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Kinetics of Color Degradation in Thermal Processed Almond

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Abstract. Color degradation of almonds cultivated in South Eagean region of Turkey was investigated by Hunter colorimeter technique during roasting. Roasting process was performed in an electrical oven under isothermal conditions. The intensity of color was evaluated in terms of L, a and b values. The kinetics of color degradation in almonds was studied between the temperature range of 160-220˚C. It was observed that the color change of roasted almonds followed first order reaction kinetics. The rate of change in brown color of almond was developed by Arrhenius equation as a function of temperature. The activation energy for roasted almonds was estimated to be 20,833 kJ/mol and 9,151 kJ/mol on the basis of a and b values, respectively. It was concluded that color was more stable at low temperatures (160˚C) with respect to high temperatures (220˚C).

Keywords: roasting, temperature, reaction, color kinetics.

1. Introduction

Color and visual appearance are important quality attributes which determine the consumer preference. Heat treatment causes changes in organoleptic properties of food and roasting is one of the thermal food processing methods that makes the product different from the sensory quality point of view. Thermal processing is usually associated with the change in color. The total change in color during the heat treatment will be determined by time and the temperature. Brown color in roasted almond has been known as an desirable attribute to some extent but the formation of brown pigments in high amount may cause color to become an undesirable attribute and to loss in quality. There are various methods to determine the color by means of color indexes that are extracted from color values (L, a and b). Several studies have been conducted on the color kinetics of foods during heat treatment (Avila and Silva.,1999; Goula et al., 2006, Kumar et al., 2006; Benjar et al., 2007). The change in color during the heat treatment may be induced by some reactions such as degradation, oxidation and/or Maillard reaction (Krokida et al., 1998; Ahmed and Ramaswamy, 2005; Baini and Langrish, 2009). It has been reported that heat at 190˚C may effect carotenoids in the way of production of some degradation compounds (Moss, 2008). The color change to brown of thermally processed fruits is usually associated with Maillard reactions and the rate of browning has been reported as high at elevated temperatures. It is important to estimate the change in quality by means of the kinetic parameters (reaction order, reaction rate and activation energy) during the heat treatment and the selection of thermal processing technique may help to control the color change. Color parameters will be helpful to optimize the quality during roasting. No information is available on color degradation kinetics of almonds during roasting. This study was conducted to determine the degradation kinetics of non-enzymatic browning during roasting of almonds at different temperatures and time intervals.

2. Materials and Methods

2.1. Almonds

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Almond kernel samples were supplied by Agricultural Development Cooperation, Datça, Muğla and roasted in an electrical oven. The thermal treatment was conducted by roasting almond samples in an electrical oven at the temperature range of 160-220°C for 10, 20 and 30 min.

2.2. Colorimeter

Colorimetric measurements were performed with a Hunter Lab colorimeter (Lab Scan XE) and skin color of roasted almonds was evaluated in terms of Hunter "L" (lightness), "a" (redness) and "b" (yellowness).

2.3. Heat treatment

Roasting process was carried out as 25,0 grams of almond samples were placed as a single layer in an aluminum container and roasted at selected temperatures of 160, 180, 200 and 220°C for 10, 20 and 30 min. in an electrical oven.

2.4. Data analysis

The color change in roasted almonds was calculated by using equations (1) and (2) for a first-order reaction given below and the effect of temperature on the rate of reaction was determined from the linearised Arrhenius equation (3). Total color change (ΔE) in Hunter a, b and L values were determined using equation (4). Kinetic data was analysed by using linear regression (MS Excel 2007).

$$-\frac{dQ}{dt} = kQ \tag{1}$$

$$\ln\frac{Q}{Q_0} = -kt$$

as Q for quality attribute, t for the time (min), k the first-order reaction rate constant (min^{-1}), n order of the reaction.

$$\ln C = \ln C_0 - k.t \tag{2}$$

where C stands for the concentration at time t; C_O the concentration at time zero, k the first-order reaction rate constant (min^{-1}) and t the time (min).

$$k = k_0.\exp\left(-\frac{Ea}{R.T}\right) \tag{3}$$

where k_o denotes the pre-exponential factor (min^{-1}); E_a the activation energy (kcal/mol); R the universal gas constant (kcal mol°K); T the absolute temperature (°K). The activation energy was calculated from the slope and k_o from the intercept of the straight line given by equation (1).

$$\Delta E = \sqrt{(Lo - Lt)^2 + (a_0 - at)^2 + (b_0 - bt)^2} \tag{4}$$

where ΔE represents the total color change; L_O the lightness value at time zero, a_O the redness value at time zero, b_O the yellowness value at time zero; L_t the lightness value at time t, a_t the redness value at time t, b_t the yellowness value at time t.

2.5. Statistical analysis

The effect of time and the temperature on color values (a, b and L) of thermal processed almond samples were determined by the two sided variance analysis (ANOVA) using Tukey test p<0.05. Multivariate methods, such as PCA (Principle Component Analysis) and AHC (Agglomerative Hierarchical Clustering) were also used to show the differences among roasting at different conditions. All processings were performed with the XLSTAT, Version 2011.5.01 (Addinsoft, USA) software.

3. Results and Discussion

The effect of temperature on the Hunter (L, a and b) values were summarized in Table 1. Almond samples become darker with time that could be seen by the decrease in all color values (Fig.1). It was observed that the color change of roasted almonds followed first order reaction kinetics. Similar results on lycopene degradation during heating were also found by some researchers (Barreiro et al., 1997; Goula et al., 2006). The change in "L" value was 18,36% that it changed from its initial value 48,09 to 39,26 at 160°C; 30,76% at 180°C; 39,33% at 200°C and 48,70% at 220°C; the degradation was 2,70% in "a" value at 160°C; 27,51% at 180°C, 63,89% at 200°C and 87,84% at 220°C and the change in "b" value was 30,21% at 160°C, 48,50% at 180°C, 73,19% at 200°C and 90,85% at 220°C. The degradation in color values indicated that the value of lightness showed a smooth decrease with respect to the values of redness and yellowness. The decrease in color values ("L" and "a") could be associated with the carotenoid degradation and non-enzymatic browning as indicated by Avila and Silva (1999); Ahmed and Ramaswamy (2005) and Nisha et al (2010).

Table 1. Kinetic parameters of color change in almonds roasted at different temperatures

Color value	Reaction order	Activation energy E_a (kcal/mol)	Rate constant ln k_o(min^{-1})	Determination coefficient R^2
L	1	5,683	0,457	0,919
a	1	20,833	1,474	0,795
b	1	9,151	2,977	0,912

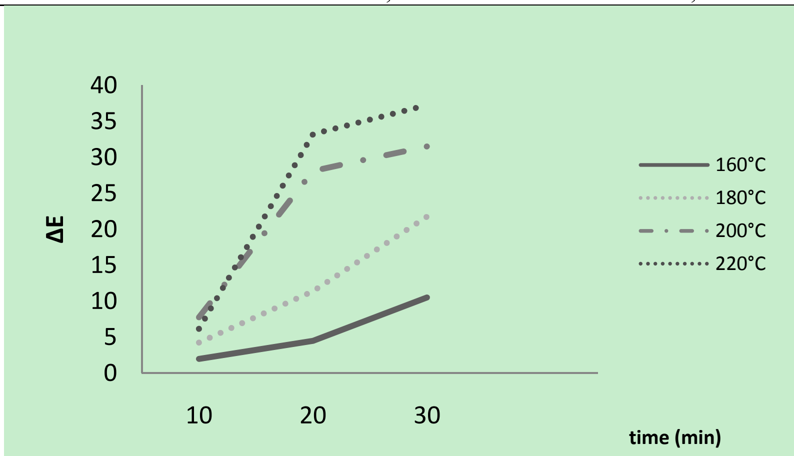

Fig 1. Total color difference (ΔE) of Hunter a,b and L values

The activation energies of roasted almond were calculated according to the linear regression analysis of natural logarithms of rate constants against reciprocal absolute temperature 1/T (˚K) (Fig. 2). The activation energies for degradation that were determined on the basis of "a"(20,833 kJ/mol), "b"(9,151 kJ/mol) and "L"(5,683 kJ/mol) values indicated that redness and yellowness were the most sensitive values against heat during roasting of almonds. Effect of temperature on reaction rate constants is shown in Figure 3. No significant differences ($p<0.05$) were detected between the temperatures and time intervals in terms of the color parameters (L, a and b) of almonds during roasting.

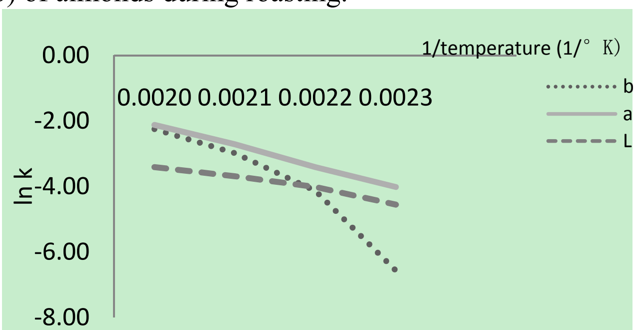

Fig 2. Arrhenius plot for color degradation ("L"), ("a") and ("b") values in roasted almond

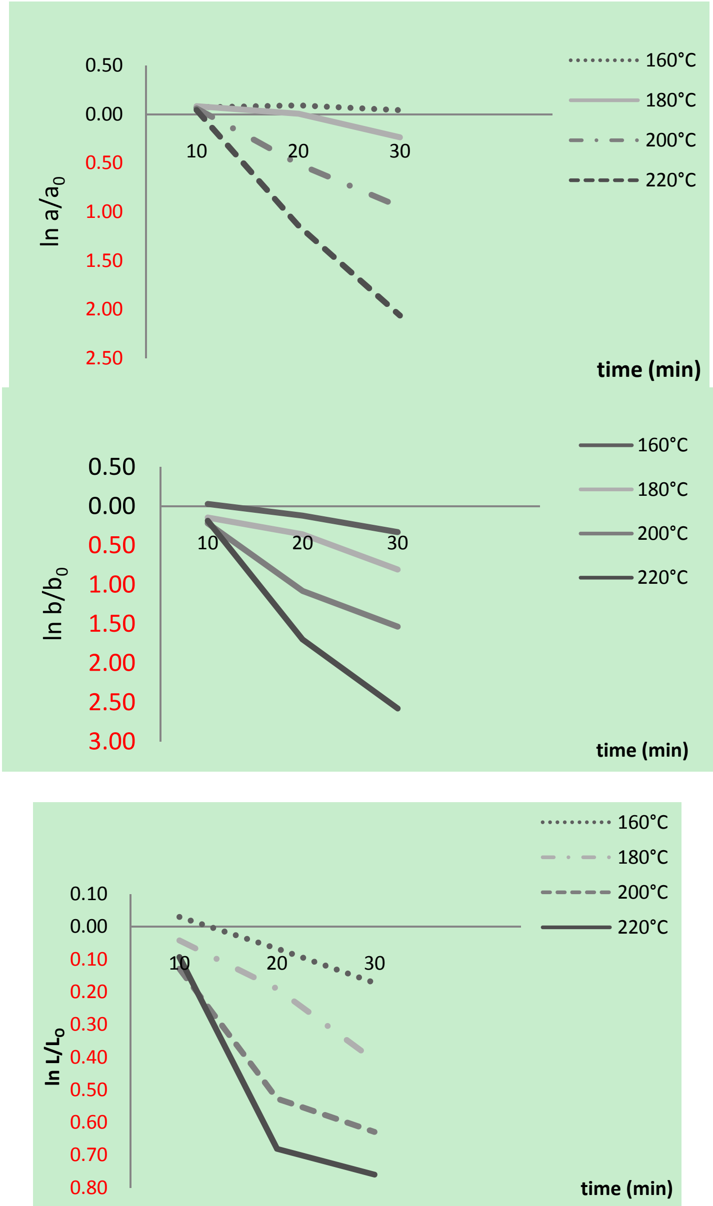

Fig 3. First order plot for color degradation Hunter ("a"), ("b") and ("L") in roasted almond at 160, 180, 200 and 220˚C

According to PCA results, two principle components were found to explain 1,87% and 98,07% of total variation (Fig 4). There is a difference in terms of color values (L, a and b) representing these three groups. Redness was corresponding color value for A3, B2, B3, C2 while yellowness was determined as the corresponding color value for the samples of A1 and D3. Rest of almonds were characterized by the color value of lightness.

The cluster diagram obtained with L, a and b values of almond samples is shown in Figure 5. Three main clusters were formed: cluster 1 was represented by A1-A2-A3-B1-B2-C1-D1, cluster 2 was represented by almond samples B3 and C2, while almond samples of C3-D2- D3 formed cluster 3. It has been observed that the heat treatment at 180˚C for 20 min. indicated the critical point on the basis of color values.

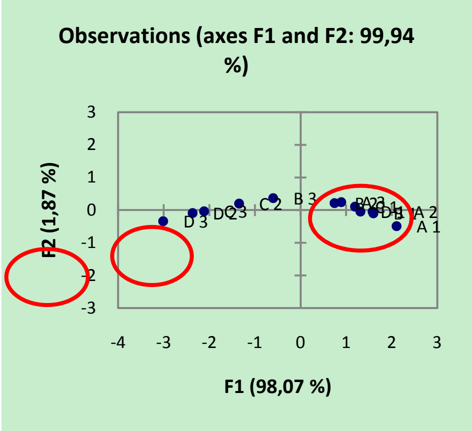

Figure 4.PCA scatterplot analysis of almonds

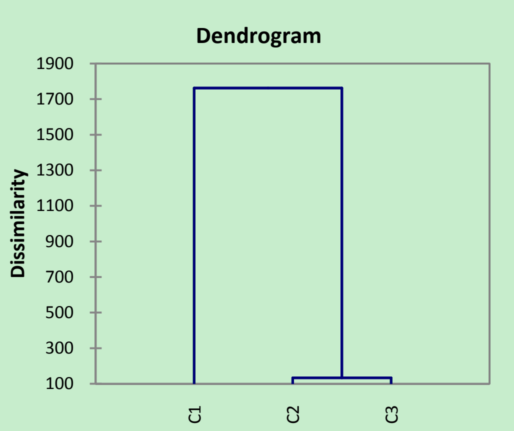

Figure 5.Dendrogram obtained from the cluster of almonds

4. Conclusion

Color degradation of roasted almonds during heating at temperatures between 160 and 220°C, followed first order reaction kinetics. Reaction rate of each color value has shown an increase as the temperature increases. Browning rate has its greatest value between the temperature range of 200-220˚C. Color parameters (L, a and b) showed that the change in quality during the heat treatment could be predicted according to the kinetic model obtained as a function of time-temperature and quality losses may be minimized during the thermal processing. It was concluded that the color value of “a” was more heat sensitive with respect to “L” and “b” values on the basis of activation energy and time-temperature profile.

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