Using Response Surface Methodology to Investigate the Effects of Drying Parameters on Browning of Dried Banana Slices

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Abstract

Response surface methodology was used to investigate the effect of some drying parameters on browning of banana slices during dehydration process. In this study, the banana slices were dried using a thin-layer dryer, made based on a computer vision system. Thus, the browning of the slices was determined using image processing technique in the MATLAB environment. Response surface technique, Box-Behnken Design (BBD) with four parameters using Design Expert.7 software, was used to investigate the effects of drying time, drying temperature, slice thickness and air velocity during drying process (as the process parameters) on the browning (as the process response). The modified quadratic-order model was chosen to describe the browning as a function of the independent parameters such as time, temperature, slice thickness and air velocity due to $R^2=0.91$ and Adj $R^2=0.83$. The results showed that the drying time, drying temperature, and air velocity had the most direct effect on the banana browning, respectively. However, the effect of slice thickness was inverse.

Keywords: Response Surface Methodology; Browning; MATLAB; Design Expert.7; Box-Behnken Design

1. Introduction

Banana is widely grown in the areas of tropical and subtropical climates. After harvesting, the quality of bananas deteriorates rapidly (Prachayawarakorn et al., 2008). Therefore, Drying as the oldest methods is used to protect foods and agricultural products and is the best choice to reduce the deterioration of the product. During the drying process, the quality of the final product is one of the most important elements. Determination and controlling of quality parameters such as color,
taste, odor and texture can be useful for ordering and marketing of foods. Among them, 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 is often associated with the Maillard reaction (Baini and Langrish, 2009). This reaction was introduced for the first time by Louis Maillard in 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 such as Maillard condensation which is 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 the color include fruit pH, acidity, processing temperature and duration, fruit cultivar and heavy metal contaminations (AbersandWrolstad, 1979; Skrede, 1985; Garcia-Viguera, et al., 1999).

Moreover, some of important drying factors affecting color include air temperature, relative humidity, slice thickness, drying time and air velocity (Demir et al;2002; Boudhrioua et al, 2002; Baini and Langrish,2009; Jokic et al,2009 ). Determination and controlling of them is a useful device to decline the formation of browning. Due to interaction between the effective parameters, finding an optimal point for browning behavior of the dried food is necessary.

Response surface methodology (RSM) has been reported to be an effective tool for optimization of a process when the independent variables have a combined effect on the desired response.RSM is a collection of statistical and mathematical system that has been successfully used for developing, improving and optimizing of such processes (Koocheki et al; 2008, Bostan et al., 2008; Cui et al., 1994; Koocheki et al, 2008; Myers & Montgomery, 1995; Wu et al., 2007).

This research investigates the browning behavior of the samples against different drying conditions (temperature, slice thickness, and air velocity) to determine the effects of them to decrease and to control the formation of the slices browning.Because all levels of the factors were not accessible, the Box-Behnken Design matrix and response surface methodology were applied for designing the experiments in order to evaluate and to approve the interactive effects of the four most important operating variables (Demirel and Kayan, 2012).

2. Materials and Methods

Fresh bananas were supplied from a local market and then transferred to the laboratory of the Research and Development of Department of Agricultural Machinery Engineering, University of Tehran. In order to obtain the initial moisture content, some of banana slices were dried in an oven at 110 °C for 24h. Average moisture content was found to be 75% (Wet basis). In each experiment, a banana was peeled and 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 a preset conditions. After finishing of each experiment, the samples were placed into oven to remove their remaining moisture. In this study, the slices were dried at temperatures of 50, 70, and 90 °C, thicknesses of 3, 5 and 7 mm and air velocities of 0.5, 1 and 1.5 m/s.
2.1 Dryer used

A thin-layer dryer was made based on computer vision to investigate the effects of drying on visual properties of the products and to obtain the relations between these properties and moisture content (Fig. 1). The dryer consisted of a centrifugal fan (Damandeh, BEF-25/25F4T, 6300 m³/hr), air duct, four electrical heating elements (a 750W 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 (Hosseinpour et al, 2012).

Fig. 1. Experimental dryer: 1.fan; 2.preheating element; 3.heating elements; 4.straightener; 5.air velocity sensor; 6.relative humidity and temperature sensor; 7.temperature sensor; 8.digital color camera; 9.fluorescent lamps; 10.platform; 11.load cell; 12.control unit; 13.outside temperature sensor; 14.HMI; 15.computer; 16.monitor; 17.keyboard.

2.2 Image capturing

For capturing of slice image a digital camera (Canon, PowerShot D30, BSI-CMOS, and 12 Mp) was used. The camera is set above sample tray. It run using a special computer software and monitor samples during drying. The image of samples was captured at a preset time during.

2.3 Processing of the images

For processing of the images, an special computer program was developed at the MATLAB R2007b environment. In this, L*a*b* color space was used to measure color of the slices. For calibration of data, a color chart was supplied (Leon et al, 2006). The hunter color parameters (L*, a* and b*) of the chart both were obtained by image analysis and measured 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). Before processing, the data were calibrated.

2.4 Color analysis

The total color difference (∆E), as the most important parameter of the color variation, was used as
browning index to describe the kinetics of the color change of banana slices. It is expressed by the following equation (Eq.5). The $\Delta E$ is a single value which takes into account the differences between $L^*$, $a^*$ and $b^*$ of the samples and their corresponding standard values.

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

(1)

### 2.5 Experimental design

Response surface technique (Box-Behnken Design(BBD)) with four parameters, was used to investigate the effect of drying time ($C_1$), drying temperature ($C_2$), slice thickness ($C_3$) and air velocity ($C_4$) during drying process (as the process parameters) on the browning ($y$, as the process response), which is defined by the following Equation.

$$
y = f(C_1, C_2, C_3, C_4)
$$

(2)

On the basis of the BBD, there are four important stages for the optimization of the experiments: (1) to perform statistically designed experiments for the experimental plan, (2) to recommend a mathematical model based on the experimental data and focus on the data of analysis of variance, (3) to control the efficiency of the model directly with diagnostic plots, and (4) to estimate the response and verify the model (Zhang and Zheng, 2009; Box and Draper, 1978).

In most of the studies that used response surface methodology, linear and quadratic models were applied to fit the model. If the response is modeled as a function of independent varies, the estimated function will be a first order model. Otherwise, the estimated function will be second or more. In this study, due to interaction between varies a second order polynomial was used as shown in Eq.3 (Koocheki et al, 2009; Marklund and Nilsson, 2001; Yunardi et al, 2011; rezzoug et al, 2008).

$$
Y = B_0 + \sum_i B_i X_i + \sum_{i=1}^d B_{ij} X_i^2 + \sum_{i<j} B_{ij} X_i X_j + \epsilon
$$

(3)

Where $Y$ is the predicted response, $B_0$, $B_i$, $B_{ii}$ and $B_{ij}$ are regression coefficients and $x_i$ are the coded variables linearly related to $C_i$, and $\epsilon$ is error. The coding of $C_i$ into $x_i$ is expressed by the following equation:

$$
x_i = \frac{2(C_i - C_i^*)}{d_i}
$$

(4)

Where $C_i$ is actual value in original units; $C_i^*$ is mean of high and low levels of $C_i$; and $d_i$ is the difference between the low and high levels of $C_i$.

Therefore the process parameters are coded as the following equation.

$$
X_1 = \frac{(-70)}{70} \quad \text{(Drying time)}
$$

(5)

$$
X_2 = \frac{(-70)}{20} \quad \text{(Drying temperature)}
$$

(6)

$$
X_3 = \frac{(-5)}{2} \quad \text{(Slice thickness)}
$$

(7)
\[ X_4 = 2(C_4 - 1) \]  

(8)

3. Results and Discussion

Box-Behnken Design with four parameters using Design Expert 7 software was used to analyze the data. At the first stage, the independent variables as the equations of 5-8 were coded to design the experiments. The coded data are shown in Table 1.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Experimental range and levels of the independent variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factors</td>
<td>Levels</td>
</tr>
<tr>
<td>Time (min)</td>
<td>-1</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>3</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>50</td>
</tr>
<tr>
<td>Air Velocity</td>
<td>0.5</td>
</tr>
</tbody>
</table>

29 experiments were designed by RSM. The experiments were done using the experimental machine vision dryer. The hunter color values (L*, a* and b*) of taken images were calculated using image processing technique in the MATLAB environment. Then, the total color difference was obtained by Eq.1. The model of \( \Delta E \) variation as a function of drying time is shown in Fig.1. According to the figure, the browning of banana slices increases during drying process. This may be occurred due to the pigment destruction, ascorbic acid browning and non-enzymatic Maillard browning (Abersand Wrolstad, 1979; Ibarz et al., 1999; Skrede, 1985; Maskan, 2001). In addition, the browning kinetics of the slices occurred as an exponential curve versus drying time (Fig.2). The rate of Maillard reaction decreases with decreasing of samples moisture content during dehydration process and thus, the browning rate of the slices increased during drying time.

Fig.2. the model of the \( \Delta E \) variation during drying time

\[ \Delta E = (0.86 - 28.87) \times \exp(-0.0059 \times t) + 28.87 \]

\[ R^2 = 0.98 \]
The results of image processing as the process responses were transferred to Design Expert 7 environment software. At the next stage, the statistical parameters were used to determine the situation model. However, the result of cubic model is aliased but it is very complex and long model. Therefore, the Quadratic model was suggested based on lower standard division and RMSE, higher R-Squared and having short terms. Other results are given for the evaluated models in Table 2.

Table 2 Statistical parameters of the models.

<table>
<thead>
<tr>
<th>Source</th>
<th>Std.Dev.</th>
<th>RMSE</th>
<th>R-Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>3.54</td>
<td>3.27</td>
<td>0.69</td>
</tr>
<tr>
<td>2FI</td>
<td>3.62</td>
<td>2.90</td>
<td>0.75</td>
</tr>
<tr>
<td>Quadratic</td>
<td>2.42</td>
<td>1.81</td>
<td>0.91</td>
</tr>
<tr>
<td>Cubic</td>
<td>1.18</td>
<td>0.55</td>
<td>0.99</td>
</tr>
</tbody>
</table>

The interaction effects between temperature-thickness and air velocity-thickness on the browning index were found to be insignificant experimentally. Therefore, they were eliminated from the parameter list. Then, the final equation in terms of coded factors was given as follows (Eq. 9).

\[
Y = 12.44 + 6.56 \times X_1 + 2.87 \times X_2 - 1.26 \times X_3 + 1.5 \times X_4 + 2.89 \times X_2 \times X_4 + 1.44 \times X_1 - 1.31 \times X_3 \times X_1 - 1.42 \times X_2^2 - 0.67 \times X_4^2 - 2.53 \times X_3^2 - 4.34 \times X_1^2
\]  

(9)

Based on Eq. 9, the drying time is the most effective factor in browning process. The effects of the temperature and air velocity were lower, respectively and the thickness had an inverse relation with browning.

Table 3 shows the experimental and predicted results for 29 runs. Some parameters such as fruit pH, acidity, fruit cultivar and heavy metal contaminations are also effective on the color change of sample, however, the results of the modeling based on drying parameters (drying time, temperature, thickness, air velocity) were acceptable due to R-Squared=0.91, Adj R-Squared=0.83. Other statistical results of the model are given in Table 4. (AbersandWrolstad, 1979; Skrede, 1985; Garcia-Viguera, et al., 1999).

Table 3 Box–Behnken design matrix for Predicted and Experimental results.

<table>
<thead>
<tr>
<th>Run</th>
<th>X1</th>
<th>X2</th>
<th>X3</th>
<th>X4</th>
<th>Predicted</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12.44</td>
<td>12.45</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>9.48</td>
<td>8.73</td>
</tr>
<tr>
<td>3</td>
<td>-1</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>6.88</td>
<td>8.88</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>12.62</td>
<td>13.13</td>
</tr>
<tr>
<td>5</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>8.87</td>
<td>4.21</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>16.93</td>
<td>19.01</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>0.93</td>
<td>0.00</td>
</tr>
<tr>
<td>8</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>8.54</td>
<td>10.02</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>8.83</td>
<td>7.20</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>0</td>
<td>-1</td>
<td>1</td>
<td>14.70</td>
<td>12.18</td>
</tr>
<tr>
<td>11</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>9.56</td>
<td>6.93</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>17.61</td>
<td>20.71</td>
</tr>
</tbody>
</table>
Table 4 Statistical results of the mathematical modeling.

<table>
<thead>
<tr>
<th></th>
<th>Std. Dev.</th>
<th>R-Squared</th>
<th>Adj R-Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>8.73</td>
<td>0.91</td>
<td>0.83</td>
</tr>
<tr>
<td><strong>C.V. %</strong></td>
<td>27.68</td>
<td>11.7</td>
<td>3</td>
</tr>
</tbody>
</table>

Analysis of variance (ANOVA) for response surface model is given in table 5. The Model F-value of 12.37 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicates model terms are significant. In this case, X1, X2, X4, X2 X4, X12, X32 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (without considering those required to support hierarchy), model reduction may improve the model. In addition, the lack of fit is not statistically significant, therefore the model is suitable to predict the browning behavior of the slices (Demirel and Kayan, 2012; Goyal, 2011).

Table 5 Analysis of variance for response surface model.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F-Value</th>
<th>p-value Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>868.2822</td>
<td>12</td>
<td>72.357</td>
<td>12.37441</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>A-temperature</td>
<td>98.84938</td>
<td>1</td>
<td>98.849</td>
<td>16.90514</td>
<td>0.0008</td>
</tr>
<tr>
<td>B-Air Velocity</td>
<td>27.18639</td>
<td>1</td>
<td>27.186</td>
<td>4.649393</td>
<td>0.0466</td>
</tr>
<tr>
<td>C-Thickness</td>
<td>19.05962</td>
<td>1</td>
<td>19.060</td>
<td>3.25956</td>
<td>0.0899</td>
</tr>
<tr>
<td>D-Drying Time</td>
<td>516.7287</td>
<td>1</td>
<td>516.729</td>
<td>88.37051</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>AB</td>
<td>33.56679</td>
<td>1</td>
<td>33.567</td>
<td>5.740565</td>
<td>0.0292</td>
</tr>
</tbody>
</table>
3.1 Interactive effect of drying time and temperature

Figure (3-a) shows that by increasing in temperature and drying time, the browning of banana slices increases. Therefore, the maximum browning was obtained at temperature of 90 °C and drying time of 140 min. The major reasons of this behavior are increasing of pigment destruction, ascorbic acid browning and non-enzymatic Maillard browning during drying process at higher temperatures (Abers and Wrolstad, 1979; Ibarz et al., 1999; Skrede, 1985; Maskan, 2001).

3.2 Interactive effect of drying time and air velocity

As seen in Figure (3-b), the color of slices during drying was made browner at the higher drying time and air velocity. The maximum browning was observed at air velocity of 1.5 m/s and drying time of 140 min. According to the figure, at the beginning of drying, the effect of air velocity is almost insignificant.

3.3 Interactive effect of air velocity and drying temperature

According to the figure (3-c), at lower drying temperatures, the effect of air velocity is almost insignificant. But at higher temperature, browning increased with increasing the air velocity. Due to the interactive effect of air velocity and drying temperature, the slices become most brown at the high temperature (90°C) and air velocity (1.5 m/s).

3.4 Interactive effect of drying time and slice thickness

Figure (3-d) presents the interactive effect of drying time and slice thickness. At the beginning of experiment, the effect of slice thickness was not significant. During drying, the effect of slice thickness was found to increase. When the thickness of drying sample was low, the amount of browning was more. As a final result, the maximum browning was occurred at the slice thickness of 3mm and drying time of 140 min.

3.5 Optimization of browning

Due to different effects of the drying parameters on browning, selection of a suitable condition for drying of slices to obtain the low color change samples is necessary. This means that at a lower
temperature, the browning is low. However, decreasing drying temperature was found to increase the time of equilibrium moisture content (EMC). Therefore the drying must be done at a condition with high thickness, low air velocity and medium temperature.
4. Conclusion

In this study, the effect of some drying parameters on browning of banana slices during dehydration process was investigated using Response Surface Methodology, Box-Behnken Design (BBD) with four parameters using Design Expert 7 software. The modified quadratic-order model was selected to describe the browning as a function of the independent parameters (time, temperature, slice...
thickness and air velocity) due to R-square=0.91 and Adj R-Squared=0.83. Moreover, the results showed that the drying time, drying temperature, and air velocity had the most direct effect on the banana browning, respectively, though the effect of slice thickness was inverse.

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