Vietnam J. Agri. Sci. 2016, Vol. 14, No. 3: 432-438 Tạp chí KH Nông nghiệp Việt Nam 2016, tập 14, số 3: 432-438
www.vnua.edu.vn

# PREDICTION MODELS FOR COLOUR CHANGES IN ORANGE FLESHED SWEET POTATO (*Ipomoea batatas* L. Lam.) DURING HOT AIR DRYING

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Received date: 27.06.2015 Accepted date: 11.03.2016

## ABSTRACT

The main objective of this study was to investigate the effect of different temperatures of hot air drying on the quality attributes of orange fleshed sweet potato including colour parameters and colour sensory quality. The drying experiments were carried out at five air temperature of 40, 50, 60, 70 and 80°C. The colour parameters, *L* (whiteness/darkness), *a* (redness/greenness) and *b* (yellowness/blueness) for colour change of the materials were quantified by the Hunter Lab system. These values were also used for calculation of total change ($\Delta E$), hue angle, chroma and browning index. A consumer preference test was conducted with 80 consumers to assess the colour quality of five dried orange fleshed sweet potato samples. Relationship between colour sensory scores of consumer's taste and quantification of three Hunter parameters using least square regression indicated that all colour values significantly affect colour quality ranking of dried orange fleshed sweet potato. The zero-order model appeared best suited to explain the colour change kinetics during hot drying orange fleshed sweet potato slices at 70°C.

Keywords: Colour, drying predictive model, orange fleshed sweet potato.

## Ảnh hưởng của sấy nóng lên thành phần hóa lý và chất lượng cảm quan màu sắc của khoai nghệ vàng (*Ipomoea batatas (*L.) Lam.*)*

## TÓM TẮT

Mục tiêu chính của nghiên cứu này là đánh giá sự ảnh hưởng của nhiệt độ sấy trong phương pháp sấy khí nóng lên chất lượng của khoai nghệ vàng bao gồm thông số màu và chất lượng cảm quan màu. Thí nghiệm sấy được tiến hành ở bốn mức nhiệt độ gồm 40, 50, 60, 70 và 80°C. Thông số màu Hunter gồm 3 giá trị *L, a, b* được sử dụng để xác định màu của khoai nghệ vàng lát trong quá trình sấy. Các giá trị này cũng được sử đụng để tính toán giá trị sự thay đổi màu tổng thể ($\Delta E$), Chroma, Hue angle và chỉ số nâu hóa (Browning index). Phép thử cảm quan thị hiếu trên 80 người được sử dụng để đánh giá chất lượng cảm quan màu của 05 mẫu khoai nghệ vàng sấy. Phương trình hồi quy tương quan được sử dụng để xác định mối tương quan giữa điểm cảm quan thị hiếu màu và các giá trị màu của mẫu sấy, trong đó giá trị L và b làm giảm giá trị cảm quan, còn giá trị a góp phần làm tăng giá trị cảm quan màu sắc của sản phẩm. Mô hình động học bậc 0 (zero-order) phù hợp nhất để dự báo sự biến đổi màu sắc trong quá trình sấy khoai nghệ vàng ở nhiệt độ sấy 70°C.

Từ khóa: Khoai lang nghệ, mã màu sắc, mô hình dự báo sấy.

## 1. INTRODUCTION

Sweet potato is one of the top five food crops that feed the world, the others being wheat, corn, sorghum and rice. Generally, sweet potato fleshes are red, white, yellow or orange in colour. The texture, the sweetness, size and shape of sweet potato roots vary with varieties. Sweet potato roots have the following components: starch, sugar, amylose, amylopectin, vitamin A, vitamin C, tannins, phytin, oxalate, crude protein, either extract and crude fibre (Makki, Abdel-Rahman *et al.*,, 1986; Teow, Truong *et al.,* 2007). The postharvest method is important for keeping quality of orange fleshed sweet potato. Most farmers, however, did not have any knowledge of orange fleshed sweet potato drying which could add more value to the produce to have much market alteration to users or consumers (Teow *et al*., 2007).

Drying is one of the oldest methods of processing and preserving sweet potato for later use. Sweet potato can be dried under the sun, in an oven, or in a food dehydrator by using the right combination of warm temperature, low humidity and air flow. The common drying method applied for sweet potato in Viet Nam is sun drying which has so many disadvantages. Therefore, more rapid, safe and controllable drying methods are required. The forced convection hot air drying is an effective and rapid method to produce a uniform, hygienic and attractive colour product. Therefore, a forced convective cabinet dryer has been developed to address such problem (Law *et al*., 2014). However, the colour of orange fleshed sweet potato product could be affected by hot temperature during drying. Besides, the chemical composition and the colour also significantly affect the sensory quality of products. Hence, it is crucial to determine and control the colour and chemical composition of the processed orange fleshed sweet potato. The changes of colour can be related with the degradation of nutritional compounds during processing that have important nutritional properties (Ding *et al*., 2012). Standardized instrumental colour measurements corresponding to visual assessments of food colour are critical objective parameters that can be used as quality index (raw and processed foods) for the determination of conformity of food quality to specification and for analysis of quality changes as a result of food processing, storage and other factors. Several colour scales have been used to describe colour, those most being used in food industry are the Hunter colour *L, a, b* CIE system and the Munsell colour soild (Choudhury 2014). Maintaining the natural colour in processed and stored foods is a major challenge in food processing. Most studies were concerned with changes in colour due to time and temperature treatments during food processing such as drying and heating.

The drying behaviour of different materials was studied by several authors and a variety of kinetic models have been established such as for pumpkin, sweet potato, carrot, apricot, etc... (Diamante and Munro, 1991; Toğrul and Pehlivan, 2003; Doymaz, 2004). However, no significant research on the kinetics model for colour of orange fleshed sweet potato during hot drying as well as relation between colour and sensory evaluation has been reported so far. Therefore, the objectives of the present work were to study the effect of hot drying temperature on colour change kinetics and to find the relationship between colour and sensory quality to predict the quality of orange fleshed sweet potato colour changes with time by drying techniques.

## 2. MATERIALS AND METHODS

### 2.1. Materials

The orange fleshed sweet potato samples were collected from a local market in Ha Noi. The roots were stored at 4 ± 0.5°C in refrigerator. To determine the initial moisture content, 50 g samples were oven-dried at 70°C for 24h. The initial moisture content of orange fleshed sweet potato was calculated as 68.5 d.b as an average of the results obtained.

Drying treatment was performed in laboratory convection dryer. The airflow was measured by a portable, 0-15 m/s range digital anemometer and adjusted by means of a variable speed blower. Prior to drying, roots of orange fleshed sweet potato (OFSP) were taken out of storage, washed and sliced in thickness of 2 mm. About 150g of OFSP slices were uniformly spread in a tray and kept inside the dryer. The hot air drying was applied until the weight of the sample reduced to a level corresponding to 2-3 d.b moisture content. The experiment was operated at temperatures of

40°C, 50°C, 60°C, 70°C and 80°C with fixed air velocity at 1.3 m/s.The drying experiments were replicated three times for each temperature and the average values were computed.

### 2.2. Color measurements

The colour was measured before drying and at pre-specified time interval during drying period by Hunter-Lab ColorFlex, A60-1010-615 model colorimeter. This system uses three values (L, a and b) to describible the precise location of a colour inside a three-dimensional visible colour space. The colorimeter was calibrated against standard white and green plates before each actual colour measurement. For each sample at least five measurements were performed at different positions and the measured values (mean values) were used. The measurements were displayed in L, a and b values which represent light-dark spectrum with a range from 0 (black) to 100 (white), the green - red spectrum with a range from -60 (green) to + 60 (red) and the blue-yellow spectrum with a range from -60 (blue) to + 60 (yellow) dimensions, repestively (Choudhury, 2014).

Total colour difference was calculated using following equation, where subscript "0" refers to color reading of fresh sweet potato flesh which was used as the reference and a larger ΔE indicates greater colour change from the reference material.

$$\Delta E = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2} \quad (1)$$

$$\text{Chroma} = (a^2 + b^2)^{0.5} \quad (2)$$

$$\text{Hue Angle} = \tan^{-1}(b/a) \quad (3)$$

$$BI = \frac{[100(x - 0.31)]}{0.17} \quad (4)$$

Where

$$x = \frac{(a + 1.75L)}{(5.645L + a - 3.012b)}$$

### 2.3. Consumer test

A consumer preference test was conducted with 80 consumers to assess the colour quality of five dried sweet potato samples. Viet Namese consumers, age between 18 and 45, were recruited from the Ha Noi, Viet Nam. Consumers indicated their degree of liking of the products on the 7- point horizontal lines with "dislike extremely" on the left end and "like extremely" on the right end of line.

### 2.4. Statistical analysis

Statistical comparisons of the mean values for each experiment were performed by one-way analysis of variance (ANOVA), significance was declared at $p \leq 0.05$. Experimental data for the different parameters were fitted to prediction models (zero and first-order model) and processed by using SPSS version 22 software. PLS regression was performed by XLSTAT (version, 2014).

## 3. RESULTS AND DISCUSSION

### 3.1. Colour and sensory evaluation of dried orange fleshed sweet potato.

The result of consumer preference test on 80 consumers to evaluate e dried orange fleshed sweet potato showed that the product dried at 70°C was the most preferable (mean 6.27), followed by the sample dried at 60°C (mean 5.94), 40°C (mean 4.72), 50°C (3.58) and least preferable at 80°C (3.36) ($p \leq 0.05$) (Fig 1). The significant differences observed in the colour evaluation provides a reasonable basis for the evaluation of possible relationship between three values (*L, a* and *b*) and colour characteristics and/or colour evaluations.

Based on the Hunter colour parameters analyzed by Hunter-Lab ColorFlex and preference scores of five dried orange fleshed sweet potato products, the PLSR analysis indicated the positive and negative correlations between Hunter colour parameter and specific sensory attributes. The validation coefficients of three colour values which were developed from regression models are given in Table 1. Both the weight vectors of b values was positively correlated with sensory attributes (colour quality), while the others were negatively or positively correlated.

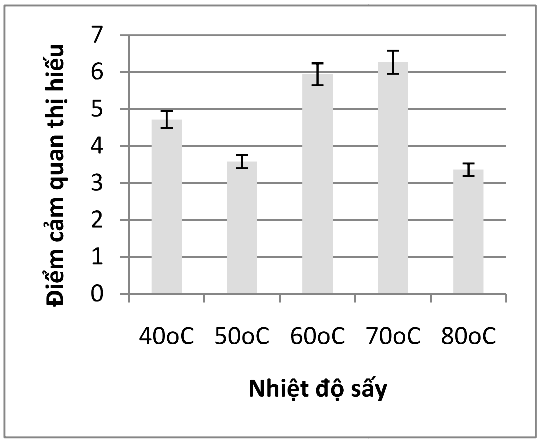


**Fig 1. Preference scores and products**

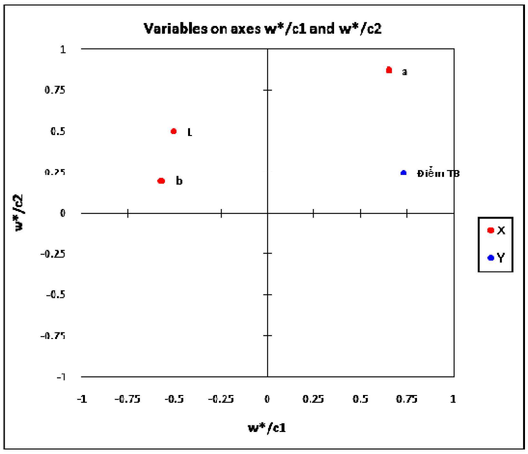


**Fig 2. Consumer preference (Y) and Hunter colour parameter (X) of orange fleshed sweet potato dried**

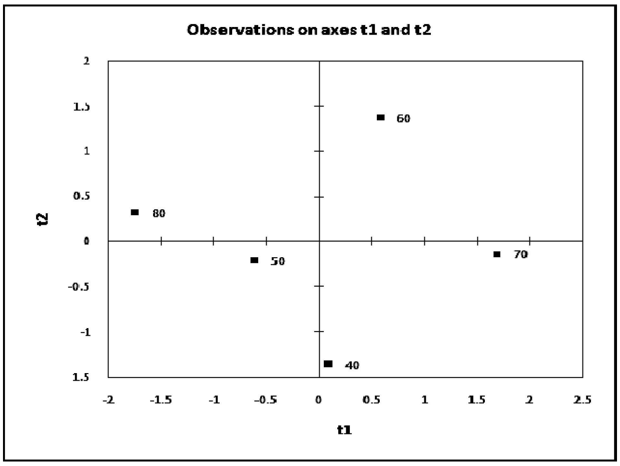


**Fig 3. The correlations map on t1 and t2 of products (obs), Hunter colour parameter (X) and consumer preference (Y)**

When considering the calibration sets, a good correlation between three values (*L, a* and *b*) and colour quality ranking could be achieved as observed from a high coefficient of determination ($R^2 = 0.938$). The error rate of predictability of calibration model could be expressed from a term of root mean square error of estimation (RMSE), which was found at 0.294. The close correlation of the reliable calibration model suggested that the complexity of sensory perception could be related directly to the three values (*L, a* and *b*) by means of multivariate analysis. The low RMSE values of this model suggested that three values (*L, a* and *b*) obtained from instrumental methods provided sufficient correlation information to the colour sensory quality ranking.

**Table 1. Correlation matrix of the variables (correlation matrix of W)**

| Variable | w*1 | w*2 |
|---|---|---|
| L | -0.5057 | 0.5011 |
| a | 0.6502 | 0.8658 |
| b | -0.5670 | 0.1963 |

**Table 2. Key values contributing to the construction of predictive model using Hunter colour parameters**

| Variable | VIP | Standardized coefficients |
|---|---|---|
| a | 1.1262 | 0.6877 |
| b | 0.9821 | -0.3660 |
| L | 0.8758 | -0.2463 |

Furthermore, compounds with high relevance for explaining dependent Y-variables were also identified from variable importance in the projection values (VIP). Large VIP values, > 0.8, are the most relevant for explaining the colour quality rankings of orange fleshed sweet potato dried and the compounds with VIP values greater than 0.8 are presented in Table 2. It was found that key values contributing to creating the colour quality predictive model composed of various Hunter colour parameters.

All VIP values were higher than 0.8, therefore a simplified model of favourable products was obtained (Equa.1).

Y = 0.6877*a - 0.3660*b - 0.2463*L (Equa.1)

Equation of the model of favourable products showed that all three colour values significantly affected colour quality ranking of dried orange fleshed sweet potato.

### 3.2. Prediction Models for Colour Changes

To investigate the effect of hot air on colour change kinetics of orange fleshed sweet potato slices during drying, air temperature of 70°C was used for drying of constant amount of 1.0 kg fresh orange fleshed sweet potato. The values of *L, a, b* and total colour change (ΔE) obtained from the experimental data during hot air drying and model data are presented in Table 3. The L value decreased with drying time. The change in brightness of dried samples decreased from 65.08 to 52.31 during hot air drying of orange fleshed sweet potato samples at 70°C.

The “a” values were varied from 23.54 to 18.85 as the drying time increased. Therefore, the colour of orange fleshed sweet potato sample tended to lose its greenness when drying time increased. The b value decreased to the end of drying time from 28.91 to 24.93 as the time increased. The change of colour may be due to decomposition of pigment compounds, non-enzymatic Maillard reaction (Rizzi, 2005). As a whole, the total colour change (ΔE) of orange fleshed sweet potato slices increased with hot air drying time and ranged from 1.08 to 11.55 as drying time increased.

Chroma, hue angle and browning index (BI) were calculated by using equations (2)-(4) and the results are shown in table 3. The values of chroma decreased as a function of drying time. On the other hand, the hue angle and BI values

**Table 3. The changing of L value, a value and b value as function of drying time at 70°C**

| Time (minutes) | Hunter colour parameter | | | Total colour change (ΔE) | Chroma | Hue angle | Browning index |
|---|---|---|---|---|---|---|---|
| | L | a | b | | | | |
| 0 | 65.08 ± 1.24 | 23.54 ± 0.75 | 28.91 ± 1.758 | | 37.28 ± 0.81 | 50.85 ± 0.55 | 83.71 ± 0.96 |
| 25 | 65.65 ± 1.04 | 24.30 ± 0.56 | 29.42 ± 1.851 | 1.08 ± 0.36 | 38.16 ± 0.46 | 50.44 ± 0.61 | 84.97 ± 1.12 |
| 50 | 62.66 ± 1.04 | 23.46 ± 0.41 | 29.00 ± 1.634 | 1.43 ± 0.23 | 37.30 ± 0.62 | 51.03 ± 0.39 | 87.82 ± 1.02 |
| 75 | 63.45 ± 0.94 | 23.09 ± 0.47 | 28.32 ± 1.381 | 1.79 ± 0.46 | 36.53 ± 0.55 | 50.81 ± 0.33 | 84.23 ± 1.06 |
| 100 | 60.54 ± 0.86 | 22.81 ± 0.46 | 28.15 ± 1.265 | 4.67 ± 0.67 | 36.23 ± 0.78 | 50.98 ± 0.43 | 88.36 ± 1.11 |
| 125 | 58.09 ± 1.13 | 22.40 ± 0.39 | 27.65 ± 1.045 | 7.13 ± 0.62 | 35.58 ± 0.34 | 50.99 ± 0.51 | 90.92 ± 1.16 |
| 150 | 57.48 ± 0.74 | 21.34 ± 0.54 | 26.88 ± 1.888 | 8.17 ± 0.70 | 34.31 ± 0.39 | 51.55 ± 0.34 | 88.45 ± 0.88 |
| 175 | 54.53 ± 1.14 | 20.15 ± 0.23 | 25.93 ± 1.692 | 11.48 ± 0.97 | 32.84 ± 0.66 | 52.15 ± 0.44 | 89.73 ± 1.01 |
| 200 | 52.31 ± 0.96 | 18.85 ± 0.49 | 24.93 ± 1.736 | 11.55 ± 0.88 | 31.25 ± 0.55 | 52.91 ± 0.22 | 89.29 ± 0.78 |

**Table 4. Model summary, ANOVA and Coefficients of prediction model for colour changed**

| Colour Values | Model | Equation | Adjusted $R^2$ | p (ANOVA) | P (Coefficient) | |
|---|---|---|---|---|---|---|
| L | Zero-order | L = 66.19 - 0.059t | 0.929 | 0.000 | t | 0.000 |
| | | | | | C | 0.000 |
| | First-order | L = 66.37*exp(-0.001t) | 0.928 | 0.000 | t | 0.000 |
| | | | | | C | 0.000 |
| a | Zero-order | a = 24.63- 0.0241t | 0.846 | 0.000 | t | 0.000 |
| | | | | | C | 0.000 |
| | First-order | a = 24.76*exp(-0.0011t) | 0.829 | 0.000 | t | 0.000 |
| | | | | | C | 0.000 |
| b | Zero-order | b = 29.77- 0.02t | 0.883 | 0.000 | t | 0.000 |
| | | | | | C | 0.000 |
| | First-order | b = 29.84*exp(-0.0008t) | 0.874 | 0.000 | t | 0.000 |
| | | | | | C | 0.000 |

*Note: C- Constant; t -time*

were direct proportional to drying time. The hue angle value corresponds to whether the object is red, orange, yellow, green, blue, or violet. The initial hue angle of orange fleshed sweet potato slices was about 51°C, which represents a colour in slightly yellow region of the colour solid dimensions. Upon heating, the hue angle increased, shifting towards the more yellow region.

For the mathematical prediction of colour change of orange fleshed sweet potato, zero-order and first-order models were used. It was observed that L, a and b values were fitted to the zero-order prediction model. The estimated prediction parameters of these models and the statistical values of coefficients of determination adjusted $R^2$ as well as significant values are represented in Table 4.

## 4. CONCLUSION

On the basis of the Hunter colour parameters, *L*, *a* and *b*, a model (coefficient of determination ($R^2$) of 0.938, and root mean square error of estimation of 0.294) was constructed to predict the colour quality of dried orange fleshed sweet potato. The colour change of orange fleshed sweet potato slices using the L, a and b system totally explained the real behavior of orange fleshed sweet potato samples undergoing hot air drying. The final values of L, a, b and total colour change ($\Delta E$) were influenced by hot air drying. The zero-order and first-order models were used to explain the colour change kinetics and it was observed that *L, b* and *a* were fitted to zero-order model. The $\Delta E$ increased; on the other hand, L, a and b decreased when the air temperature was increased. From the results obtained in this study, the *L, a* and *b* values profiling by instrument methods in the combination with sensory and multivariate data analysis should be a useful reference for colour quality prediction of orange fleshed sweet potato slices.

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