Effects of pre-drying treatments such as blanching and dipping (soaking) in a sucrose solution on browning of lemon peel during drying were investigated. A color analysis method using a digital camera and computer software based on the HSL color system was employed for determination of the degree of browning of lemon peels. Hue (H) value decreased as the browning increased. Other two parameters, saturation (S) and lightness (L), were not sensitive to the browning reaction monitoring. The browning rate was faster at the beginning of the drying and became slower when the water content became low. The pre-treatments resulted in less browning during drying. In order to examine the browning rate as a function of water content, the samples of different water contents were incubated in an airtight container (no water loss during incubation), and the H values were determined as a function of incubation time. The browning became faster when the water content was high. Sample pre-treatments such as blanching and dipping in a sucrose solution slowed down the browning rate compared with non-pre-treated samples. The browning during drying was significant when the air temperature was above 318K. The pre-drying treatments (blanching and soaking in a sucrose solution) resulted in much slower browning.

**Keywords:** lemon peel, hot air drying, water activity, browning, HSL color system

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**1. Introduction**

Lemon, one of citrus varieties, is a very popular fruit, which contains citric acid, vitamins, minerals, dietary fibers, sugars and anti-oxidants (polyphenols) [1]. Lemon fruits are processed into various commercial food products such as lemon peel as garnish for food and drinks, lemon powder, and lemon juice. As the shelf life of fruits such as lemon is quite short, it is needed to decrease the water content in order to reduce the water activity, \(a_w\) to a certain level where the deterioration and microbial growth rates become very low [2, 3]. Drying is commonly employed for reducing the water content of food [2, 3]. However, during drying, various unwanted chemical, bio-chemical and physical changes occur such as changes of color, loss of flavour and deterioration of nutritional values.

Among such critical quality attributes of fruits, the color of food surface is quite important as it is the first quality parameter evaluated by consumers [4, 5]. During drying, color degradation of fruits, called “browning” is caused by enzymatic and non-enzymatic reactions. Enzymatic browning can be prevented by inactivating enzymes with blanching and other thermal treatments. On the other hand, non-enzymatic browning reactions such as the Maillard reaction and oxidation reaction ascorbic acid and lipids [4] are not readily controlled. Especially, the Maillard reaction is a complex reaction, which includes several consecutive reaction steps. It has been shown that the browning reaction due to the Maillard reaction is a function of water content as well as temperature [3, 6]. In order to analyse the browning reaction quantitatively it is needed to use a method for evaluating the browning. Several methods have been developed for evaluating the browning such as colorimetric and spectrophotometric measurements. Quantification of hydroxymethylfurfural (HMF), an intermediate component in the Maillard reaction, is quite sensitive as HMF is the trigger for developing brown pigments [7]. However, it is laborious and time-consuming to quantify HMF of dried or semi-dried food products.

Methods using a digital camera and computer software have been successfully applied to evaluation of the surface color of foods or agricultural products [3, 8, 9]. They are non-destructive methods and easy to use. The RGB color information of an acquired digital image can be transformed into color components (hue, H and satura-
tion, S) and an illumination component (lightness, L). This method is quite useful as quantity of light as well as uneven lighting or uneven surface shape does not affect the H and S values. In addition, the data obtained by this method correspond to human interaction and perception [3, 8, 10]. In this study we employed this method for evaluation of the browning by using the software developed by Hashimoto and his group, who have been successfully applied this method to various different applications on agricultural and food product color evaluations [8, 9].

Pre-drying treatments such as blanching and dipping (soaking) in inorganic or organic solutions improve the quality of dried foods such as prevention of browning and uneven shrinkage. Blanching in hot water is usually applied for fruit and vegetables to increase drying rates and prevent browning [11]. Blanching helps the inactivation of enzymes such as polyphenoloxidases that cause browning, and phenolase, catalase and peroxidase that are responsible for off-flavors development. Unfortunately blanching cannot prevent shrinkage of final products. We have shown that addition of sugars such as sucrose, trehalose, maltodextrin, maltosyl-trehalose to sliced fruits and vegetables prior to drying is effective for preventing damages of tissue structures [12-14].

The purpose of this study is twofold: (a) to establish a simple and easy method for monitoring the browning reaction by using a digital camera image and (b) to examine the effects of pre-treatments (blanching and dipping in a sucrose solution) on browning of lemon peels during drying.

For the first purpose, the browning was evaluated based on the HSL values obtained from a digital camera image. For the second purpose, the following experiments were carried out. The desorption isotherms of lemon peel samples were determined by the static method. The drying experiments were carried out in a constant air temperature box [12-15]. The air in the box was completely mixed by two fans. The relative humidity (RH) was adjusted by silica gels (RH < 2%). A Testo 608-H2 (Newman Lane, UK) monitor was installed in the drying box, which can monitor RH from 2 to 98% (accuracy ± 2%). The air temperature was monitored by the thermometer. The sample was placed on an aluminium dish, which was hanged to an electronic balance placed on the drying box. In order to avoid direct contact of the sample with the aluminium dish surface, a silicon mesh sheet was placed on the dish. The solid mass of the sample (Ws) was measured by drying the sample at 378 K for 4 hours.

2.2 Drying experiment

Isothermal drying experiments were performed in a constant air temperature box [12-15]. The air in the box was completely mixed by two fans. The relative humidity (RH) was adjusted by silica gels (RH < 2%). A Testo 608-H2 (Newman Lane, UK) monitor was installed in the drying box, which can monitor RH from 2 to 98% (accuracy ± 2%). The air temperature was monitored by the thermometer. The sample was placed on an aluminium dish, which was hanged to an electronic balance placed on the drying box. The aluminium dish eliminates unwanted vibrations of the wire net cage by the hot air stream. In order to avoid direct contact of the sample with the aluminium dish surface, a silicon mesh sheet was placed on the dish. The solid mass of the sample (Ws) was measured by drying the sample at 378 K for 4 hours.

2.3 Isothermal incubation experiments

In order to adjust water contents of the sample for the incubation experiments, freeze or vacuum drying was performed by using a Freeze dryer (Eyela Freeze Dryer, FD-1000, Tokyo Rikakikai, Japan) for 0.5, 1, 2, 3, and 6 hours (trap temperature=223±1 K, chamber pressure=6.5±0.5 Pa). Lemon peel samples adjusted to designated water contents were contained in an air-tight glass container with a silicon stopper, covered with a plastic film and aluminium foil to avoid light. The container was incubated in a hot block bath (TPB-32, Toyo Seisakusho, Japan) at 333 K. The solid mass of the sample (Ws) was measured by drying the sample at 378 K for 4 hours.

2.4 Color analysis

Color images of the sample were captured by a digital camera (Ricoh R10, Ricoh, Tokyo, Japan) as a function of
Effects of Pre-Treatments on Browning of Lemon Peels during Drying

The experimental setup consisted of a digital camera with 7.1x optical wide zoom lens (Ricoh R10, Ricoh, Tokyo, Japan) and a tripod. We did not use a special light setting. Florescent lamps (color temperature=5200 K) were used, which were placed ca. 180 cm above the sample plane. The distance between the camera lens and the sample plane was set to be 8 cm. The sample was placed on a white drafting paper, so that the image background was white. The sample images were recorded as a JPEG format (3648×2736 pixels), and transferred to a PC for the color image processing. The images were then analyzed with a software developed by Hashimoto [8, 9]. The software requires that the background of image should be removed, the pixel size should be lower than 800×800 pixels and the image should be saved in Tiff format. These requirements were accomplished by using Adobe Photoshop CS. The digital image was transformed from the RGB coordinate system to the HSL coordinate system by the software. H value is defined as a color wheel chart, with red-purple at an angle of 0, yellow at π/2, bluish green at π and blue at 3π/2 rad. This software converts radian to digital value by multiplying (255/2π) [8, 9]. H value decreased as the browning score increased as shown in Figure 1, where the calculated H, S and L values along with RGB values for standard color samples are tabulated. The surface color of lemon peel changes from white-yellow to orange-brown, which corresponds to the change of H value from 44 to 24. Unfortunately, the samples in this study did not show significant changes of the S and L values (see Fig. 1). For lemon peel samples, three image data were obtained for one sample and the average H value was calculated.

2.5 Determination of desorption isotherm

Dried peel, lemon powder and lemon juice samples were stored in an airtight plastic container in the presence of salt solutions of known \( a_w \) values at 303 K. The samples were weighed every 24 hours until the weight loss became less than 2% per 12 hours [12-16].

The desorption isotherm data were fitted by the three parameter Guggenheim-Anderson-de Boer (GAB) model [6, 17, 18].

\[
X = \frac{C K W_m a_w}{(1 - K a_w)(1 - C K a_w)}
\]

(1)

\( W_m \) implies the water content equivalent to monolayer coverage. \( C \) and \( K \) are constants related to the binding energies. The three parameters were determined by fitting the experimental data to Eq. (1) with the aid of the fit function of GNUPlot (windows version, WGNUPlot 4.0). It uses the nonlinear least-squares (NLLS) Marquardt-Levenberg algorithm.

3. Results

3.1 Desorption isotherms

Desorption isotherms (lemon peel and lemon juice) are shown in Fig. 2. All isotherms showed a typical food isotherm shape, which can be described well by the GAB equation. The equilibrium water contents for lemon juice were higher compared with lemon peel and lemon powder for higher water activity regions. Lemon juice is quite hygroscopic compared with other lemon products [19].

3.2 Effects of pre-treatments on drying and on color changes during drying

The isothermal drying curves of lemon peels with and
without pre-treatments are shown in Fig. 3. Blanching is known to facilitate water removal as the cell structure is partially weakened, which permits easier migration of water. It may also cause starch gelatinization and inactivate polyphenoloxidases that lead to quality degradations. Further possibilities of blanching effects are the collapse of the cell, the decrease in turgor pressure, deformation of the cell walls and even plasmolysis [11, 20-22]. However, the presence of sugars in lemon peel resulted in low drying rates at the late stage of drying. This is due to slow drying rates of sucrose solutions [15].

Dipping in a sucrose solution decreased the initial water contents of lemon peel samples due to osmotic dehydration. The drying rates decreased after 3 hours. The final water content of lemon peel dipped in a sucrose solution was slightly higher compared with others.

It is a common practice to prepare a standard color chart for subjective/visual evaluation of agricultural and food products. Although objective digital methods are preferred, it is still useful to understand the relationship between the standard color chart and the values obtained from the digital image. As already shown in Fig. 1, the hue (H) value can present the browning quite precisely whereas the other two parameters, S and L values were not suitable for the present analysis.

As shown in Fig. 4, the H value decreased sharply at the beginning of drying, and then did not change appreciably with time especially for pre-treated samples. Similar trends were observed for the data obtained at drying temperature=303 K and 333 K. As expected, higher temperature accelerated the browning.

The H values at 6 hours are shown in Fig. 5. The pre-

treatment (blanching followed by dipping in a sucrose solution) was found to be very effective for better color retention during drying.
3.3 Effect of pre-treatments on color changes during incubation under constant water content conditions

In order to understand the effect of water content on color changes (browning), samples of different water contents were incubated for 24 hours. The samples adjusted to designated water contents were placed in an airtight container in order to avoid water loss during incubation. The H values as a function of incubation time are shown in Fig. 6. The H value decreased with incubation time. Figure 7 shows the H values after 6 hour incubation for different water contents. At low water contents the color of sample was found to be more stable. The decrease in H value for blanched and sucrose treated samples was much lower compared with that for non-treatment samples.

4. Discussion

Both consumers and food industry concern the surface color of food products although it is still difficult to connect the digitized surface color information to the food quality such as nutritional values quantitatively [5]. In this study a method using digital image captured by a digital camera was successfully applied to evaluating the browning reaction during drying and isothermal incubation of lemon peels. The main advantages in using a digital camera are non-destructive testing, easy to use protocol and non-expensive devices. This type of method is quite convenient and useful for checking agricultural products in the field [5, 8, 9]. It can also be employed as a tool for process analytical technology for food processes.

The present study has shown that the browning of lemon peel products occurs during thermal processing such as drying and the browning rate decreases with decreasing water content. Most chemical and biochemical reactions become very slow when the water content $X$ or the water activity $a_w$ becomes low [3, 6]. For example, enzyme inactivation rates become extremely low when $X < 0.2-0.3$ [23]. Therefore, once the sample water content decreases to such low values, enzymes are no more inactivated even when the sample temperature is high [23]. As for the browning reaction (the Maillard reaction), it is claimed that the rate is higher in the intermediate $a_w$. 

![Fig. 6](image1.png) Hue (H) values as a function of incubation time at 333 K. (Non-treatment)

![Fig. 7](image2.png) Hue (H) values at 6 hours during incubation experiments at 333 K.
regions [3, 6]. Our data has shown that the browning rate becomes lower with decreasing water content. Consequently, the $H$ value did not decrease significantly even during drying at 333 K. Rapid drying with low humidity air is recommended for obtaining dried lemon peels of good color retention.

Blanching is known to inactivate enzymes responsible for enzymatic browning. This can be confirmed by measuring peroxidase activity [24]. Blanching of lemon peels in boiling water for 1 minute completely inactivated peroxidase activity (data not shown). Therefore, enzymatic browning of blanched lemon peels was not expected during drying. Dipping of lemon peels in a sucrose solution resulted in uptake of sucrose. Enzymes or proteins become stable during drying in the presence of sucrose due to vitrification or water replacement [23]. Blanched sliced potatoes and carrots were dipped in a sucrose solution before drying. When samples prepared in this way were dried, irregular shrinkage was avoided and cell structure was well preserved [12, 13, 24]. Effect of sucrose on non-enzymatic browning is not well understood. In the present study a protective effect of sucrose against browning was not apparent. However, irregular shrinkage of lemon peels during drying was prevented in the presence of sucrose, which was observed for sliced carrots and potatoes in our previous study [12, 13, 14]. Blanching followed by dipping in a sucrose solution was found to be effective for preventing browning and shrinkage of lemon peels during drying.

Conclusions

Effects of blanching and dipping in a sucrose solution as pre-treatment methods of hot air drying of lemon peel on color retention (browning) were studied.

Digital image captured by a digital camera was processed to obtain the HSL values for color analysis. The browning was well evaluated by the $H$ value.

The decrease in $H$ value (browning) was larger when the water content and the temperature were high.

Dipping in a sugar solution after blanching and controlling water contents on drying can provide better product qualities of dried lemon peels.

Nomenclature

$H$ Hue value
$K$ GAB sorption constant related to multilayer properties
$W_{\text{m}}$ water content equivalent to a monolayer coverage kg-water/kg-dry solid
$W_s$ Mass of solid in the absence of water kg
$X$ water (moisture) content kg-water/kg-dry solid

REFERENCES

11) N. Leeratanarak, S. Devalastin, N. Chiewchan; Drying kinetics and quality of potato chips undergoing different drying


レモンピールの乾燥時の褐変に対する前処理の効果

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レモン製品は褐変しやすいことが知られており、乾燥中あるいは乾燥後の褐変速度を簡便に定量化することは重要である。レモンピールの褐変をデジタルカメラ画像から数値化し、褐変速度の含水率依存性を調べた。これらのデータを基に、乾燥前処理および乾燥条件がどのように褐変に影響を与えるかについて検討した。

市販のレモンの皮を剥き、2.5 cm×0.5 cmにカットした。乾燥前処理として次の2つの手法を行った。
【前処理1（ブランチング）】試料を沸騰水中で5分間煮沸。
【前処理2（糖溶液浸漬）】ブランチング処理した試料を40 wt% Sucrose溶液に10分間浸漬。一定温度、湿度（相対湿度RH<2%）に維持された密閉ボックス内に試料を入れ、対流伝熱により乾燥を行い、経時的に試料重量を測定し、含水率を算出した。

【一定含水率での加熱による褐変実験】試料を任意の含水率まで乾燥し、その後密閉容器に入れ、一定含水率を保ったまま333 Kで加熱した。
【デジタルカメラ画像からの色彩画像解析】デジタルカメラを用いて乾燥または褐変実験後のレモンピールを撮影し、HSL座標系における色彩画像解析を行った。褐変は色相（Hue）H値により数値化できた。他の彩度（Saturation）S、明度（Lightness）Lは有意な値を得ることができなかった。

乾燥実験は303, 318, 333 Kで除湿状態の乾燥ボックス中で行い、含水率およびH値を乾燥時間の関数として求めた。318 Kの乾燥において前処理1, 2は乾燥速度に大きな影響は与えなかった。乾燥時のHは乾燥初期に急激に減少し、その後、減少割合は緩やかとなった。とくに前処理2では、乾燥時間が1時間後はほぼ一定となり、高いH値、すなわち初期の色が保持された（褐変が抑制された）。乾燥6時間後のH値を303, 318, 333 Kについて比較したところ、乾燥温度が高くなるにつれH値が減少した（褐変が進行した）。どの温度においても前処理は褐変を抑制した。糖浸漬は乾燥製品の収縮抑制効果が高かった。

褐変速度の含水率依存性を調べるために、あらかじめ一定含水率に調整したサンプルを密閉容器に入れて、333 Kで保持し、H値を測定した。含水率が低いときは、H値は減少せず、褐変速度が著しく遅くなることが明らかとなった。333 Kで6時間保持したときのH値の前処理効果について比較したところ、低含水率における褐変の抑制に加えて、前処理が有効であることが示された。

結論としてレモンピールの乾燥時の褐変をデジタルカメラ画像からH値の減少として数値化して簡便に評価することができた。褐変は乾燥前処理、ブランチングと糖溶液浸漬処理により抑制された。一定含水率の褐変速度は低含水率で著しく遅くなることが明らかとなった。酵素の乾燥では、試料温度が高くなりないうちに低含水率にすると活性が保持される。同様に低温度の熱風により迅速に乾燥すると良好な色彩の乾燥レモンピールを製造できることが示唆された。

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