2013 4th International Conference on Food Engineering and Biotechnology
IPCBEE vol.50 (2013) © (2013) IACSIT Press, Singapore
DOI: 10.7763/IPCBEE. 2013. V50. 9

Effect of Blanching and Freeze-thaw Treatment on the Drying Rate and Electrical Impedance Characteristics of Carrots

Yasumasa Ando [1 +], Koichi Mizutani [2] and Naoto Wakatsuki [2]

[1] Graduate School of Systems and Information Engineering, University of Tsukuba
[2] Faculty of Engineering, Information and Systems, University of Tsukuba

Abstract. The objective of this study is to investigate the relationship between drying rate and physiological status of the blanched and frozen-thawed carrots. Electrical impedance spectroscopy was applied to measure electrical impedance characteristics as physiological status of the pretreated samples. Single exponential model was applied to describe moisture content changes during drying process. In the experimental results, drying rate constant k of the blanched and frozen-thawed samples were greater than that of control. Frozen-thawed sample had the highest values of k. Blanched samples showed higher values of k as the blanching temperature increases. The modified Hayden model which is an equivalent circuit model to represent plant cells was applied to describe impedance characteristics of each sample. Frozen-thawed sample took the significantly low value of R_e/R_i which is the parameter representing healthiness of the cell membranes. R_e/R_i of the blanched sample was lower as the blanching temperatures increases. In terms of the relationship between R_e/R_i and drying rate constant k, negative correlation between them was found. From these results, it was suggested that increase of drying rate is due to increase of the water permeability caused by injury of cell membranes.

Keywords: Electrical impedance spectroscopy, drying, blanching, freeze-thaw, carrot

1. Introduction

Agricultural products are rich in water and with a short shelf life, therefore, various kinds of processing has been performed since early times. Drying is a classical method of food preservation, which provides an extension of shelf-life, lighter weight for transportation, and less space for storage [1]. Although there are a lot of drying methods, hot air drying has been used as a simple and common drying method for vegetables or fruits [2]. Large amount of data has been reported in the literature on the drying properties of various products and it has been known that the drying rate generally decreases as drying progresses [3] and [4]. Therefore, energy efficiency and productivity would be improved if drying rate could be increased [5]. The effect of pretreatment on the drying rate of vegetables has been studied. Blanching is one of the most important steps of processing of vegetables. Although the main purpose of blanching is inactivation of enzymes which causes quality losses such as brownish discoloration, nutrient loss and etc., blanching is also effective in increasing the drying rate of vegetables such as avocado, potato, beets [6] and carrots [7]. Eshtiaghi *et al.* [8] and Dandamrongrak *et al.* [1] have reported that the freeze-thaw treatment before drying also increases the drying rate of several agricultural products. Nieto *et al.* [9] investigated drying characteristics of apples after blanching and suggested that the increase of drying rate of the blanched sample were caused from disruption of cell structure of the sample. However, their discussion was based on qualitative evaluation by structural observation. To analyze the relationship between the drying rate and the cell structure, further accumulation of quantitative data is necessary.

[+] Corresponding author. Tel.: +81-29-853-5468.
E-mail address: ando@aclab.esys.tsukuba.ac.jp.

Electrical impedance spectroscopy (EIS) has been used to measure electrical properties of solid material. EIS measuring is simple in principle and easy to be conducted [10]. Therefore, it has been used to estimate the physiological state of various biological tissues. EIS generally makes use of electrical equivalent circuits to characterize experimental frequency response of impedance. Among numerous equivalent models proposed for biological tissues, the Hayden model proposed by Hayden *et al.* [11] seems to be most popular. In the Hayden model, cellular structures, such as plasma membrane and cytoplasm, are represented by elements of a linear electrical equivalent circuit [12]. The Hayden model has widely been applied to the EIS analysis of various plant tissues and has provided a lot of useful physiological information such as cold injury [13], heat injury [14] and injury during drying [15]. In this paper, EIS was applied to understand the physiological status of the cells of the blanched and frozen-thawed carrots. In addition, effect of the degree of cell damage caused by pretreatment on the drying rate was investigated.

2. Material and Methods

2.1. Material

Carrot is widely cultivated in the world and often consumed as dried products. Thus we chose it as an experimental sample. Carrots were purchased from a local market and stored in refrigerated chamber at 10 ℃ before the experiment. The central part of each carrot was cut in a rectangle shape (25 mm × 30 mm × 20 mm).

2.2. Pretreatment

Blanching and freeze-thaw treatment were applied to the samples before drying. The procedures of each treatment are described as follows;

Blanching; Samples were blanched in water at 70, 80 and 100 ℃ for 5 min. Water temperature was controlled by using heater and controller with temperature sensor. Samples were immediately cooled in iced water for 20 min after blanching.

Freeze-thaw; Fresh sample wrapped in plastic film was frozen at -20 ℃ in an freezer for 12 h, thawed by soaking in water at 15 ℃ for 15 min, and chilled in iced water for 5 min.

Samples soaked in iced water for 20 min were used as control.

2.3. Procedure for drying

Samples were placed in the thermostatic chamber and dried at 60 ℃ for 10 h. Moisture content M (dry basis) of the drying sample was calculated using the following equation:

$$M = \frac{w}{W_d}, \quad (1)$$

where W_d is dry mass of the sample and w is the mass of water content of the sample. The mass of the drying sample was measured by a digital balance and changes of the mass during drying were considered as moisture changes. After the experiment, the samples were crushed by a mill, and the mass of dry matter of the sample was measured using the infrared drying moisture meter (MS-70, A&D) at 100 ℃ and for 30 min.

2.4. Mathematical model for the drying curves

The transport of water during the food dehydration process takes place predominately in the falling rate period [16]. To describe changes of moisture content in this period, various models based on the diffusion theory has been proposed. The single exponential model is incorporating a single drying rate constant for the combined effect of the various transport phenomena existing represented:

$$MR = \frac{M - M_e}{M_0 - M_e} = \exp(-kt). \quad (2)$$

Where MR is the moisture rate, M_e is the equilibrium moisture content, M_0 is the initial moisture content and k is the drying rate constant. The constant M_e and k are estimated by fitting eq. (2) to the experimental data using the method of least squares.

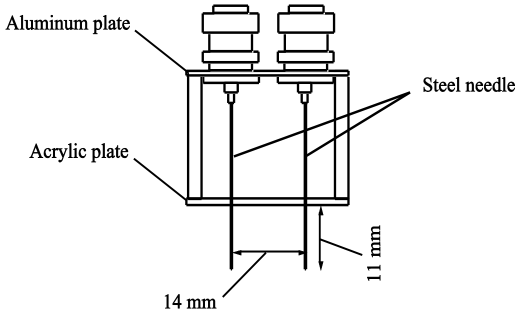

Fig. 1: Needle electrodes used for experiment.

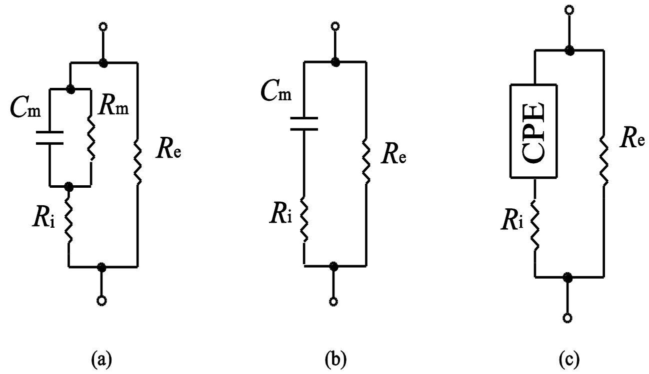

Fig. 2: Equivalent circuit models for cells of plants.

2.5. Impedance measurement

The impedance data of the samples were measured using an impedance analyzer (HP4194A, Hewlett-Packard) with needle electrodes made of steel (Fig. 1). The electrodes are connected to the impedance analyzer with coaxial cables by means of the four terminal pair configuration. During drying process, the impedance magnitude $|Z|$ and phase angle θ were measured at 81 points (logarithmic frequency intervals) over the frequency ranging from 100 Hz to 10 MHz and automatically recorded by a computer for analysis.

2.6. Equivalent circuit models and curve-fitting

The resistance R (Ω) and reactance X (Ω) were calculated from the equation below:

$$R = |Z|\cos\theta, \tag{3}$$

$$X = |Z|\sin\theta. \tag{4}$$

The relationships between the R and X of the complex impedance are known as Cole-Cole plot [17]. For the biological tissue, Cole-Cole plot was described as a circular arc. Model (a): Hayden model, for plant tissues shown in Fig. 2 takes account of the intracellular resistance R_i, extracellular resistance R_e and the resistance and capacitance of cell membrane R_m and C_m. We can assume that the membrane resistance R_m could be neglected because of its large resistance. Thus the Hayden model could be simplified into model (b): the simplified Hayden model. This model represents the structure of one cell and describes an exact semicircle as a Cole-Cole plot. However, tissues composed of many cells produce time constant distribution, therefore, Cole-Cole plot is described as a distorted semicircle in a vertical direction. In order to model this distorted semicircle, we introduce constant phase element (CPE) [18] instead of C_m (The modified model (Model (c) shown in Fig. 2)). The impedance of CPE Z_{CPE} is calculated by the equation below:

$$Z_{\mathrm{CPE}} = \frac{1}{(j\omega)^p T}, \tag{5}$$

where j is the imaginary unit, ω is the angular frequency, T is the CPE constant and p is the CPE exponent. p is a factor within the range of 0 through 1 which describes the time constant distribution in the system. In this study, modified model was applied for the carrot tissue samples. The parameters of the equivalent circuits were estimated with complex non-linear least squares curve-fitting [19].

3. Results and Discussion

The moisture content was plotted versus drying time for the control and each pretreated samples in Fig. 3. Solid lines in Fig. 3 represent approximated values derived from eq. (2). Both blanching and freeze-thaw treatment has found to be effective to decrease moisture content. However, focusing on the rate of moisture transport, freeze-thaw treatment showed the significant effect than blanching. The estimated value of each parameter in eq. (2) and residual sum of squares (RSS) between experimental and approximated values were shown in Table 1. The values of RSS were up to 0.88. Drying rate constant k of the blanched and frozen-thawed samples were greater than that of control. Frozen-thawed sample had the highest values of k and this result shows freeze-thaw treatment before drying is quite effective in removing water content. Blanched samples showed a higher drying rate constant as blanching temperatures increases.

The Cole-Cole plot of the pretreated samples and control were shown in Fig. 4. Impedance arc of the control was observed clearly while those of blanched and frozen-thawed sample were significantly shrank or almost disappeared. This phenomenon occurs when cell membrane were injured [20]. The shape of the impedance arc is quantified by equivalent circuit analysis. The parameters of the equivalent circuit model were shown in Table 2. The most significant aspect of these parameters is the values of R_e and R_i. In normal cells, intracellular fluid with high concentration of electrolyte and extracellular fluid with low concentration of electrolyte are divided by cell membrane. When cell membranes are injured, intracellular fluid leaked to outside of cells. As a result, the values of R_e and R_i are approaching to the same value. Therefore, the ratio of

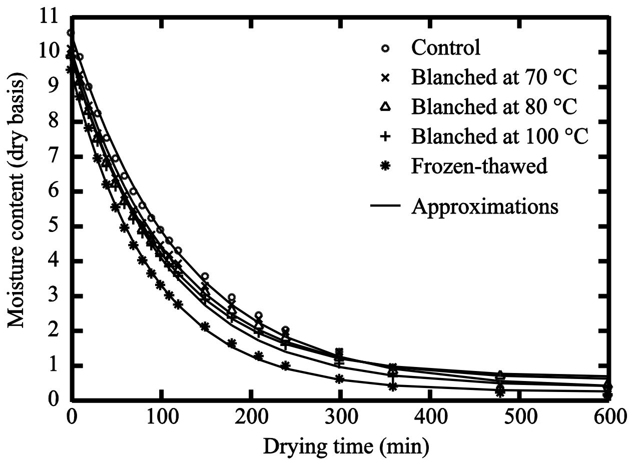

Fig. 3: Temporal changes of the moisture content.

Table 1: Parameters of the single exponential model.

Pretreatment	k	M_e	M_0	RSS
Control	0.00804	0.31	10.5	0.50
Blanched at 70 °C	0.00896	0.55	10.1	0.88
Blanched at 80 °C	0.00933	0.35	9.9	0.47
Blanched at 100 °C	0.00946	0.63	9.9	0.42
Frozen-thawed	0.01090	0.21	9.5	0.13

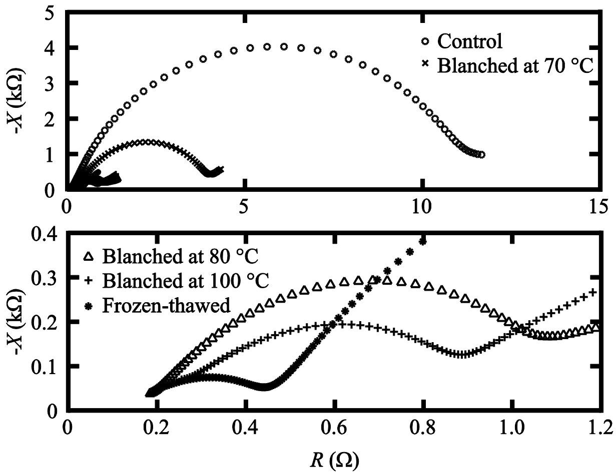

Fig. 4: Cole-Cole plot of the pretreated samples,
lower figure represents magnified view of the upper figure.

Table 2: Parameters of the modified Hayden model.

Pretreatment	Equivalent circuit parameters				R_e / R_i
	T (nF $s^{(p-1)}$)	p	R_e (Ω)	R_i (Ω)	
Control	54.8	0.73	10541	185	59.8
Blanched at 70 °C	85.4	0.70	3922	323	12.5
Blanched at 80 °C	738.5	0.56	1108	164	6.6
Blanched at 100 °C	548.4	0.55	787	203	3.8
Frozen-thawed	2570.4	0.47	462	190	2.5

the values of R_e to R_i could be an index of the healthiness of the cells. From Table 2, frozen-thawed sample took the significantly low values of R_e/R_i due to injury of cell membrane caused by formation of ice crystals around cells. R_e/R_i of the blanched sample was lower as the blanching temperature increases. Injury of Cell membrane of plants start at around 50 ℃ [15]and[21]. Therefore, it was suggested that the injury of cell membranes of the blanched samples were caused by exposing to high temperature conditions.

In terms of the relationship between drying rate constant k and R_e/R_i, the damage of cell membrane became greater (the lower values of R_e/R_i) as the values of k increase. From these results, it was suggested that injury of cell membrane caused by blanching and freeze-thaw treatment involved the drying rate. Dick [22] found that injured cells show higher water permeability. Thus, it was suggested that injury of cell membrane caused by pretreatment increased the water permeability of cell membranes and has resulted in an increase of the drying rate.

4. Conclusions

The effect of cell membrane damage caused by blanching and freeze-thaw treatment on the drying rate of vegetables was investigated. In the experimental results, the drying rate constant k tended to increase as R_e/R_i decreased. From this result, it was suggested that the injury of the cell membrane was involved to increase the drying rate. However, blanched sample showed linear relationship between drying rate constant and R_e/R_i while the drying rate constant of frozen-thawed sample was significantly high value. Since this result indicates that there could be factors other than injury of the cell membranes to increase the drying rate, detailed consideration of the other factors should be done in the future.

5. Acknowledgment

This work was supported by JSPS KAKENHI [Grant-in-Aid for JSPS Fellows, 241232].

6. References

[1] R. Dandamrongrak, G. Young, and R Mason. Evaluation of various pre-treatments for the dehydration of banana and selection of suitable drying models. *Journal of Food Engineering.* 2002, **55**: 139-146.

[2] T. Orikasa, L. Wu, T. Shiina, A. Tagawa. Drying characteristics of kiwifruit during hot air drying. *Journal of Food Engineering.* 2008, **85**: 303-308.

[3] A. Maskan, S. Kaya, and M. Maskan. Hot air and sun drying of grape leather (pestil). *Journal of Food Engineering.* 2002, **54**: 81-88.

[4] S. J. Babalis, E. Papanicolaou, N. Kyriakis, V. G. Belessiotis. Rvaluation of thin-layer drying models for describing drying kinetics of figs (*Ficus carica*). *Journal of Food Engineering.* 2006, **75**: 205-214.

[5] R. Dandamrongrak, and R. Mason G. Young. The effect of pretreatments on the drying rate and quality of dried bananas. *International Journal of Food Science and Technology.* 2003, **38**: 877-882.

[6] S. M. Alzamora and J. Chirife. Some factors controlling the kinetics of moisture movement during avocado dehydration. *Joural of Food Science*. 1980, **45**: 1649-1651.

[7] G. Mazza. Dehydration of carrots. Effect of pre-drying treatments on moisture transport and product quality. *International Journal of Food Science and Technology*. 1983, **18**: 113-123.

[8] M.N.Eshtiaghi, R. Stute, and D. Knorr. High-pressure and freezing pretreatment effects on drying, rehydration, texture and color of green beans, carrots and potatoes. *Journal of Food Science*. 1994, **59**: 1168-1170.

[9] A. Nieto, D. Salvatori, M. A. Castro, and S. M. Alzamora. Air drying behavior of apples as affected by blanching and glucose impregnation. *Journal of Food Engineering*. 1998, **36**: 63-79.

[10] L. Wu, Y. Ogawa, A. Tagawa. Electrical impedance spectroscopy analysis of eggplant pulp and effects of drying and freezing-thawing treatments on its impedance characteristics. *Journal of Food Engineering*. 2008, **87**: 274-280.

[11] R. I. Hayden, C. A. Moyse, F. W. Calder, D. P. Crawford, and D. S. Fensom. Electrical impedance studies on potato and alfalfa tissue. *Journal of Experimental Botany*. 1969, **20**: 177-200.

[12] M. I. N. Zhang and J. H. M. Willison. Electrical impedance analysis in plant tissues: a double shell model. *Journal of Experimental Botany*. 1991, **42**: 1465-1475.

[13] D. R. Cooley and D. R. Evert. Normalized electrical impedance evaluates cold injury to stem sections of ‘Delicious’ apple. *Journal of the American Society for Horticultural Science*. 1979, **104**: 561-563.

[14] M. I. N. Zhang, J. H. M. Willison, M. A. Cox, and S. A. Hall. Measurement of heat injury in plant tissue by using electrical impedance analysis. *Canadian Journal of Botany*. 1993, **71**: 1605-1611.

[15] Y. Ando, K. Mizutani, and N. Wakatsuki. Electrical impedance analysis of potato tissues during drying process. *2012 IFT Annual Meeting Technical Program Abstracts*. 2012, pp. 75-76.

[16] Y. I. Sharaf-Eldeen, J. L. Blaisdell, and M. Y. Hamdy, A model for ear corn drying. *Transactions of the ASABE*. 1980, **23**: 1261-1265.

[17] K. S. Cole. Electric phase angle of cell membranes. *The Journal of General Physiology*. 1932, **15**: 641-649.

[18] K. S. Cole, and R. H. Cole. Dispersion and absorption in dielectrics. *Journal of Chemical Physics*. 1941, **9**: 341-351.

[19] J. R. Macdonald. Impedance spectroscopy. *Annals of Biomedical Engineering*. **20**, 1992: 289-305.

[20] T. Repo, M. I. N. Zhang, A. Ryyppo, E. Vapaavuori, and S. Sutinen. Effects of freeze-thaw injury on parameters of distributed electrical circuits of stems and needles of scots pine seedlings at different stages of acclimation. *Journal of Experimental Botany*. 1994, **45**: 823-833.

[21] J. R. Martineau, J. E. Specht, J. H. Williams, and C. Y. Sullivan. Temperature tolerance in soy beans. I. Evaluation of a technique for assessing cellular membrane thermostability. *Crop Science*. **19**, 1979: 75-78.

[22] D. A. T. Dick. Water movement in cells. In: E. E. Bittar. *Membranes and ion transport*. London: Wiley Interscience. 1970.