Characteristics of okara color change during convective drying process

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Abstract. Okara is a byproduct of the tofu factory that is perishable in nature and requires an immediate handling and treatment to preserve it. Drying has been a preferred method since it can increase the product compactness. However, the majority of okara drying studies done in the past are disregarding the influences of process condition on color change characteristic. Hence, this work aimed to investigate the characteristic of okara color changes during convective drying at temperatures of 85, 100, and 115°C. The okara color was expressed in terms of L a b values and its derivative attributes, i.e. whiteness, hue angle, chroma and the total color difference. The results showed that an increase in drying time and temperatures decreased the lightness, yellowness and the total color difference, but conversely increased the redness of okara. Fitting of two exponential models to the experimental data revealed that the Page’s equation was better in predicting the okara color degradation than Newton’s model.

1. Introduction
Manufactures of tofu or soymilk always generates okara, a byproduct that appears usually in a creamy white color and semi-solid form with 75-80% moisture on wet basis. Okara consists of remaining nutrients derived from soymilk such as protein, lipid, and fiber [1]. These nutrients quality are greatly high and therefore, it encourages people to utilize it as ingredient for human diets. However, okara must be processed rapidly through refrigeration or drying to prevent quick spoilage of this material.

Although refrigeration is a good method to preserve okara, but the people prefer mostly a drying operation because it can reduce the weight of final product. Several works have been reported on drying of okara for different methods, i.e. hot-air drying [2], spouted-bed drying [3], pneumatic tube and rotational drum-drying [4], flash drying [5], combination of vacuum-tray and microwave drying [6]. These studies are beneficial for them who will select drying methods for drying okara. Unluckily, there were no studies on okara drying that have been done in the past regarding to the okara color change during drying process. Hence, the aim of this study was to investigate the characteristic of okara color changes during convective drying for different temperatures between 85 and 115°C.

2. Materials and Methods
2.1. Raw okara
Raw okara was obtained from a small-scale tofu enterprise in Jember city, East Java, Indonesia. This was packaged in plastic bags and stored in a refrigerator (~4°C) for less than 4 days before the drying
experiments. Initial moisture content of okara was determined using an AOAC standard method [7]. About 3 g of sample was weighed accurately and rapidly in the dish and then dried at 105°C in the oven for 3 h. The samples were cooled in a desiccator to the room temperature prior to weighing.

2.2. Experimental procedure

Three identical aluminum containers were filled with a thin layer of ±100 g okara and that of 1.5 cm thickness. They were placed horizontally on the same shelf in a hot-air oven (Memmert UNB400) and then dried at temperatures of 85, 100 and 115°C. Weight losses of samples were measured every hour till drying process was completed when the product moisture content reached 5% on wet basis. These data were then used to determine the change of okara moisture content during convective drying.

The color of okara was measured using a tristimulus colorimeter (Konica Minolta CR-10) in terms of Hunter L, a, and b values. The “L” or lightness value varies from 0 (black) to 100 (white). The “a” value represents the color range between green (-a) and red (+a), while the “b” value ranges from blue (-b) to yellow (+b). The change of okara color were measured periodically based on their L, a, and b values under similar interval time done for a sample weighing. Four readings of L, a and b values were taken from four different positions on sample surface. Derived color attributes such as whiteness (Wt), chroma (Ch), hue angle (ϕ) and total color difference (ΔE) were calculated using Equation 1-4 [8, 9].

\[
\text{Whiteness (Wt)} = 100 - \left[100 - L^2 + a^2 + b^2 \right]^{1/2} \\
\text{Chroma (Ch)} = \left(a^2 + b^2 \right)^{1/2} \\
\text{Hue Angle (ϕ)} = \arctan \left(\frac{b}{a} \right) \\
\Delta E = \left[(L - L_o)^2 + (a - a_o)^2 + (b - b_o)^2 \right]^{1/2}
\]

where \(L_o, a_o\) and \(b_o\) represent the reading at time zero, and \(L, a\) and \(b\) represent the instant individual readings during drying process. All experiments were performed in three replicates.

2.3. Data analysis

The relationships between the okara color attributes and drying time were developed for different drying temperatures. The change of okara color was assumed to follow first–order reaction kinetics and expressed by Equation 5 [10, 11]. The kinetic of change for selected okara color attributes during drying were analyzed using exponential models listed in Table 1.

\[
CR = \frac{C}{C_0} = \exp(-kt)
\]

where \(C\) is a measured color attribute value based on \(L, a, b\) values (dimensionless) and \(C_0\) is a measured color attribute value when drying did not begin yet (\(t=0\)).

| Table 1. Exponential models selected for approximation. |
|-------------|----------------|
| No | Model | Name |
| 1 | \(CR = \exp(-kt)\) | Newton |
| 2 | \(CR = \exp(-kt^n)\) | Page |

The constant value of \(k\) and \(n\) were determined by nonlinear regression analysis using SPSS 14 software. The accuracy of the models in estimating experimental data was evaluated using \(R^2,\ RMSE\)
and P values as shown in Equation 6 to 8. The $R^2$ is a coefficient of determination that measures a goodness of fit, while a root mean square error (RMSE) shows a deviation between the experimental and estimated values. The P is the percentage error of estimated value by model in comparison to experimental value. The best fit of model should result in specifically the P value less than 10% [12].

$$R^2 = 1 - \frac{\sum_{i=1}^{N} (CR_{est,i} - CR_{obs,i})^2}{\sum_{i=1}^{N} (CR_{obs,i} - \bar{CR}_{obs})^2}$$  \hspace{1cm} (6)

$$RMSE = \left[ \frac{1}{N} \sum_{i=1}^{N} (CR_{est,i} - CR_{obs,i})^2 \right]^{1/2}$$  \hspace{1cm} (7)

$$P = \frac{100}{N} \sum_{i=1}^{N} \frac{|CR_{est,i} - CR_{obs,i}|}{CR_{obs,i}}$$  \hspace{1cm} (8)

3. Results and Discussion
The present experimental setup could dry okara from 82.5-83.7% to 2.5-3.8% moisture on wet basis for about 8-10 h depending upon drying temperatures. In general, the okara dried entirely during the falling rate period. It might be due to the highly porous nature of okara that make easy moisture transfer rate. The change of okara color during convective drying are theoretically almost always three-dimensional, but not all three dimensions may be of practical importance [11]. Therefore, the color change analysis in the present study was based on the simplified methods proposed by former researchers, as discussed in the followings

3.1. Color change characteristics
The L a and b values of okara obtained during drying experiment were represented in the forms of $L/L_o$, $a/a_o$ and $b/b_o$, where $L_o$, $a_o$ and $b_o$ indicated the values when the drying time was a zero. The relationship between these okara color parameters and drying time were shown in Figure 1 to 3. It is shown in Figure 1 that an increase in drying time and temperature decreased the $L/L_o$ values, causing a slight darker appearance on okara in comparison with the fresh conditions. The L values of dried okara degraded about 6.3-10.4% of its initial values. The highest change of L values was found for a sample dried at 115°C, while the lower changes were indicated by the samples dehydrated at 100 and 85°C, respectively. It was concluded that convective drying of okara at low drying temperature resulted in brighter color appearance, and thus produced the better product quality. This result was comparable to study that investigating the change of mango color due to drying process [13].

It is depicted in Figure 2 that the $a/a_o$ values of okara increased when the drying temperature and time increased. The present drying experiment tended to produce a redder look of okara color at the final drying process. It was confirmed that the longest duration of drying performed at 85°C revealed strongest effect in increasing redness of okara among the drying temperatures.
The lightness change of okara during drying at 85, 100, and 115°C

\[ \frac{L}{L_0} \]

**Figure 1.** The lightness change of okara during drying at 85, 100, and 115°C

The redness change of okara during drying at 85, 100, and 115°C

\[ \frac{a}{a_0} \]

**Figure 2.** The redness change of okara during drying at 85, 100, and 115°C

The decreased relative b values \( \frac{b}{b_0} \) of okara were observed while drying time and temperatures increased from 85 to 115°C as shown in Figure 3. It seemed that okara was experiencing a yellowness loss during convective drying process. This phenomenon together with an increase in redness \( a \) value was claimed to cause the degradation of the okara lightness that had been found in this study. This was in agreement with the result obtained by Marcel et al [14].

The yellowness change of okara during drying at 85, 100, and 115°C

\[ \frac{b}{b_0} \]

**Figure 3.** The yellowness change of okara during drying at 85, 100, and 115°C

The characteristics of derivative color attributes, i.e. whiteness, chroma, hue angle and total color difference, during drying of okara are presented in Figure 4 to 7. The whiteness decreased throughout the drying as indicated by decreasing the WI/WI₀ values and due to the drying time and temperatures. Figure 4 show that okara samples dried at drying temperatures from 85 to 115°C suffered the whiteness loss about 5.3-9.3% at the end of process. The relative chroma values \( \frac{Ch}{Ch_0} \) decreased during drying, suggesting the change of okara color intensity due to drying process as shown in Figure 5. An increase in temperature decreased significantly the chroma around 17.8-45.0% from an original condition. Changes in chroma values were determined predominantly by its redness and yellowness properties. The relative hue angle \( \frac{ϕ}{ϕ_0} \) was decreased due to an increase in drying time and temperatures. The use of higher drying temperature resulted in a lower ϕ value, indicating redder okara samples. Total color difference (ΔE) is parameter that frequently used to describe color variation in a test sample relative to a reference. The drying time and temperature used for drying okara was found...
significantly to affect the ΔE values. An increase in drying time and temperature from 0 to 8-10 h and from 85 to 115°C, respectively, increased the ΔE value. A higher ΔE values indicated a greater change on okara color [15]. Accordingly, it is shown in Figure 7 that the drying of okara at temperatures of 85°C produced the least discoloration in comparison with that of using 100 and 115°C.

Figure 5. The change of chroma of okara during drying at 85, 100, and 115°C

Figure 6. The change of hue angle of okara during drying at 85, 100, and 115°C

| Parameter | Model | T (°C) | Constants | RMSE (%) | P |
|-----------|-------|--------|-----------|----------|---|
| WI/WIo    | Newton 85 | 0.005 | 0.960 | 0.004 | 3.0 |
|           | 100 | -0.009 | 0.761 | 0.009 | 7.1 |
|           | 115 | 0.013 | 0.905 | 0.009 | 7.0 |
|           | Page 85 | 0.003 | 1.245 | 0.980 | 0.003 | 2.3 |
|           | 100 | 0.023 | 0.496 | 0.969 | 0.003 | 2.6 |
|           | 115 | 0.024 | 0.667 | 0.985 | 0.003 | 2.6 |
| Ch/ChIo   | Newton 85 | 0.024 | 0.919 | 0.031 | >10.0 |
|           | 100 | 0.053 | 0.980 | 0.026 | >10.0 |
|           | 115 | 0.075 | 0.959 | 0.048 | >10.0 |
|           | Page 85 | 0.059 | 0.451 | 0.999 | 0.011 | 9.2 |
|           | 100 | 0.058 | 0.957 | 0.981 | 0.026 | >10.0 |
|           | 115 | 0.147 | 0.600 | 0.984 | 0.030 | >10.0 |
| φ/φIo     | Newton 85 | 0.011 | 0.979 | 0.007 | 5.6 |
|           | 100 | 0.017 | 0.948 | 0.011 | 8.9 |
|           | 115 | 0.018 | 0.961 | 0.009 | 6.3 |
| 1-ΔE      | Newton 85 | 0.172 | 0.975 | 0.567 | >10.0 |
|           | 100 | 0.361 | 0.998 | 0.229 | >10.0 |
|           | 115 | 0.293 | 0.994 | 0.511 | >10.0 |
|           | Page 85 | 0.056 | 1.637 | 0.992 | 0.318 | >10.0 |
|           | 100 | 0.308 | 1.134 | 0.999 | 0.187 | >10.0 |
|           | 115 | 0.289 | 1.010 | 0.994 | 0.511 | >10.0 |
3.2. Effect of temperature on kinetics of color change

The kinetics of okara color degradation during drying process was evaluated in terms of whiteness (WI), chroma (Ch), hue angle (ϕ) and total color difference (ΔE). Nonlinear regression analysis of the models (Table 1) for selected color parameters in correlation with the drying time had resulted in the value of constants k and n as summarized in Table 2. The influence of drying temperatures on the constants value and accompanied by the respective R², RMSE and P values is shown in Table 2. It was confirmed that an increase in drying temperature increased generally the rate of okara color change as indicated by the k values for selected color parameters. The values of R² indicated a good fit for all models since they were more than 0.9. The Page’s model proved generally as the most fitted equation to the experimental CR data, as indicated by the higher R² and the lower RMSE and P values in comparison to the Newton’s model. However, it is not suggested definitely to use this model for estimating the change of total color difference (ΔE) since it revealed the P value greater than 10%.

![Figure 7. Total color difference of okara during drying at 85, 100, and 115℃](image)

The plots between the observed and the estimated of okara color change based on the Page’s model are presented in Figure 4 to 7. It is verified that a Page’s model were generally suitable in describing the okara color change during convective drying process. However, it is important to understand that application of such Page’s model allow design calculations within the range of temperatures varied in this work and for similar experimental setup.

4. Conclusion

Drying of okara at temperature of 85, 100 and 115℃ resulted in change of okara color. An increase in drying time and temperature decreased the lightness and yellowness but increased the redness appearance of okara. The Page’s model was in general better than Newton’s model in estimating experimental data of kinetics of color change. The information obtained in this works may be used as a rule for selecting the operating condition of drying to reduce the quality degradation of okara.

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