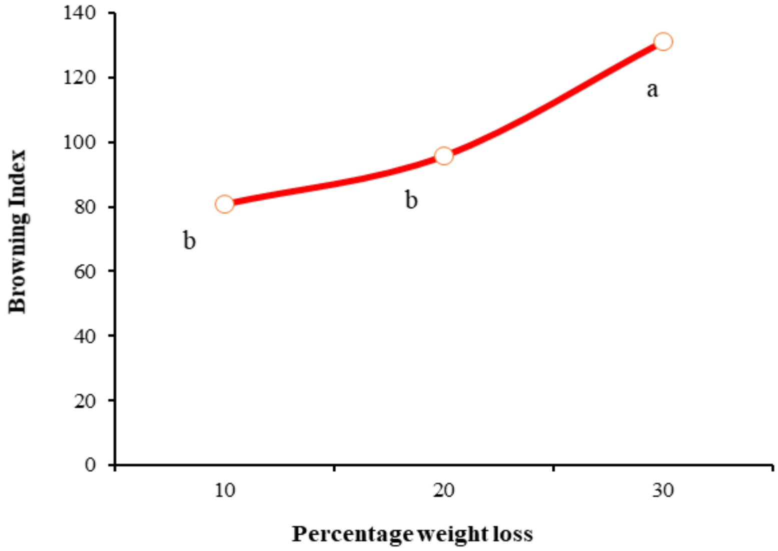
In Figure 3a, the mean values of b* are shown for voltage gradient factors and weight loss percentage. With the increase in the voltage gradient and weight loss, b* increased for sour orange juice during the heating process. Also, there was no statistically significant difference between values of b* regarding voltage gradients of 8.33 and 10.83 V cm^{-1}, both of which were significantly different from the voltage gradient of 13.33 V cm^{-1}. There was no significant difference between weight loss percentages between 10% and 20%, both significantly different from the weight loss percentage of 30%. The increase in b* value means that the samples progressed toward yellowing, since the higher positive value indicates yellowing and the amount of anything approximating zero and negative values indicates the more blue color in the sample. Ishita and Athmaselvi(2017) concluded that the amount of b* lemon juice would increase during the heating process (Ishita and Athmaselvi, 2017). Aguiló-Aguayo et al. (2010) research on tomato paste concluded that the heating of limy augments the amount of b* (Aguiló-Aguayo et al., 2010).

3.4 Browning index (BI) value

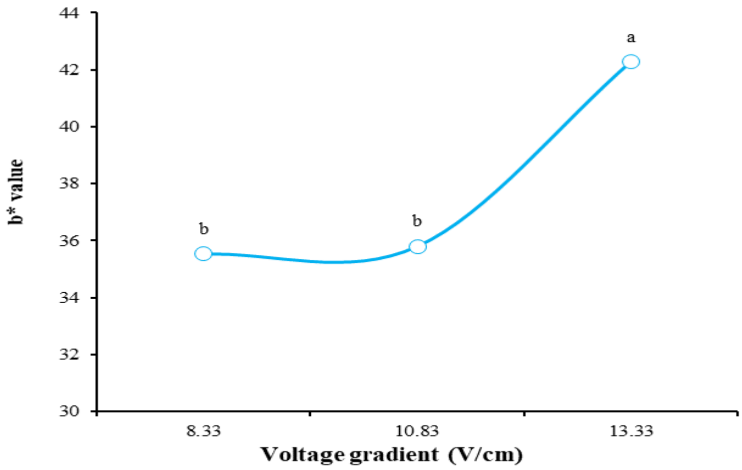
The comparison of the mean values of voltage gradient factors and weight loss percentage for BI is shown in Figure 3b where the increase in the gradient voltage and weight loss percentage augmented BI value; differences were not statistically significant between 10 and 20%, both significantly different from a weight loss of 30%. There were no significant differences between 8.33 and 10.83 V cm^{-1} gradients concerning voltage gradients, but for voltage gradient 13.33 V cm^{-1}, there was a statistically significant difference with the other two gradients. The highest values of BI were at the voltage gradient of 13.33 and 30% weight loss, and the lowest was observed at the voltage gradient of 8.33 V cm^{-1} and weight loss percentage of 10%. This finding is similar to the reports of Grimi et al. (2011), which concluded that browning increases with the use of ohmic heating (Grimi et al., 2011).



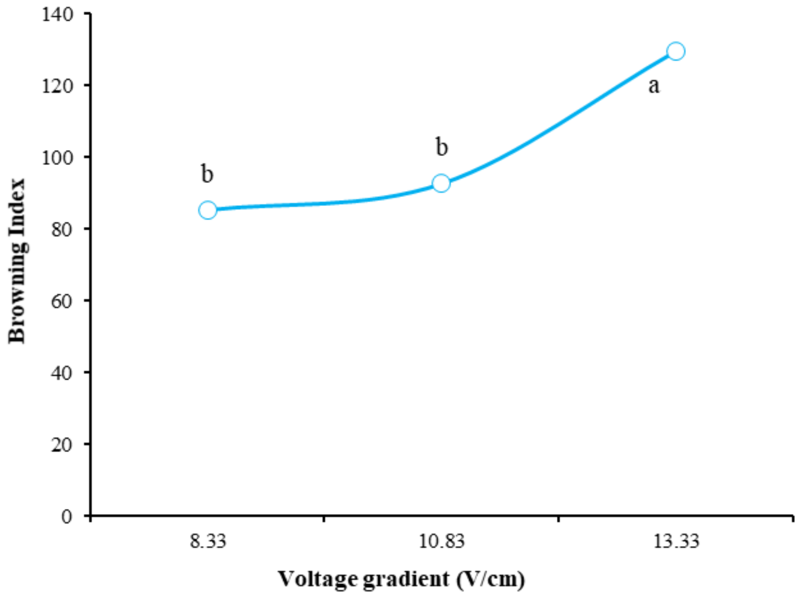
(a) Comparison of the mean



(b) Comparison of the mean



(c) Comparison of the mean

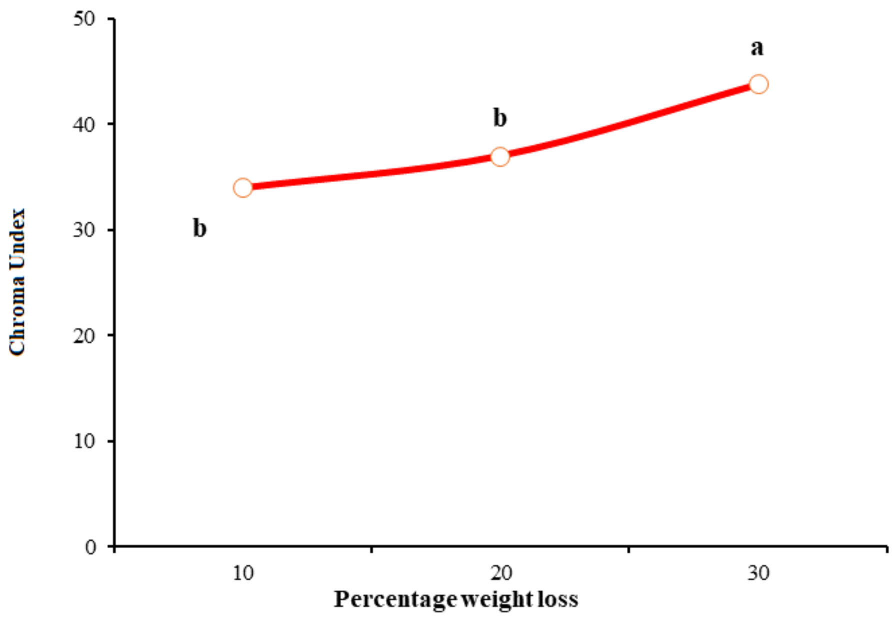


(d) Comparison of the mean

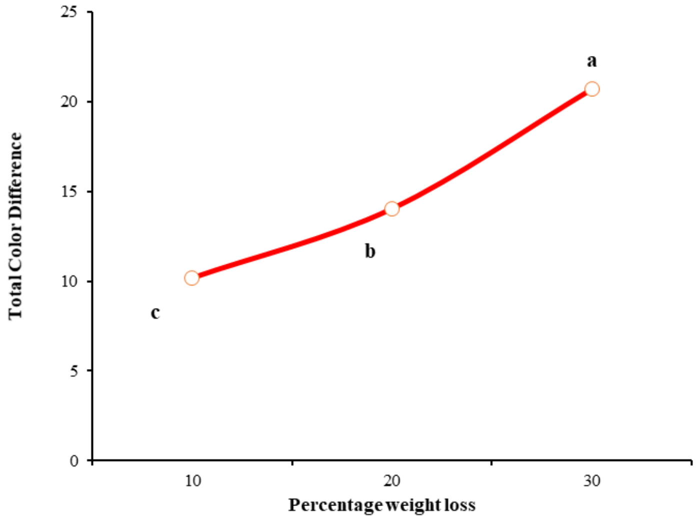
Figure 3 The results of statistical analysis: a&c: b* and b&d: Browning index in the voltage gradient and weight loss percentage

3.5 Chroma value

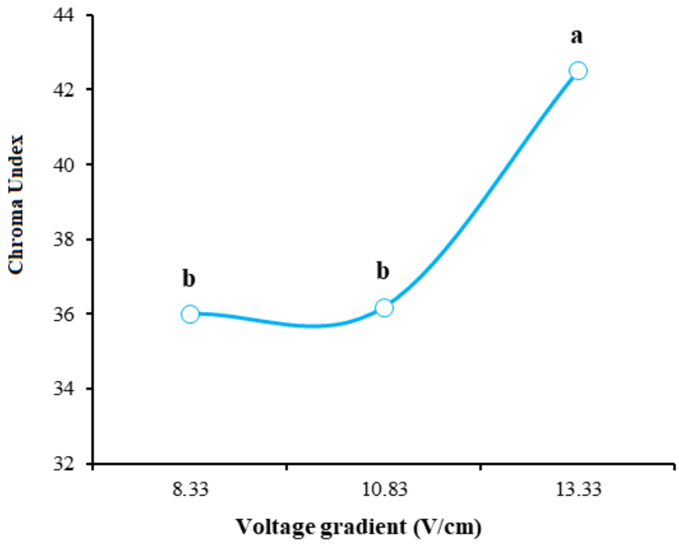
Figure 4a compares the mean C where by increasing both the voltage gradient factors and the weight loss percentage, the C value increased; the highest value was seen at the voltage gradient of 13.33 V cm^{-1} and 30% weight loss, indicating that the samples had a higher redness compared with the other samples in this weight reduction and voltage gradient. The lowest value was found at the gradient of 8.33 and the weight loss percentage of 10% and there was no significant difference between the voltage gradients of 10.83 and 8.33 V cm^{-1}, and the weight loss percentages of 20% and 30%; however, they were statistically different from the voltage gradient of 13.33 V cm^{-1} and 10% weight loss, respectively. Similarly, Lee and Coates (2003) reported changes in the color of orange juice in the pasteurization thermal process in order to increase the rate of chroma index (Lee and Coates, 2003).



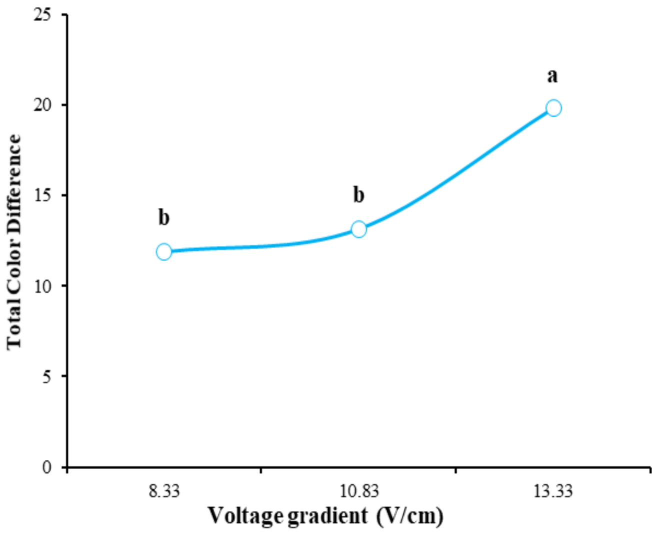
(a) Comparison of the mean



(b) Comparison of the mean



(c) Comparison of the mean



(d) Comparison of the mean

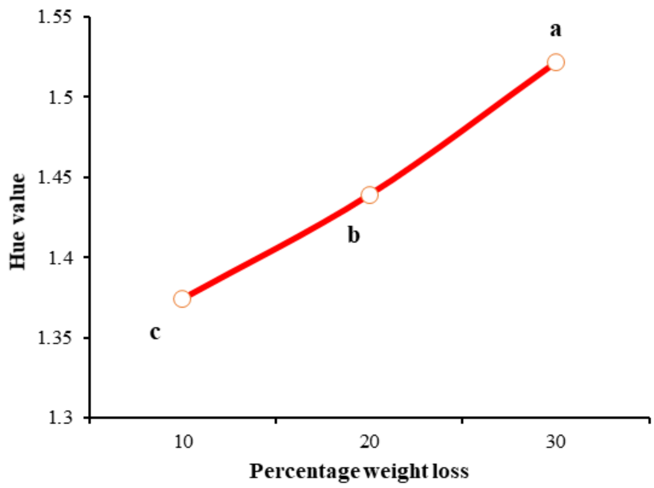
Figure 4 The results of statistical analysis: a&c: Chorma index and b&c: total color difference-value in voltage gradient and weight loss

3.6 Total color difference (TCD) value

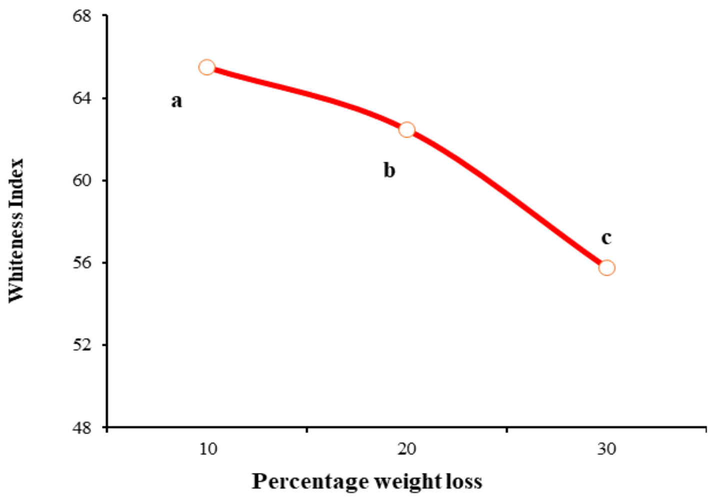
Figure 4b compares the mean weight loss percentage and voltage gradient for TCD. According to the figure, TCD increased with the augment in weight loss percentage and voltage gradients; as for weight loss percentage, there was a significant difference between all three reduction percentages, but for voltage gradient, there was no significant difference between the 8.33 and 10.833 V cm^{-1} gradients; these two voltage gradients, however, had a significant difference with the 13.33 V cm^{-1} gradient. Non-enzymatic brown destruction and pigment degradation can be considered as the main causes of color change rather than enzymatic enhancement because enzymes are degraded at temperatures above 50°C (Rattanathanalerk et al., 2005). The results are similar to that of Bhat on the changes in the color of bottle gourd juice in the ohmic heat treatment method, where the temperature of the color changes increased with the increase in temperature (Bhat et al., 2017). Moreover, Rattanathanalerk et al. (2005) reported an increase in the process time by the increase in the color variation in their study on the thermal process on pineapple juice (Rattanathanalerk et al., 2005).

3.7 Hue value

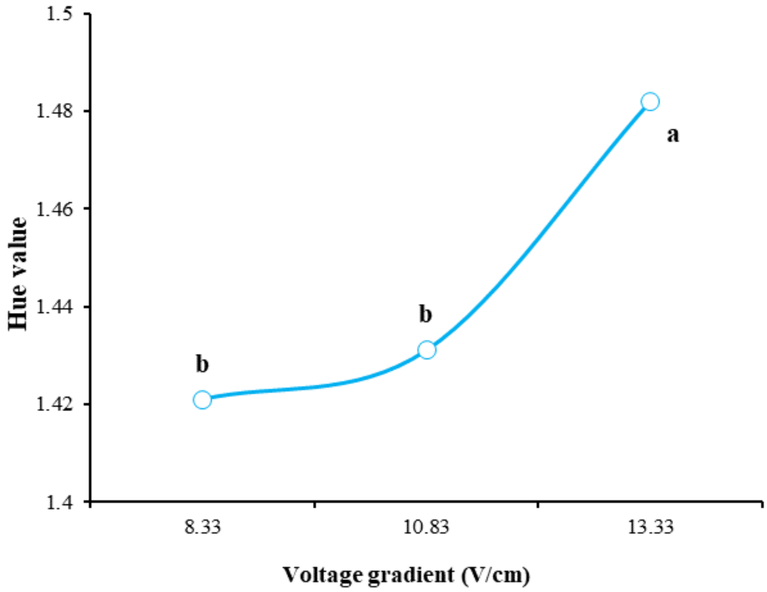
Hue is an indicator of the color of a food ranging from zero to 360 degree angles, with red representing 180 and 270 degrees, and yellow green and blue showing a 90 degrees. In other words, the hue angle represents the dominant color, and the closer the angle is to zero, the more red the color becomes. According to the results obtained in Figure 5a, the highest hue value was at 13.33 V cm^{-1} voltage gradient and weight loss of 30%, with the lowest value at the voltage gradient of 8.33 V cm^{-1} and the weight loss percentage of 10%.



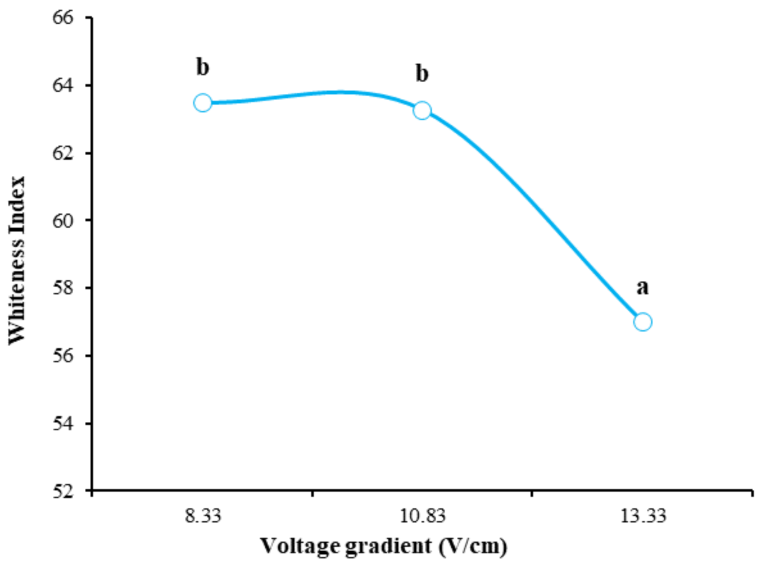
(a) Comparison of the mean



(b) Comparison of the mean



(c) Comparison of the mean



(d) Comparison of the mean

Figure 5 The results of statistical analysis: a&c: Hue and b&d: Whiteness Index in the gradient of voltage and weight loss percentage

3.8 Whiteness index value

The whiteness index is shown in Figure 5-B where it was reduced with the increase in weight loss percentage from 10% to 30%; the reason for this is the increase in the duration of high temperatures for the samples which changed the color; as the voltage gradient increased, the whiteness index decreased, which, with the increase in the voltage, accelerates the rate of increase in the speed of the samples. And the samples get higher to a high temperature and this also lowers the brightness index.

4 Conclusion

According to the obtained results, the ohmic heating caused color variations in the sour orange juice, which indicates the effect of the thermal process on the content of the sour orange juice compounds. With regard to the voltage gradient, the greater the degree of voltage gradient, the L* value, which indicates the brightness of the sour orange juice, has decreased. Also, with respect to factor a*, it can be stated that the changes have not led to redness; and due to the amount of b*, color changes in the fruit juice have been towards the yellow during the heating process. TCD changes are more than the percentage of weight loss, which increases the weight loss percentage, increasing the duration of the heating process, which can be said to increase TCD by the increase in the duration of the process. Also, the browning hue and chroma index have the same trend and increased with the increase in voltage gradient and weight loss percentage. The whiteness index of the voltage gradient increased and the weight loss percentage was reduced. According to the results, the magnitude of the voltage gradient increased from 8.33 to 10.83 V cm^{-1} and from 8.33 to 13.33 V cm^{-1}, the values of L * 5.4 and 11.3%, and a * 2.1 and 40.79, and for the Whiteness indexes 0.34% and 10.23%, decreased during the heating process. The values of b * 0.7 and 15%, BI 7.8 and 34.10%, C 0.51 and 15.31%, and TCD 9.482 and 39.851%, and Hue angle 0.75 and 4.29%, respectively. Also, to increase weight loss percentage from 10% to 20% and from 10% to 30%, the values of L* 5.2 and 10.18 and a* 38.35 and 229.1%, respectively, and for Whiteness index 4.62% and 14.85% respectively, were lowered compared to the original state and for values b* 69.22 and 23.7, the values of BI 15.73 and 38.57%, C 8.22 and 22.4%, and for TCD 27.53 and 50.87%, and for Hue angle 4.733 and 10.77%, respectively, were observed.

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