Using online image processing technique for measurement the browning in banana during drying (a new and automatic method)

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Abstract: Determination and controlling of quality parameters can be useful for ordering and marketing of fruits. Color is the first and the most important parameter in the visual appearance of fruits, specifically in banana. The aim of this study is to use image-processing technique (online operation) to measure and analyze the color change of banana slices during thin layer drying. Using online-image-processing technique resulted in designing a machine vision system to control the color change of products automatically. The results show a linear relation with high correlation coefficient for L*, a* and b* (0.967, 0.962 and 0.991 respectively) between the data of the image-processing technique and the hold-hand colorimeter. In this study, parameters of chroma, hue and browning index were determined to describe the kinetics of color change in banana slices. The change of chroma was not significant, but hue was decreased and browning index was increased during drying time. In addition, the experimental data of the L* and ΔE was fitted using zero and first order models with high correlation coefficient (0.80-0.97).

Keywords: image processing, machine vision, online, banana

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1 Introduction

The quality of the final product is one of the important elements that should be considered during the drying process. Determination and controlling of quality parameters such as color, taste, odor and texture can be useful for ordering and marketing of foods. Color is the first and the most important parameter in the visual appearance of food.

The color of the dried fruit changes due to the formation of browning, which has often been associated with the Maillard reaction (Bainiand Langrish, 2009). This reaction was described for the first time by Louis Maillard in 1912 (Maillard, 1912) and can be described using Hodge's reaction scheme (Hodge, 1953). Discoloration and browning due to thermal treatments are the results of several reactions. These include Maillard condensation reducing sugars and amino acids, caramellisation and ascorbic acid browning processes (Cornwell and Wrostad, 1981) and pigment destruction (Beveridge, et al., 1986).

Other factors affecting color include fruit pH, acidity, processing temperature and duration, fruit cultivar and heavy metal contaminations (Abersand Wrolstad, 1979; Skrede, 1985; Garcia-Viguera, et al., 1999).

The determination of color can be carried out by visual inspection, spectrophotometry, and the color meter or by advance methods such as image processing technique. In the first method, many parameters such as variation of visual of the human, tedium, and vision errors can produce many errors during the measurement. In the spectrophotometry method, further sample

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preparation steps are required before the color can be analyzed using the spectrophotometer (Bainiand Langrish, 2009). Therefore, this method is very time-consuming. Using colorimeter to measure the color has been very common in the research papers, however, in this method, the samples must be removed from the dryer and then measurement is performed separately.

In recent years, computer vision has been used to objectively measure the color of different foods since they provide some obvious advantages over conventional colorimeter, namely, the possibility of analyzing of each pixel of the entire surface of the food, and quantifying surface characteristics and defects (Brosnan and Sun, 2004; Du and Sun, 2004).

In the advance method that uses image-processing technique, the samples are not removed from the dryer. In this method, a camera takes the picture of the product, and then it is processed by special computer software.

Evaluation of fruits browning during drying process has been one of the major aims of researchers to decrease or control it. Among, Ibarz et al. (1999) for pear puree, Maskan (2000) for banana, Maskan (2001) for kiwifruit, Demir et al. (2002) for hazelnut. Yam and Papadakis (2004) presented a simple digital imaging method for measuring and analyzing the color of food surfaces. Leon et al. (2006) suggested a methodology for calculating accurate device-independent L*a*b* color units from device dependent RGB color units captured by a digital color camera. They used five models such as direct, gamma, linear, quadratic and neural, which are able to measure color in L*a*b* units and simultaneously measure the color of each pixel on the target surface. Baini and Langrish (2009) assessed color development in dried bananas at different degrees of ripeness. They reported that the rate of browning formation had been decreased with an increase in the drying time and with a decrease in the moisture content, and the effect of air velocity on the color development was small. In addition, they reported that the amounts of browning for overripe and ripe bananas had been found to be higher than those for unripe bananas, concluding that the sugar content may limit the browning reaction in the bananas.

The aim of this study is to use image-processing technique to measure and analyze the color change of banana slices during thin layer drying.

2 Materials and methods

2.1 Sample preparation

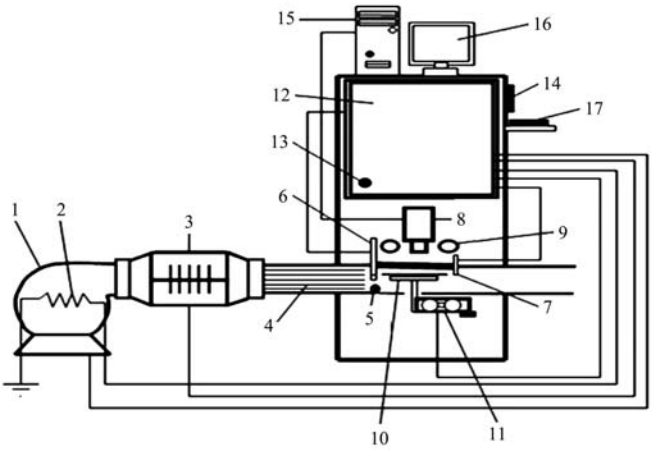
Fresh bananas were supplied from a local market and then, the bananas were transferred to the laboratory of the Research and Development of Department of Agricultural Machinery Engineering, University of Tehran. In order to calculate the initial moisture content, some of banana slices were dried in an oven at 110°C for 24 h. The average moisture content was found to be 75% (Wet basis). In the each experiment, a banana was peeled and was sliced into layers of 3, 5 or 7 mm in thickness by a meat slicer. Then, the samples were arranged upon a rectangular tray (20 cm in length and 15 cm in width) and the tray was placed into an experimental dryer at preset conditions. After each experiment was finished, the samples were placed into an oven to remove their remaining moisture. In this study, the slices were dried at temperatures of 50, 60, 70, 80 and 90°C, and the thicknesses of 3, 5 and 7 mm at a constant air velocity of 0.5 m s^{-1}.

2.2 Dryer used

A thin-layer dryer was made based on computer vision for measuring the effects of drying on the change of visual properties of products and relation between these properties and moisture content of products (Figure 1). The dryer consisted of a centrifugal fan (Damandeh, BEF-25/25F4T, 6,300 m^3 h^{-1}), air duct, four electrical heating elements (a 750 W element in the centrifugal fan for preheating the airflow and 3×2000 W elements in the air duct for heating the airflow), straightener, control unit, illumination and imaging chamber, a single point load cell, measurement sensors and drying chamber with one layer tray. Whole body of the dryer was thermally insulated with glass wool.

The control unit consisted of a programmable logic controller (PLC, FATEK, Fbs-20MA), analogue to digital converter (FATEK, Fbs-6AD), digital to analogue converter (FATEK, Fbs-4AD), a 12V DC power supply (Acro, AD1048-24FS), Load cell transmitter (ESiTT, TR-3, turkey), an inverter to control speed of the fan

(Rhymebus, RM5E-2002), a power controller (Autonics, SPCI-35) to control voltage of the elements and relative humidity and temperature sensors boards.



1. Fan 2. Preheating element 3. Heating elements 4. Straightener 5. Air velocity sensor 6. Rrelative humidity and temperature sensor 7. Temperature sensor 8. Digital color camera 9. Fluorescent lamps 10. Platform 11. Load cell 12. Control unit 13. Ooutside temperature sensor 14. HMI 15. Computer 16. Monitor 17. Keyboard

Figure 1 Schematic view of experimental dryer

Figure 2 Photographic view of the experimental dryer

The temperature of the airflow was controlled within ±1ºC with the use of PLC, power controller and two PT-100 temperature sensors (before and after the samples tray). Outside air temperature was measured using a temperature sensor (LM35, NSC, USA) and PLC. Relative humidity of the airflow was measured by means of a high-temperature relative humidity sensor (EE99-03-FP6AD 802, E+E Elektronik). Weight loss and moisture of samples along drying was measured by means of a high precision aluminum single point load cell (Tedea, Huntleigh, model 1004) with an accuracy of 0.001 g, PLC and Load cell transmitter. The air velocity was measured by an anemometer (Lutron, AM-4201, Taiwan) and controlled using the inverter. The PLC was interfaced to a PC (Intel-Pentium 4, 3.06 GHz, 512 MB RAM, 200 GB hard disk) via RS-232 port. All measured data (temperatures, relative humidity, air velocity, weight of samples and time) were transferred and were saved to the PC via the PLC and a written program in MATLAB 7.7. A human machine interface (HMI, FV035ST-C10) was used to enter set- points, to communicate with the dryer, digital camera, fluorescent lamps and the load cell, to determine the paths in which measured data should be saved and to view the dryer performance graphically.

2.3 Processing of the images

RGB is a non-absolute color space, i.e., the RGB color measurement depends on external factors such as sensitivity of the sensors of the camera, illumination, etc (Leon et al, 2006). Therefore, L*a*b* color space was used to measure the color of banana slices. The L*a*b*, or CIELab, color space is an international standard for color measurements, adopted by the Commission Internationaled'Eclairage (CIE) in 1976. In this standard, L* is the luminance or lightness component, which ranges from 0 to 100, and parameters a* (from green to red) and b* (from blue to yellow) are the two chromatic components, which range from -120 to 120 (Papadakis, et al., 2000; Segnini et al., 1999; Yam and Papadakis, 2004).

For processing of the images, a computer program was developed at the MATLABR2007b environment. In the program, the images were processed at three parts, isolating the images from background, converting RGB to L*a*b*color space, converting RGB values to L*a*b* values. In the end, the Hunter color parameters ($\overline{L^*}$, $\overline{a^*}$, $\overline{b^*}$) were obtained from the processed images.

In RGB color spaces, the values are not standard. Therefore, after converting the color space, the following conversions were applied (Yam and Papadakis, 2004).

$$\overline{L^*} = \frac{Lightness}{255}\quad 100 \tag{1}$$

$$\overline{a^*} = \frac{240a}{255} - 120 \tag{2}$$

$$\overline{b^*} = \frac{240b}{255} - 120 \tag{3}$$

2.4 Color analysis

The total color difference (ΔE^*), as the most important parameter of the color variation, was calculated using the Equation (4). The ΔE^* is a single value which takes into account the differences between the L*, a* and b* of the sample and their standard values.

$$\Delta E^* = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \tag{4}$$

Chroma is the quality that distinguishes the difference from a pure hue to a gray shade. The Chroma axis extends from the value axis at a right angle and the amount of Chroma is noted after the value designation .

$$\text{Chroma} = \sqrt{a^{*2} + b^{*2}} \tag{5}$$

Hue is one of the main properties of a color, defined technically (in the CIECAM02 model), as the degree to which a stimulus can be described as similar to or different from stimuli that are described as red, green, blue, and yellow (Fairchild, 2004). An angle of 90° represents a typical yellow color. Fruits with higher than 90° hue angle were less yellow and slightly more green, while lower than 90° Hue angle were slightly more orange-red (Waliszewski et al., 1999).

The browning index (BI) represents the purity of brown color and is reported as an important parameter in processes where enzymatic and non-enzymatic browning takes place (Maskan, 2001; Palou et al., 1999).

Hue angle and browning index were calculated from the following equations (Maskan, 2001).

$$\text{Hue angle} = \tan^{-1}\left(\frac{a^*}{b^*}\right) \tag{6}$$

$$BI = \frac{[100(x - 0.31)]}{0.17} \tag{7}$$

where,

$$x = \frac{(a^* + 1.75 \quad L^*)}{(5.645 ?\ L^* \quad a^* \quad 3.012 \quad b^*)} \tag{8}$$

2.5 Modeling of browning

In this study, some browning parameters such as ΔE^*, L^*, a^* and b^* as a function of drying time were modeled. For this purpose, two primary models inclusive the zero-order (Equation (9)) and the first order model (Equation (10)) were used (Ibarz et al., 1999; Demir et al., 2002).

$$C = C_0 + k_0 t \tag{9}$$

$$C = (C_0 - C_{\infty})\exp(k_1 t) + C \tag{10}$$

where, C is the variable content studied at time t; C_0 is the value at time zero; C_∞ is the value at time extreme; k_0 the zero order kinetic constant, and k_1 is the first order kinetic constant.

3 Results and discussion

Some experiments were designed to investigate the ability of the online image processing technique to descript the kinetics of color change during drying process.

The results showed an exponential relation between moisture content ratio (MR) and drying time. Therefore, the rate of dehydration decreased during drying time. The effect of drying temperature on the rate of dehydration was clear. Increasing of drying temperature was found to increase drying rate due to further thermal energy. In addition, the rate of drying had a direct relation with the slice thicknesses (Sankat and Castaigne, 2004; Ceylan et al., 2007; Yadollahinia and Jahangiri, 2009).

For calibration and comparison of data between old and new method, a color chart was supplied. The hunter color parameters of the chart were measured by image analysis and by the hold-hand colorimeter. The results showed a linear relation with high correlation coefficient for L*, a* and b* (0.967, 0.962 and 0.991 respectively).

$$L^* = 1.233 ?\ \overline{L^*} \quad 4.518 \qquad R^2 = 0.970 \tag{11}$$

$$a^* = 1.657 ?\ \overline{L^*} \quad 0.736 \qquad R^2 = 0.960 \tag{12}$$

$$b^* = 1.663 ?\ \overline{L^*} \quad 0.175 \qquad R^2 = 0.980 \tag{13}$$

Lightness is the major parameters in banana color that changed during drying process. Therefore, decreases in L* value correlated well with increases in the browning of the banana slices (Maskan, 2002). Hunter a* and b* values in the color of banana was a few and change of this parameters during drying were observed insignificant as compared to L* value. Therefore, these parameters may not contribute to perception of color change. The variation range of these parameters is shown in Table 1. The a^*-value increased during drying process and its value before and after drying was obtained negative (between -12.5 and -1) indicating greenness. This means that greenness of samples was lost and become more red after drying process. According to the standard deviation (Table 1), the Hunter a* value changed rather than the Hunter b* value. The variation rate of b*-value was not clear.

Table 1 The values of a^* and b^* regarding to the drying time

Thickness=7 mm					Thickness=5 mm					Thickness=3 mm					Temp. /°C
ΔT /min	b*		a*		ΔT /min	b*		a*		ΔT /min	b*		a*		
	S.D	Ave	S.D	Ave		S.D	Ave	S.D	Ave		S.D	Ave	S.D	Ave	
630	1.53	14.80	2.36	-4.58	565	1.46	15.98	2.33	-3.28	415	1.29	13.41	1.98	-4.61	50
600	1.23	14.01	1.55	-5.16	480	1.31	13.04	2.07	-4.79	440	1.28	13.47	1.90	-5.17	60
390	1.48	14.09	1.39	-4.61	345	1.59	14.45	1.84	-4.59	220	1.36	15.54	2.50	-5.12	70
320	1.38	15.47	1.93	-5.02	280	1.84	16.19	2.05	-4.16	280	1.24	17.10	2.12	-6.27	80
225	1.21	12.86	1.24	-4.71	210	1.11	9.50	1.11	-5.52	140	1.91	15.31	1.55	-5.24	90

The change of Lightness (L^*) and the total color difference (ΔE) as a function of drying time, were shown in Figure 3, respectively. The figures represent that L^* parameter was decreased and ΔE was increased during drying time (Baini and Langrish, 2009; Masken, 2001; Ibarzetal, 1999). Variation of L* was measured between 81 and 42 that it resulted to increasing samples total color difference about 40 unit.

The experimental data of the a^*, b^*, L^* and ΔE was fitted using zero and first order models. The results of the modeling are shown in Tables 2 and 3 for the zero and first order models, respectively. However the models could not model the variation of a^* and b^*. But, the result for L^* and ΔE were suitable, due to R^2 between 0.80 and 0.97 for zero and between 0.86 and 0.98 for first order model. However the fitting results of the zero-order model were acceptable, but, a comparison the models showed that the first-order model represented L^* and ΔE better than the zero-order. Demir et al. (2002), Ibarz et al. (1999) reported similar results for hazelnut and pear puree, respectively.

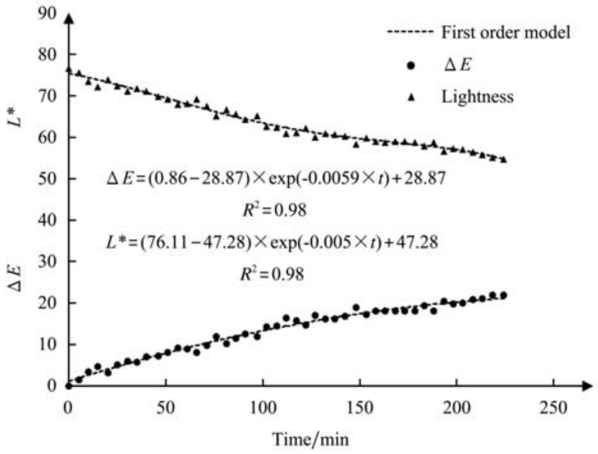


Figure 3 Model of change of the $L^*$and the ΔE during drying time (air temperature of 90°C, slice thickness of 7 mm

Table 2 Non-regression Results of modeling at the different drying conditions using zero-order model

Temp /°C	C	Thickness=3 mm			Thickness=5 mm			Thickness=7 mm		
		k_0	C_0	R^2	k_0	C_0	R^2	k_0	C_0	R^2
50	L*	-0.033	69.16	0.87	-0.031	73.04	0.89	-0.031	74.16	0.94
	ΔE	0.030	6.21	0.80	0.03	3.69	0.89	0.03	3.81	0. 92
60	L*	-0.039	66.89	0.81	-0.041	83.64	0.88	-0.029	73.57	0.93
	ΔE	0.038	9.24	0.82	0.040	6.96	0.86	0.028	3.85	0.93
70	L*	-0.070	76.02	0.86	-0.051	73.26	0.93	-0.033	73.50	0.88
	ΔE	0.071	7.21	0.79	0.048	4.57	0.89	0.031	6.10	0.87
80	L*	-0.020	70.27	0.55	-0.069	77.23	0.94	-0.061	75.11	0.97
	ΔE	0.023	7.65	0.42	0.067	6.77	0.93	0.061	2.85	0.97
90	L*	-0.115	74.86	0.84	-0.058	52.87	0.85	-0.090	73.81	0.95
	ΔE	0.116	6.57	0.83	0.049	2.89	0.85	0.089	3.25	0.95

Table 3 Non-regression Results of modeling at the different drying conditions using first-order model

Temp /°C	C	Thickness=3 mm				Thickness=5 mm				Thickness=7 mm			
		k_1	C_0	C_∞	R^2	k_1	C_0	C_∞	R^2	k_1	C_0	C_∞	R^2
50	L*	-0.0061	72.95	56.04	0.97	-0.0039	76.98	55.66	0.97	-0.0025	77.13	51.20	0.98
	ΔE	0.0051	3.47	18.83	0.86	0.0038	0.046	20.68	0.96	0.0022	1.16	27.43	0.95
60	L*	-0.0081	73.55	52.45	0.98	-0.0045	87.96	63.82	0.96	-0.0029	76.56	54.49	0.98
	ΔE	0.0071	3.62	24.03	0.96	0.0046	2.62	26.16	0.94	0.0027	1.16	22.94	0.97
70	L*	-0.011	79.76	61.06	0.95	-0.0026	74.71	44.74	0.95	-0.0049	76.01	59.60	0.94
	ΔE	0.011	3.15	21.95	0.89	0.0024	3.34	32.86	0.91	0.0061	3.17	17.91	0.95
80	L*	-0.0029	75.09	66.23	0.81	-0.0057	80.07	55.16	0.97	-0.0029	76.74	44.42	0.98
	ΔE	0.041	0.05	11.98	0.76	0.0048	4.50	30.54	0.95	0.0029	1.24	33.5	0.98
90	L*	-0.0217	79.59	60.80	0.97	-0.0097	55.27	40.3	0.91	-0.0056	76.11	47.28	0.98
	ΔE	0.0215	1.85	20.79	0.95	0.0104	0.72	13.17	0.91	0.0059	0.86	28.87	0.98

According to Tables 2 and 3, the increasing of drying temperature was found to increase the absolute value of the zero order kinetic constant (k_0) and the first order kinetic constant (k_1). Therefore, the variation rate of browning was increased. However, the effect of various thicknesses was not clear, but at the higher thicknesses, the estimation of models was better. In addition, the data of tables showed that the values of k_0 and k_1 are small; this means that the change of browning was done very slowly.

In the zero-order model, the absolute value of k_0 for the lightness and ΔE^* is almost same. It shows that the dependence of the ΔE^* on the L^* is more than the a^* and the b^*parameters. Therefore, the total color difference can be described only by the kinetics of the L^*. Table 4 represents the results of the modeling of the ΔE^* as a function of the L^* with R^2 between 0.874 and 0.998. Baini and Langrish (2009) performed a linear regression analysis on the data and obtained the correlation between the browning and the color parameters of banana slice.

Table 4 The modeling of the ΔE as a function of the L*

Temp/°C	Thickness=3 mm		Thickness=5 mm		Thickness=7 mm	
	Relation	R^2	Relation	R^2	Relation	R^2
50	$\Delta E = -0.886L^* + 67.58$	0.906	$\Delta E = -0.962L^* + 73.99$	0.990	$\Delta E = -0.984L^* + 76.79$	0.981
60	$\Delta E = -0.969L^* + 74.20$	0.979	$\Delta E = -0.986L^* + 89.37$	0.989	$\Delta E = -0.964L^* + 74.86$	0.993
70	$\Delta E = -1.027L^* + 85.21$	0.958	$\Delta E = -0.938L^* + 73.26$	0.968	$\Delta E = -0.918L^* + 73.68$	0.960
80	$\Delta E = -1.174L^* + 89.96$	0.874	$\Delta E = -0.973L^* + 82.00$	0.985	$\Delta E = -0.996L^* + 77.67$	0.997
90	$\Delta E = -1.012L^* + 82.37$	0.993	$\Delta E = -0.828L^* + 46.80$	0.962	$\Delta E = -0.992L^* + 76.50$	0.998

After calculating the independent parameters of browning such as a^*, b^* and L^*, other dependent parameters such as Chroma, Hue and BI were determined.

The Chroma value is proportional to the strength of the color (Maskan, 2001). Because of dependence on a* and b*, little change were observed in Chroma. This indicates stability of yellow color in banana. The average value of Chroma was measured 15.23 with standard deviation of 1.7.

The Hue angle values decreased from about 130° to 100° during drying time (Figure 4). Therefore, change of this parameter was placed in the more green sector (Hue > 90°) (Waliszewski et al., 1999).

Pigment destruction, ascorbic acid browning and non-enzymatic Maillard browning (AbersandWrolstad, 1979; Ibarz et al., 1999; Skrede, 1985; Maskan, 2001) resulted in production of brown compounds (Maskan, 2001). Therefore, the browning index values increased during drying process. The changes of the BI value were calculated between 10 and 30 (Figure 5).

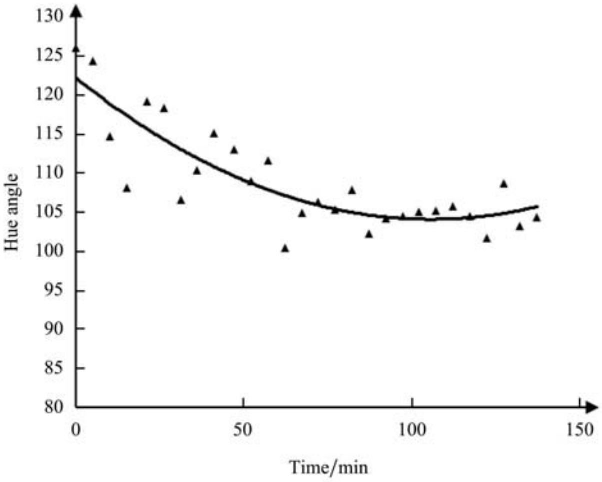


Figure 4 The model of change of the hue during drying time (air temperature of 90℃, slice thickness of 3 mm)

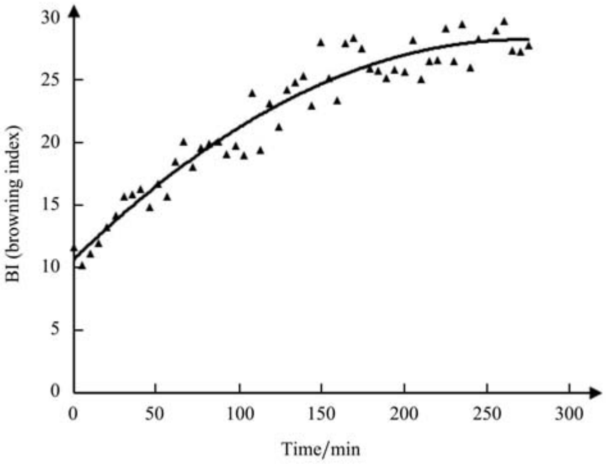


Figure 5 The model of change of the BI during drying time (air temperature of 80℃, slice thickness of 5 mm)

4 Conclusions

Image processing technique was used to investigate variations of the Hunter color parameters (L^*, a^*, b^*) during drying process. The result due to linear relation with high correlation coefficient for L*, a* and b* (0.967, 0.962 and 0.991 respectively) between image analysis and the hold-hand colorimeter, showed that this technique is capable to measure the color variations as online, automatic, continues and quick.

Effects of the drying temperature and the slice thickness on drying rate were clear. Parameters, the ΔE and the BI, increased and Hue angle decreased during drying process. The L^* was the most important Hunter that it changed during drying time. Stability of yellow color in banana resulted in insignificant variation in a^*, b^* and Chroma. Comparison between the models showed that the first-order model had the best representation of the total browning kinetics (ΔE) and Lightness (L^*) due to R^2 between 0.874 and 0.998. Because of the insignificant variations of a^* and b^*, this models could not represent the kinetics of them.

This obtained results from the online image processing technique is comparable with the results of Ibarzetal, 1999; Masken, 2001; Sankat and Castaigne, 2004; Ceylan et al., 2007; Yadollahinia and Jahangiri, 2009; Baini and Langrish, 2009, etc.

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