CROATICA CHEMICA ACTA
CCACAA **81** (2) 325–331 (2008)

ISSN-0011-1643
*CCA*-3248
*Original Scientific Paper*

# Dehydration of Celery by Infrared Drying

**Damir Ježek,[a,*] Branko Tripalo,[a] Mladen Brnčić,[a] Damir Karlović,[a] Suzana Rimac Brnčić,[a] Dražen Vikić-Topić,[b] and Sven Karlović[a]**

[a]*Faculty of Food Technology and Biotechnology, University of Zagreb, Pierottijeva 6, 10000 Zagreb, Croatia*

[b]*Ruđer Bošković Institute, Bijenička 54, 10000 Zagreb, Croatia*

RECEIVED OCTOBER 19, 2007; REVISED MARCH 31, 2008; ACCEPTED APRIL 1, 2008

*Keywords*
dehydration
celery
diffusion coefficient
infrared drying

In this work kinetics of dehydration process was investigated according to dehydration temperature changes, samples dimensions and technological treatment of samples. Investigations were conducted at two working temperatures: 50 °C and 75 °C. Samples were cut into $5\times5\times5$ mm cubes and $20\times5\times1$ mm gratings. Tests were carried out on fresh and blanched samples. Celery samples dehydration was performed in a laboratory infrared dryer (DIR) Mettler LJ16 (Mettler, Switzerland). Sample mass changes were followed during dehydration. For all process conditions (dehydration temperature, sample dimensions and technological treatment), the mass content of dry matter in samples, moisture content, diffusion coefficient and dehydration rate were determined. Diffusion coefficient was the highest for celery gratings at temperature of 75 °C – $2.38\times10^{-6}$ m$^2$ min$^{-1}$, and the lowest for celery cubes at temperature of 50 °C – $1.4\times10^{-6}$ m$^2$ min$^{-1}$.

## INTRODUCTION

Determination of moisture content has a great importance in quality control of foodstuffs because the amount of water has significant influence on their physical, chemical and nutritive characteristics, and on various manufacturing processes.[1,2]

Average water contents in foodstuffs vary from 0.05–97 %. Typical composition of 100 g of celery comprises 87.3 grams of water, 1.1 grams of proteins, 0.2 g of fats, 4.3 grams of ash, 7 mg of vitamin C.[1,3]

Celery (*Apium graveolens*) contains a significant amount of essential oils and is recognized as a healthy plant and spice. Healthy substances in celery are its vitamins and mineral salts, essential oils with different terpenes and limonenes such as *p*-cimol, α-santalol, α-limonen and β-pinen.[4,5]

Eatable parts of celery include the aromatic meat of its callous celeriac and aromatic leaf.[3]

Volatile components can be removed from materials by drying.[6] This usually refers to water, which has very weak bonds with material, which bonds can be very easily broken during drying at the usual temperatures of drying (120 °C).[7,8]

Drying processes of moisturized materials are connected with the basic physical rule of mass and heat transfer (moisture) in capillary-porosity materials, but also with the method of material preparation.[9] Increasing usage of drying procedures within various technological

* Author to whom correspondence should be addressed. (E-mail: djezek@pbf.hr)

lines in the food industry and biotechnology has made studies of the drying process of important practical interest. On the other hand, the mechanism of heat and mass transfer itself in capillary-porosity materials is very complex and still insufficiently defined, and therefore its studying is of great theoretical and practical importance and interest.[8]

The mechanism and kinetics of dehydration are evaluated on the basis of the dehydration curve and the dehydration rate curve.

At the beginning of drying, the temperature of material rises while the content of moisture in the material remains unchanged. This material heating lasts a short time and the material is heated to the point of cool-down temperature (wet thermometer temperature).

Drying rate in the period of decreasing rate is directly proportional to the content of free moisture.[10]

Determination of the content and amount of dry matter in foodstuffs provides a quality and nutritive evaluation of foodstuffs. Through the content of dry matter and water, chemical composition of foodstuffs can be expressed and it gives a direct insight into the physical, mechanical, chemical and microbiological stability of food products.[11]

Various properties of food materials (color, taste, aroma, vitamin composition, microbiological activity, enzyme properties) depend on these activities, because these activities enable selection of the best technological procedure to be applied in the processes of drying and processing.[12]

## EXPERIMENTAL

### *Material*

Celeriac was purchased on the local market. At the beginning of drying, the moisture content of fresh celery was approximately 80 %.

### *Methods*

The experiment was conducted using two procedures:

*First procedure:* In first procedure, fresh celery samples were dried. Celeriac was cut into 5×5×5 mm cubes and 20×5×1 mm gratings. 2 g of each sample was scaled, disposed over the complete surface of an aluminum dish and dried in an infrared dryer LP16 (Mettler Company) provided with a scale. DIR works on the principle of electromagnetic radiation in the domain of middle-waves to short-waves of infrared radiation, with the wave length between 2 mm and 3.5 mm. Moisture content and temperature parameters were determined directly and sensed on the display of the device. Drying was carried out at two operational temperatures: 50 °C and 75 °C.

*Second procedure:* In the second procedure, blanched celery samples were dried. Celeriac was cut into 5×5×5 mm cubes and 20×5×1 mm gratings. Samples were then blanched in 1 % solution of citric acid at 75 °C for 4 minutes. Of the obtained squashed and blanched celery samples, the amount of 2 grams was scaled and dried in the infrared dryer at temperature of 50 °C and 75 °C until constant mass.

Dehydration kinetics was monitored on the display of the device during the entire process observing the sample mass within a particular time interval. After each three minutes, the status of the sample mass was expressed, *i.e.*, its current value in grams was presented on the display. The process lasted until the mass change of the sample was stabilized at a constant value, regardless of further drying duration.

### *Calculations*

Estimation of drying curves may be done using analytical functions $X = f(t)$ and $(-\mathrm{d}X / \mathrm{d}t) = g(t)$, which fulfill the following conditions:[13]

$$X(t) > 0,\ t \in [0, t_{eq})$$

$X(t)$ is a monotonously decreasing function at interval $[0, t_{eq})$.

$$X(t) \to X_{eq} \text{ for } t \to t_{eq}$$

$$(-\mathrm{d}X(0)/\mathrm{d}t) = 0$$

$$(-\mathrm{d}X(t)/\mathrm{d}t) > 0 \text{ for } t \in [0, t_{eq})$$

$$(-\mathrm{d}X(t)/\mathrm{d}t) \to 0 \text{ for } t \to t_{eq}$$

$t_{eq}$ is the time required for the sample to reach balanced state equilibrium $X_{eq}$.

The mathematical form of the function satisfying the above conditions is as follows:

a) for time-dependent change in the moisture content:

$$X(t) = X_0 e^{-bt^{d}} \tag{1}$$

b) for time-dependent drying rate:

$$(-\mathrm{d}X / \mathrm{d}t) = b \cdot d \cdot t^{(d-1)} \cdot X(t) \tag{2}$$

Parameters $b$ and $d$ in the model are determined by regression analysis by the least-squares method, *i.e.,* function minimization:

$$S(a,b,d) = \sum_{i=1}^{n} (X_0 - X_{eq}) \cdot \exp(-b \cdot t^{d}) - X_{eq}) - X_i)^2 \tag{3}$$

$S(b,d)$ is the sum of squares of $X(t)$ deviation from experimental results, $X_o$ / $\mathrm{kg_w\ kg_{w.s.}^{-1}}$, is the initial moisture content (for $t = 0$, $X(0) = a$) in drying.

Total moisture from the material can be eliminated by infrared drying, in which case $X_{eq} = 0$ and $b,d$ are parameters dependent on the dryer geometry and drying conditions.

The obtained values of moisture content and drying rate enabled calculation of the diffusion coefficient by the expression:[13]

$$\frac{dX}{dt} = \frac{\pi^2 \cdot D \cdot (X - X_{eq})}{h^2} \quad (4)$$

where $D$ is the diffusion coefficient expressed in $m^2 \ min^{-1}$, and $h$ is the characteristics dimension of samples in m.

## RESULTS AND DISCUSSION

Tables I and II show the values of estimated model parameters *(b, d)* for celery samples, where *r* and *s* denote the coefficient of correlation and standard deviation, respectively.

On the basis of the values for dehydration time and diffusion coefficient obtained by calculations, diagrams of dehydration rate *vs*. coefficient of diffusion and drying time are presented in the way this was already demonstrated in some previous works.[14,15]

Figures 1 and 2 show experimental data of moisture content and drying time for non-blanched and blanched cube samples of celery, dried at 50 °C and 75 °C, and for non-blanched and blanched samples of celery gratings, also dried at 50 °C and 75 °C, respectively.

Figures 3, 4, 5 and 6 illustrate the dependence of the coefficient of diffusion on drying time at two different temperatures.

TABLE I. Estimated model parameters *(b, d)* for celery samples (cubes and gratings) dried at 50 °C, with and without blanching[(a)]

| SAMPLES | *b* | *d* | *r* | *s* |
|---|---|---|---|---|
| cubes (5 mm) | 0.010 | 1.201 | 0.993 | 0.027 |
| blanched cubes (5 mm) | 0.008 | 1.184 | 0.991 | 0.044 |
| gratings (20 × 5 × 1 mm) | 0.010 | 1.201 | 0.993 | 0.027 |
| blanched gratings (20 × 5 × 1 mm) | 0.009 | 1.176 | 0.991 | 0.044 |

[(a)] *b* – coefficient of two-parameter model; *d* – coefficient of two-parameter model; *r* – coefficient of correlation; *s* – standard deviation.

TABLE II. Estimated model parameters *(b,d)* for celery samples (cubes and gratings) dried at 75 °C, with and without blanching[(a)]

| SAMPLES | *b* | *d* | *r* | *s* |
|---|---|---|---|---|
| cubes (5 mm) | 0.015 | 1.306 | 0.990 | 0.044 |
| blanched cubes (5 mm) | 0.011 | 1.323 | 0.994 | 0.042 |
| gratings (20 × 5 × 1 mm) | 0.015 | 1.306 | 0.990 | 0.044 |
| blanched gratings (20 × 5 × 1 mm) | 0.011 | 1.323 | 0.994 | 0.042 |

[(a)] *b* – coefficient of two-parameter model; *d* – coefficient of two-parameter model; *r* – coefficient of correlation; *s* – standard deviation.

In each figure, two curves are presented for the samples of the same dimension, within the same time interval but at different temperatures. Thus the figures directly show the difference in the curve regarding the applied dehydration temperature.

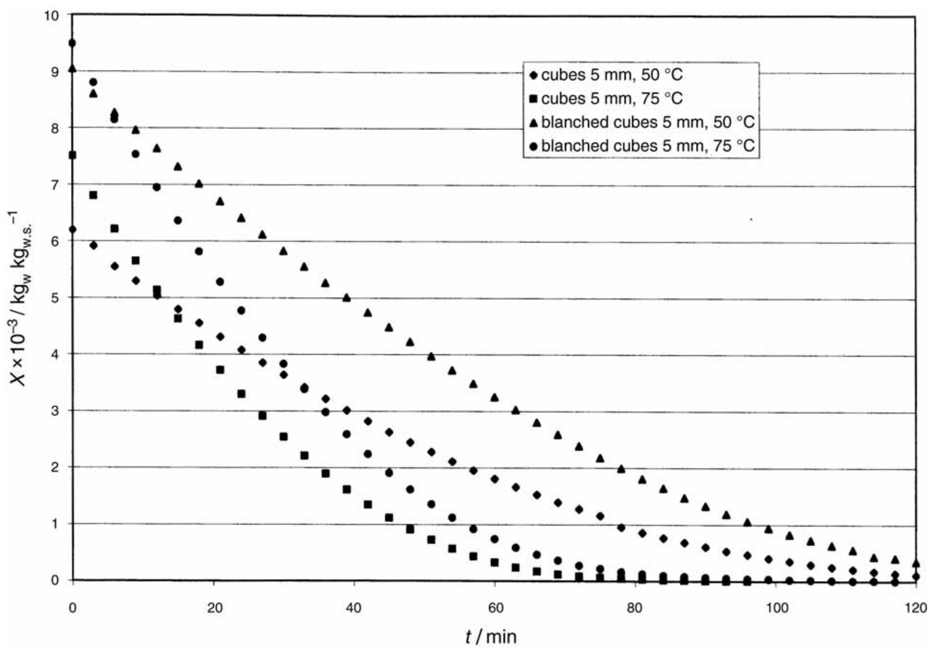


Figure 1. Experimental data of moisture content and drying time (for 5 × 5 × 5 mm cubes and blanched cubes of celery dried at 50 °C and 75 °C).

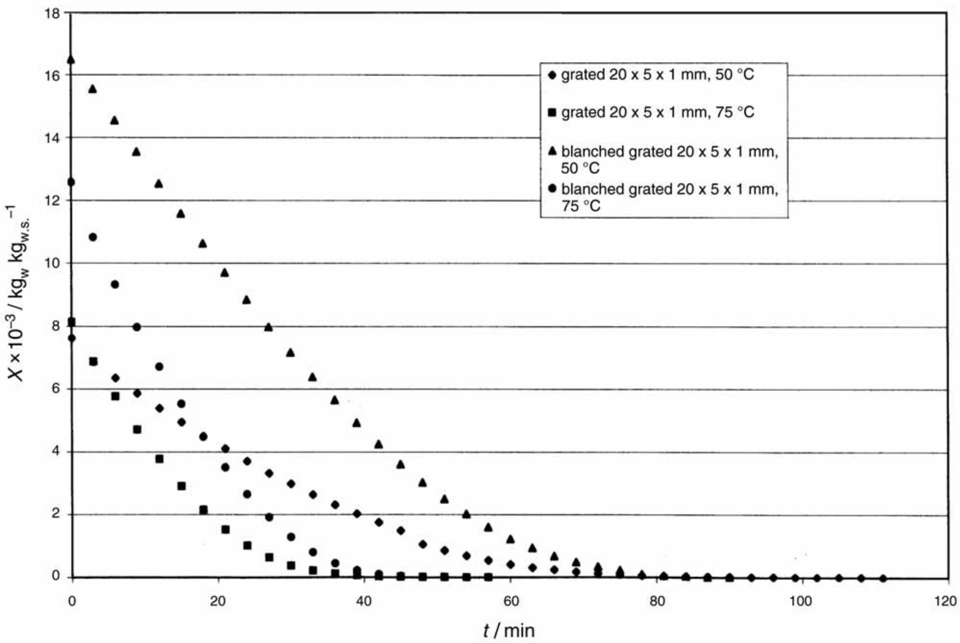


Figure 2. Experimental data of moisture content and drying time (for 20 × 5 × 1mm gratings and blanched gratings of celery, dried at 50 °C and 75 °C).

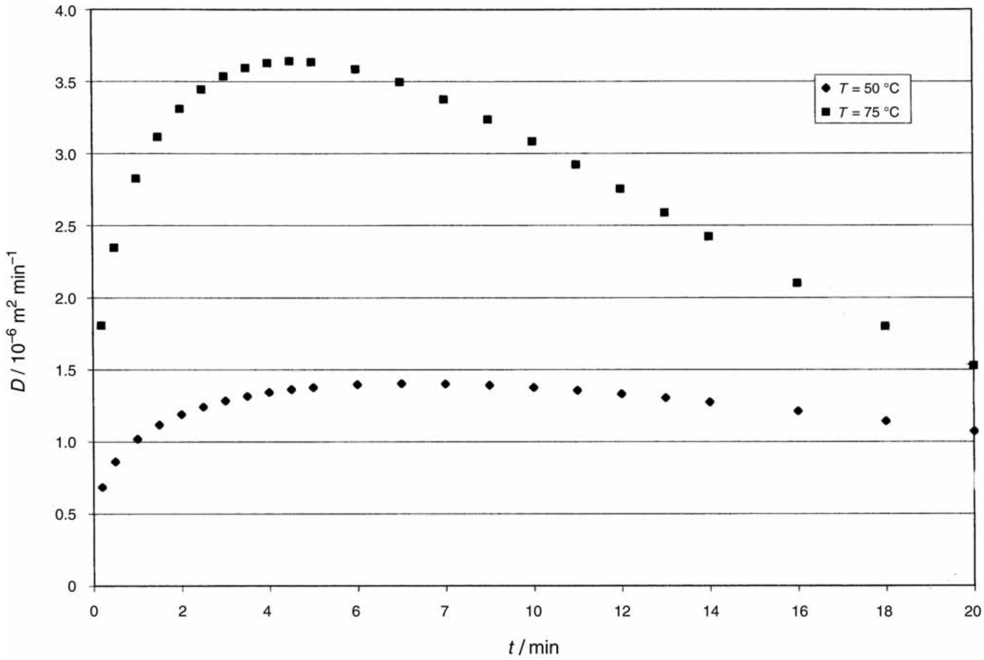


Figure 3. Dependence of diffusion coefficient on drying time (cubes of celery, 5 mm, dried at 50 °C and 75 °C).

Diffusion coefficient increased with time until critical moisture was achieved, then stagnated briefly, and after that decreased proportionally with the decreasing moisture content in the material.[16]

Diffusion coefficient increased more under higher working temperature (75 °C) than under lower temperature (50 °C) for the same sample (cubes in Figure 3, gratings in Figure 6), and it had a higher value for celery gratings at 75 °C – $2.38 \times 10^{-6}$ $m^2$ $min^{-1}$. Also, the diffusion coefficient was lower for celery cubes at 50 °C – $1.4 \times 10^{-6}$ $m^2$ $min^{-1}$.

Blanched samples reached higher diffusion coefficient values than fresh samples, while grated samples had lower diffusion coefficient values than cube samples at the same temperature. Blanched samples of gratings had a higher contact surface than cubes.

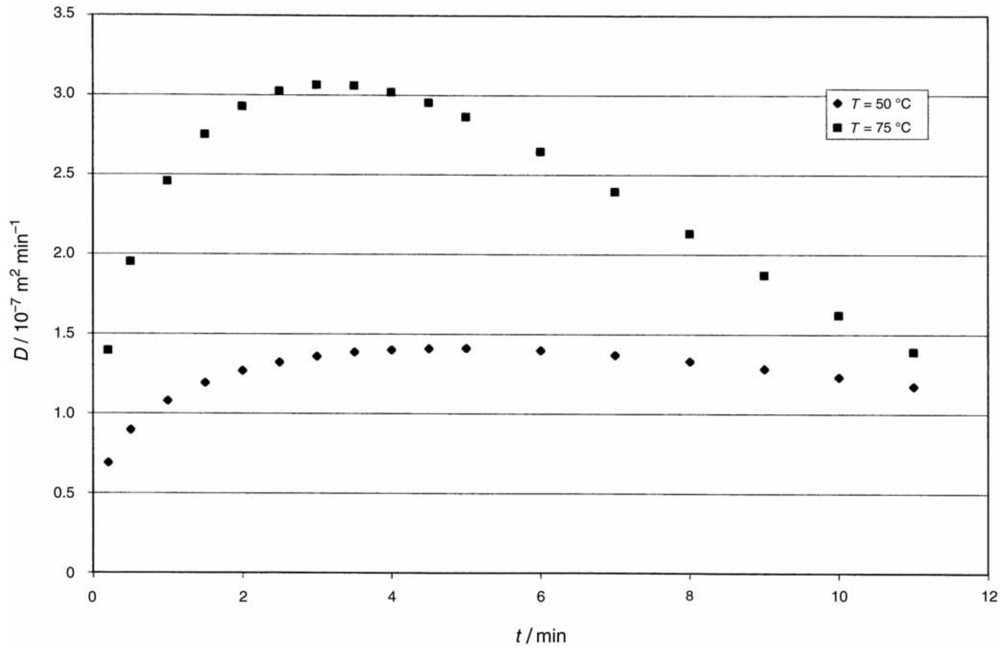


Figure 4. Dependence of diffusion coefficient on drying time (gratings of celery, 20 × 5 × 1 mm, dried at 50 °C and 75 °C).

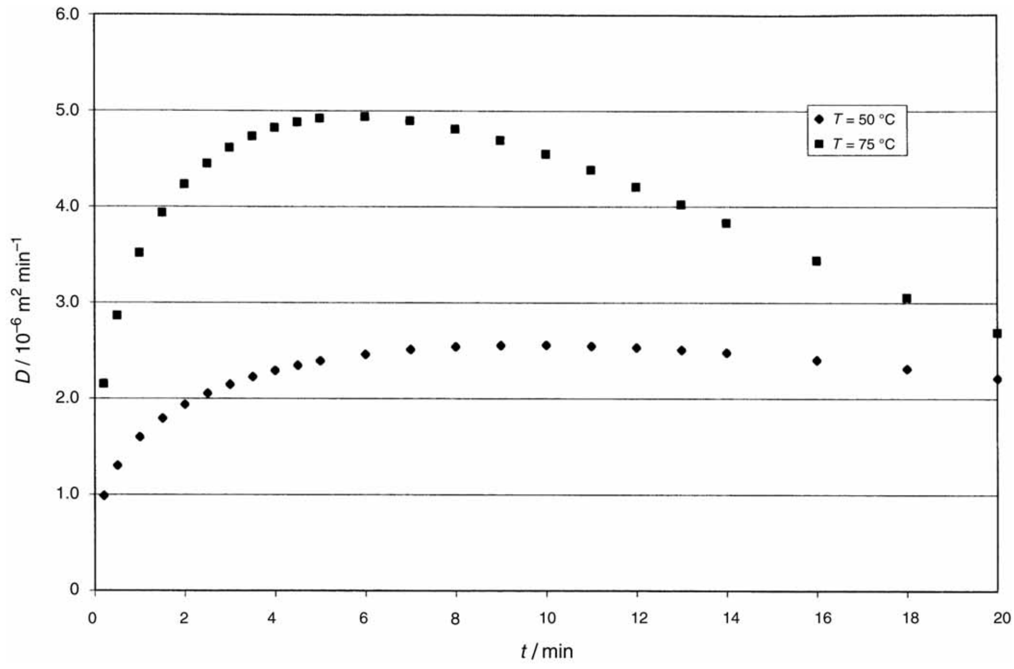


Figure 5. Dependence of diffusion coefficient on drying time (blanched cubes of celery, 5 mm, dried at 50 °C and 75 °C).

Figures 5 and 6 show the curves for diffusion coefficient dependence on time for blanched cubes and blanched gratings at two working temperatures.

Diffusion coefficient increased most slowly for blanched cubed samples at 50 °C, and they took 9 minutes to reach the maximum value $-2.56 \times 10^{-6}$ m$^2$ min$^{-1}$ (Figure 6). The fastest increase of diffusion coefficient was achieved with celery gratings at 75 °C, and the maximum was reached in 3 minutes and amounted to $0.3 \times 10^{-6}$ m$^2$ min$^{-1}$ (Figure 4).

When critical moisture was reached, the dehydration rate depended on the moisture diffusion rate throughout the sample.

Dehydration rate had higher values in blanched samples than in fresh samples, and also higher values were achieved with blanched gratings than with blanched cubes

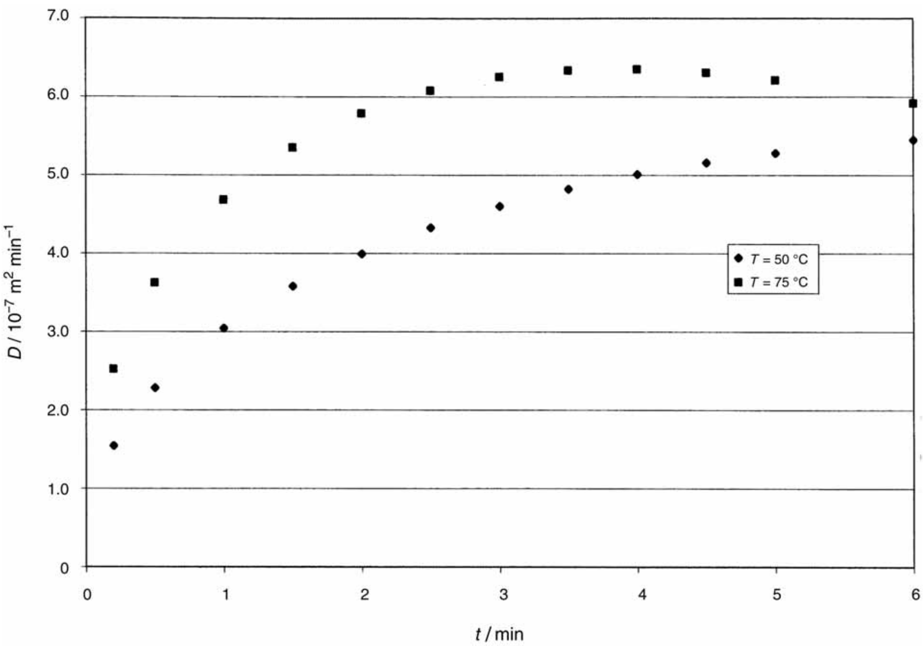


Figure 6. Dependence of diffusion coefficient on drying time (blanched gratings of celery, 20 × 5 × 1 mm, dried at 50 °C and 75 °C).

(sample shapes). Maximum time values were achieved in fresh samples before in blanched samples, but the empirical value of the maximum rate was higher for blanched samples.

Samples were cooked during blanching, which led to certain changes in sample structure and partial release of tied water which was not able to evaporate in the same fresh sample. This resulted in an increase of the amount of free water in the sample as well as an increase of the dehydration rate for its removal.[16,17]

The cubes had a smaller surface area than the gratings, which led to slow water evaporation from their surfaces than from the surfaces of gratings. Thickness of the samples is also very important because it influences the diffusion rate of moisture from sample inside to its surface.[18] As the sample was thicker, in this particular case cubes, the diffusion rate, *i.e.*, the evaporation rate from its surface was slower. In the case of gratings, the diffusion rate was increased because celery gratings were less thick than celery cubes. Diffusion coefficients evaluated by mathematical equations have showed that the size of the sample is important for the moisture diffusion rate from the sample.

## CONCLUSIONS

The results of measurements and calculated data, shown graphically, point to the following conclusions:

a) Duration of the dehydration process depends on the content of volatile components in celery samples, *i.e.*, the higher is the amount of these components (free moisture), the longer would be the time for their removal.

b) Dehydration at higher temperatures (75 °C) decreases the process duration because of increased diffusion of moisture through the sample and its evaporation from the surface.

c) Dehydration time increases with blanching in comparison with fresh samples of the same dimensions.

d) Sample dimensions affect the process duration and water evaporation rate from the surface of samples.

e) Diffusion coefficient was higher for celery gratings at 75 °C – $2.38 \times 10^{-6}$ m$^2$ min$^{-1}$. Also, the diffusion coefficient was lower for celery cubes at 50 °C – $1.4 \times 10^{-6}$ m$^2$ min$^{-1}$.

## LIST OF SYMBOLS

$X$ – moisture content / $kg_w\ kg_{w.s.}^{-1}$
$t$ – time (min)
$D$ – diffusion coefficient / m$^2$ min$^{-1}$
$b$ – coefficient of two–parameter model
$d$ – coefficient of two–parameter model
$r$ – coefficient of correlation
$s$ – standard deviation

## REFERENCES

1. D. Ježek, D. Ćurić, B. Tripalo, and D. Karlović, *Chem. Biochem. Eng. Q.* **10** (1996) 103–106.
2. D. Ćurić, D. Karlović, B. Tripalo, and D. Ježek, *Chem. Biochem. Eng. Q.* **12** (1998) 63–71.
3. P. Pavlek, *Specijalno povrćarstvo*, Fakultet poljoprivrednih znanosti, Zagreb, 1993.

4. E. Strasburger, F. Noll, H. Schenck, and A. F. W. Schimper, *Morfologija i fiziologija*, Školska knjiga, Zagreb, 1982.
5. P. M. Smith, *The Chemotaxonomy of Plants*, Edward Arnold Limited, London, 1976.
6. D. Ježek, B. Tripalo, M. Brnčić, D. Karlović, D. Vikić-Topić, and Z. Herceg, *Croat. Chem. Acta* **79** (2006) 385–391.
7. M. A. M. Khraisheh, W. A. M. McMinn, and T. R. A. Magee, *Food Res. Int.* **37** (2004) 497–503.
8. L. Mayor and A. M. Sereno, *J. Food Eng.* **61** (2004) 373–386.
9. Z. Herceg, V. Lelas, M. Brnčić, B. Tripalo, and D. Ježek, *Powder Technol.* **139** (2004) 111–117.
10. Z. Herceg, V. Lelas, M. Brnčić, B. Tripalo, and D. Ježek, *Sadhana* **29** (2004) 13–26.
11. M. Brnčić, B. Tripalo, D. Ježek, D. Semenski, N. Drvar, and M. Ukrainczyk, *Sadhana* **31** (2006) 527–536.
12. S. Papeša, D. Ježek, and D. Kujundžić, *Food Technol. Biotechnol.* **39** (2001) 129–133.
13. A. S. Mujumdar, *Handbook of Industrial Drying* 2nd ed., Marcel Dekker, New York, 1995, pp. 861–898.
14. I. Ruiz–López, A. V. Córdova, G. C. Rodríguez–Jimenes, and M. A. García–Alvarado, *J. Food Eng.* **63** (2004) 117–124.
15. S. Saguy, A. Marabi, and R. Wallach, *Trends Food Sci. Technol.* **16** (2005) 495–506.
16. M. Jaros, *Drying Technol.* **10** (1992) 213–222.
17. M. A. Karim and M. N. A. Hawlader, *J. Food Eng.* **70** (2005) 35–45.
18. I. N. Ramos, T. R. S. Brandão, and C. L. M. Silva, *J. Food Eng.* **67** (2005) 195–203.


## SAŽETAK

### Dehidratacija celera infra crvenim sušenjem

**Damir Ježek, Branko Tripalo, Mladen Brnčić, Damir Karlović, Suzana Rimac Brnčić, Dražen Vikić-Topić i Sven Karlović**

U radu se ispitivao tijek kinetike dehidratacije s obzirom na promjene temperature dehidratacije, dimenzija uzoraka celera i tehnološki tretman uzorka. Ispitivanja su provedena na dvije radne temperature: 50 °C i 75 °C. Uzorci su rezani na kockice dimenzija $5 \times 5 \times 5$ mm i rezance dimenzija $20 \times 5 \times 1$ mm. Ispitivanja su provedena na svježim i na blanširanim uzorcima. Dehidratacija uzoraka celera provedena je u laboratorijskoj infracrvenoj sušnici Mettler LJ16 (Mettler, Švicarska). Tijekom dehidratacije praćena je promjena mase uzorka i masa isparene vode iz uzorka. Za sve uvjete procesa (temperatura dehidratacije, dimenzije uzorka i tehnološki tretman) određen je maseni udio suhe tvari u uzorku, sadržaj vlažnosti, sadržaj isparene vode, koeficijent difuzije i brzina dehidratacije. Koeficijent difuzije ima najveću vrijednost za rezance celera pri 75 °C – $2.38 \times 10^{-6}$ $m^2$ $min^{-1}$, a najnižu vrijednost koeficijent difuzije ima kod kockica celera pri 50 °C – $1.4 \times 10^{-6}$ $m^2$ $min^{-1}$.