Biblid: 1821-4487 (2011) 15; 1; p. 39-41
UDK: 641.12:66.047.41

Original Scientific Paper
Originalni naučni rad

DENSITY OF SOME VEGETABLES DURING CONVECTIVE DRYING
GUSTINA NEKIH POVRĆA TOKOM KONVEKTIVNOG SUŠENJA

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ABSTRACT

In this paper the particle density of potato and carrot slices during convective drying was studied. Some experiments were conducted in a laboratory air-dryer. The experiment was repeated at different air temperatures and velocities. The drying air temperature was 40, 50, 60 and 70°C and the drying air velocity 1, 2 and 3 m/s. Some new mathematical models for correlating the dimensionless particle density with the dimensionless material moisture content are proposed. Regression analysis on the experimental data is made. High values of the correlation coefficients show that the differences between predicted and observed data are very small.

Key words: *density, drying, potato, carrot.*

REZIME

Gustina je važna fizička osobina koja karakteriše teksturu i kvalitet osušenog materijala. Svež krompir i šargarepa nakon ljuštenja se seku na komade (listiće) debljine 3 mm i prečnika 40 ± 0.1 mm. Pri određivanje gustine sušenih uzoraka jedan deo listića postavlja se na lesu u kanal eksperimentalne konvektivne sušare, a drugi deo se suši u laboratoriskoj peći do potpuno suvog stanja kako bi se odredio početni sadržaj vlage. Na eksperimentalnoj aparaturi je realizovana serija eksperimenata. Za svaki eksperiment unapred su zadate vrednosti temperature i brzine vazduha koji su održavani konstantnim tokom jednog režima sušenja. Listići krompira i šargarepe sušeni su na različitim temperaturama 40, 50, 60 i 70°C i različitim brzinama vazduha 1, 2 i 3 m/s. Promene dimenzija i mase sušenih uzoraka merene su svakih deset minuta. Predloženi su novi matematički modeli za aproksimaciju zavisnosti bezdimenzione gustine materijala od bezdimenzionog sadržaja vlage. Visoke vrednosti koeficijenta korelacije pokazuju da su razlike između proračunatih i izmerenih vrednosti veoma male.

Ključne reči: *gustina, sušenje, krompir, mrkva.*

INTRODUCTION

The drying of food is a complex process of simultaneous heat and mass transfer within dried material and from its surface to the surroundings caused by a number of transport mechanisms.

Quality factors are the factors that determine the worth, or value, of a food product to the consumer. This broad definition encompasses many different factors, including colour, texture, shape, sizes, porosity, density and shrinkage (*Krokida and Maroulis, 2001*). Therefore, examination of the physical properties of foods, and their responses to process conditions, is crucial for the analysis of the drying process (*Tsen and King, 2002*). The density is an important physical property characterizing the texture and the quality of dry materials. Experimental values of density are necessary for designing the facility of storage, handling and processing of agricultural materials.

The change of density of some fruits and vegetables during drying has been investigated by (*Lozano et. al., 1980; Lozano et. al., 1983, Zogzas et. al., 1994, Wang and Brennan, 1995, Mitrevski and Popovski, 2006*).

The effect of the drying method on density of apple, banana, potato and carrot has been investigated by (Krokida and Maroulis, 1997). It was concluded that particle density is not affected by the drying method, bulk density is strongly affected by the dehydration process and particle density is affected by the type of material and not by drying method.

The effect of material moisture content and temperature on true density of foods was studied by (Boukouvalas et al., 2006).

The density can be defined in different ways: true density, substance density, particle density, apparent density and bulk density (*Rahman, 2008*).

Assuming the moist material of dry solids, water and air, in literature the following definitions are used (*Saravacos and Maroulis, 2001*):

$$m_t = m_s + m_w \tag{1}$$

where m_t, m_s, and m_w are total mass and the masses of dry solids and water, respectively (kg), while the mass of air is neglected. The total volume of the sample V_t, is:

$$V_t = V_s + V_w + V_a \tag{2}$$

where V_s, V_w, and V_a are volume of dry solids, water and air pores, respectively (m^3).The true density ρ_p is defined as:

$$\rho_p = m_t / V_p \tag{3}$$

where $V_p = V_s + V_w$ is the true (particle) volume, which is the total volume of the sample, excluding air pores. The enclosed water density ρ_w can be defined as:

$$\rho_w = m_w / V_w \tag{4}$$

The particle density of dry solids (particle density) ρ_s is defined as:

$$\rho_s = m_s / V_s \tag{5}$$

Reference literature offers four methods to determine the volume of samples:

– direct measurement method (*Ratti, 1994*; *Clemente et al., 2003*),

– method of immersing the samples in n-heptane (*Zogzas et al., 1994*; *Ratti, 1994*)

– method of immersing the samples in distilled water (*Babic et al., 2008*)

– image analysis (*Clemente et al., 2003*)

The comparisons of these methods show that the differences among maximum errors are less than 10% (*Ratti, 1994; Clemente et al., 2003*). Therefore, it is the method of direct measurement with calliper that is used in this paper.

In this paper the particle density of potato and carrot during convective drying were studied. Some new mathematical models for correlating the dimensionless particle density

$$Y = \rho_{s0} / \rho_s \tag{6}$$

with the dimensionless moisture content

$$U = \frac{u_0 - u}{u_0} \tag{7}$$

are proposed.

NOMENCLATURE

A	- parameter
m (kg)	- mass
r	- correlation coefficient
V (m^3)	- volume
U	- dimensionless moisture content
Y	- dimensionless particle density
u (kg/kg)	- moisture content on dry basis

Greek symbols

ρ (kg/m^3)	- density

Subscripts

0	- initial
a	- air
c	- carrot
p	- particle
po	- potato
s	- solid
t	- total
w	- water

MATERIAL AND METHOD

Fresh potatoes and carrots were used in this study. To prepare samples, potatoes and carrots were sliced using electric slicing machine to give a uniform sample thickness of 3 mm before being reduced to a cylinder form with diameter of 40±0.1 mm. Several measurements were made using a calliper and only samples with a tolerance of ±5% were used.

The study of particle density of potato and carrot slices was conducted in a laboratory air-dryer (Figure 1). The slices were in contact with the drying air from the top and the bottom surfaces. The shelf holding three potato and carrot slices was inserted into the rectangular experimental channel with dimensions 25 x 200 mm. The slices were dried until the equilibrium moisture content was reached. The samples of potato and carrot were drawn from the dryer every 10 min and their weight and sample volume were measured. The initial moisture content and the initial slices dimensions were measured as well. The experiment was repeated at different air temperatures and velocities. The drying air temperature was 40, 50, 60 and 70 oC and the drying air velocity 1, 2 and 3 m/s.

Various mathematical models were used to determine the densities during drying in reference literature (*Wang and Brennan, 1995*; *Saravacos and Maroulis, 2001, Boukouvalas et al., 2006*).

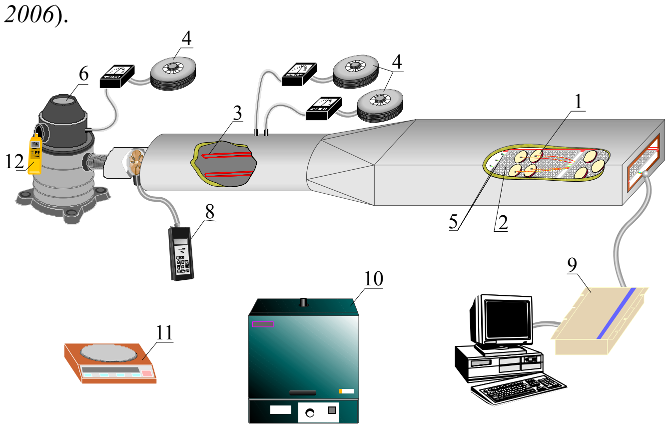

Fig. 1. Experimental apparatus
1-material, 2-shelf, 3-electrical heaters,4-transformers, 5-thermocouples, 6-centrifugal fan,7-anemometer, 8-panel meter, 9-data acquisition system, 10-stove, 11-balance, 12-hygrometer

In this paper five new mathematical models were used for correlating the dimensionless particle density with the dimensionless material moisture content (Table 1).

Table 1. Mathematical models

Model	Type	ρ_{s0}/ρ_s
1	Exponential	EXP(-A*U)
2	Logarithm	1-LOG(A*U+1)
3	Hyperbolic	1/(A*U+1)
4	Power	U**A-1
5	Linear	A*U+1

RESULTS AND DISCUSSIONS

On the basis of experimental data, for each material (potato and carrot) and each model from Table 1, the value of parameter A and correlation coefficient r were determined. The following 7 methods were used: Quasi-Newton, Simplex, Composition Simplex and Quasi-Newton, Hooke-Jeeves Pattern Moves, Composition Hooke-Jeeves Pattern Moves and Quasi-Newton, Rosenbrock Pattern Search and Composition Rosenbrock Pattern Search and Quasi-Newton. When the results for correlation coefficient r were different the highest value was accepted as relevant. The calculations were made by the computer package STATISTICA. The value of parameter A for potato and carrot are given in Table 2.

Table 2. The value of parameter A for potato and carrot

Model	Potato	Carrot
1	1.037	1.5299
2	0.947	1.2906
3	1.539	2.7068
4	2.043	1.9734
5	-0.6978	-0.8707

The values of correlation coefficients r for potato and carrot are given in Table 3. The ranking of the models (Table 4) shows that linear model 5 gives the best results, while the power model 4 gives the worst results.

Table 3. The correlation coefficients

Model	r_{po}	r_c
1	0.9474	0.9412
2	0.9545	0.9668
3	0.9167	0.8770
4	0.5887	0.9513
5	0.9581	0.9835

Table 4. Ranking of the models

Model	$(r_{po} + r_c)/2$
5	0.9708
2	0.9607
1	0.9443
3	0.8969
4	0.7700

In Figures 2-3 the variations of dimensionless particle density of potato and carrot with dimensionless moisture content are shown. Solid line is used to plot calculated values from model 5 and the value of parameter of Table 2. The differences between predicted and observed data are very small and the model is considered to be adequate.

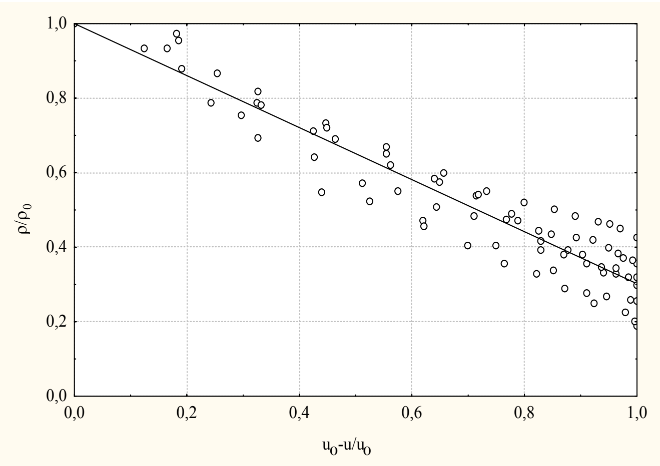

Fig. 2. Variation of dimensionless particle density of potato with dimensionless moisture content

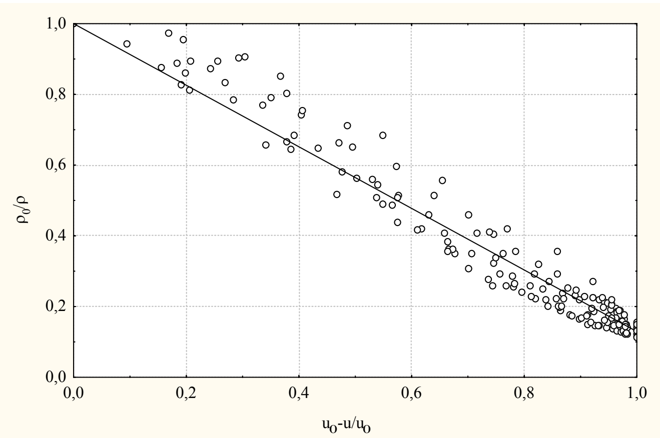

Fig. 3. Variation of dimensionless particle density of carrot with dimensionless moisture content

CONCLUSIONS

The particle density of potato and carrot slices during convective drying was studied. For this purpose some experiments were conducted in a laboratory air-dryer. Some new mathematical models for correlating the dimensionless particle density with the dimensionless material moisture content are proposed. The regression analysis made with the computer package STATISTICA shows that the linear mathematical model gives the best results.

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Received: 20.02.2011. Accepted: 01.04.2011.