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DENSITY OF SOME FRUITS DURING DRYING

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ABSTRACT

In this paper the particle density of apple and banana slices during convective drying were studied. Drying experiments were conducted in a laboratory air-dryer, repeated at different air temperatures and air velocities. The drying air temperatures considered were 40, 50, 60 and 70^{o}C at drying air velocities of 1, 2 and 3 m/s.

Some simple mathematical models, relating to the dimensionless particle density with the dimensionless material moisture content are proposed. The models were fitted to experimental data and the correlation coefficients and residual sum of squares were estimated.

KEYWORDS

Particle density, drying, apple, banana.

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 those that determine the worth, or value, of a food product to the consumer. This broad definition encompasses many different factors, including color, texture, shape, sizes, porosity, density and shrinkage [7], examination of the physical properties of foods, and their responses to process conditions, is crucial for analysis of the drying process [15].

The density is an important physical property characterizing the texture and the quality of dry materials. It can be defined in different ways: true density, material density, particle density, apparent density and bulk density. Bulk and particle densities are vital parameters in the design, modeling and optimization of food processing operations because they have a direct affect on the thermophysical properties of food materials [12].

The change of density of some fruits and vegetables during drying has been investigated [8], [9], [10], [16], [17].

The effect of drying method on densities of apple, banana, potato and carrot has been investigated by Krokida and Maroulis, [6]. It was concluded that particle density is not affected by drying method, bulk density is strongly affected by dehydration process and particle density is affected by the type of material while it is not by drying method. The effect of material moisture content and temperature on true density of foods was studied by Boukouvalas et al*.,* [3]. While variation of bulk and particle density of potato starch gel with dimensionless moisture content at various air temperature was studied from [11].

In this paper the particle density of apple and banana during convective drying were studied. Five simple mathematical models for correlating the dimensionless particle density with the dimensionless moisture content are proposed.

MATERIALS AND METHODS

Fresh apples and bananas were used in this study. In order to prepare samples, apple or banana 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 apple or banana slices was conducted in a laboratory air-dryer (Fig. 1). The slices were in contact with the drying air from the top and the bottom surfaces. The shelf holding with three apple or banana slices, separately for each experiment, were inserted into the rectangular experimental channel with dimensions 25x200x2000 mm. The slices were dried until the equilibrium moisture content was reached. The samples of apple or banana 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. During the experiments during air temperature and drying air velocity were controlled. The drying air temperature considered were 40, 50, 60 and 70 ^{o}C with drying air velocities of 1, 2 and 3 m/s.

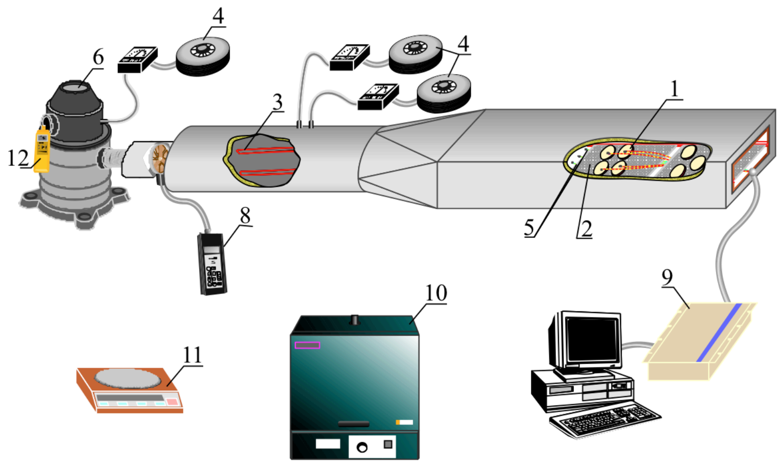

Fig. 1. Experimental apparatus
1-material, 2-shelf, 3-electrical heaters, 4-transformers, 5-thermocouples, 6-centrifugal fan, 7-anemometer,8-panel meter, 9-data acquisition system, 10-stove, 11-balance, 12-hygrometer

MATHEMATICAL MODELS

In reference literature various simple mathematical models were used to relating the densities to material moisture content and drying air temperature, [3], [14], [16].

Assuming the moist material of dry solids, water and air, in literature the following definitions are used, [14]:

$$m_t + m_s + m_w \qquad (1)$$

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

$$V_t = V_s + V_w + V_a \qquad (2)$$

where V_s, V_w, and V_a are volume of dry solids, water and air pores.

The true density r_p is defined as:

$$\rho_p = \frac{m_t}{V_p} \qquad (3)$$

where $V_p = V_s + V_w$ is the true volume, which is the total volume of the sample, excluding air pores.

The enclosed water density ρ_w can be defined as:

$$\rho_W = \frac{m_W}{V_W} \qquad (4)$$

The particle density of dry solids r_s is:

$$\rho_S = \frac{m_S}{V_S} \tag{5}$$

Reference literature offers four methods for determination of the volume of sample (volume of dry solid):

- direct measurement method [4], [13],
- method of immersing the samples in n-heptane [13], [17],
- method of immersing the samples in distilled water [1],
- image analysis, [4].

The comparisons of these methods show that the differences among maximum errors are less than 10%, [4], [13]. Therefore, it is the method of direct measurement with calliper that was used to determine volume of sample.

Simple mathematical models were used to determine the dimensionless particle density:

$$R = \frac{\rho_{S0}}{\rho_S} \tag{6}$$

as a function of dimensionless material moisture content (Table 1):

$$X = \frac{x_0 - x}{x_0}\ . \tag{7}$$

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

Table 1. Mathematical models

Statistical analysis of one model may be quantified through five standards [2]: coefficient of correlation (r), the residual sum of squares RSS, the standard error of estimate SE, the mean relative deviation MRD, and the plot of residual.

Correlation coefficient is a dimensionless index that ranges from 0 to 1. The closer the (r), values are to 1, the better are the fit.

The residual sum of squares RSS is defined:

$$RSS = \sum_{i=1}^{n} (Y_{exp} - Y_{cal})^2 \tag{8}$$

where Y_{exp} is the experimental-measure value, Y_{cal} is the value estimated true the fitting equation and n is the number of data points.

The standard error of estimate SE is the conditional standard deviation of the depended variable and is a measure of the accuracy of predictions. The standard error of estimate for large data set is defined with equation:

$$SE = \sqrt{\frac{RSS}{n}}. \qquad (9)$$

The mean relative deviation MRD is an absolute value because it gives mean divergence of the estimated data from the measured data

$$MRD = \frac{1}{n}\sum_{i=1}^{n}\frac{\left|Y_{exp} - Y_{cal}\right|}{Y_{exp}}. \qquad (10)$$

Plotting of the residuals against the independent variable is also used as a measure of the distribution of errors. If the model is correct, then the residual should be only random independent errors with a zero mean, constant variance and arranged in a normal distribution. If the residual plots indicate a clear pattern, the model should not be accepted.

In general, low values of correlation coefficient, high values of RSS, SE and MRD, and clear patterns in the residual plots mean that the model is not able to explain the variation in the experimental data. It is also evident that a single statistical parameter cannot be used to select the best model and the model must always be assessed based on multiple criteria [5].

RESULTS AND DISCUSSION

On the basis of experimental data, for each material (apple and banana) and each model from table 1, the value of parameter A, correlation coefficient (r) and residual sum of squares RSS 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, (Stat-Soft, 2006). The value of parameter A, values of correlation coefficients (r) and residual sum of squares RSS for all model are given in Table 2.

Model	Apple	Banana	r_{ap}	r_{ba}	RSS_{ap}	RSS_{ba}
1	1.107	1.167	0.953	0.943	0.449	1.272
2	1.005	1.057	0.966	0.959	0.321	0.924
3	1.670	1.783	0.910	0.893	0.832	2.328
4	1.973	1.783	0.798	0.856	1.767	3.068
5	- 0.732	- 0.769	0.981	0.974	0.185	0.582

Table 2. The value of parameter A, correlation coefficients r and residual sum of squares RSS.

From Table 2 it is evident that linear model 5 gives the best results, while the power model 4 gives the worst results.

In Figures 2 and 3, the variation of dimensionless particle density of apple and banana with dimensionless moisture content are shown. Solid line is used to plot calculated values from model. The differences between predicted and observed data are very small and the linear model is considered to be adequate.

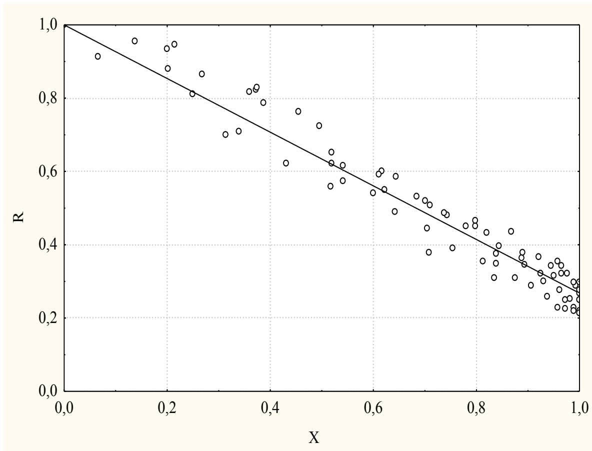

Fig. 2. Variation of dimensionless particle density of apple with dimensionless moisture

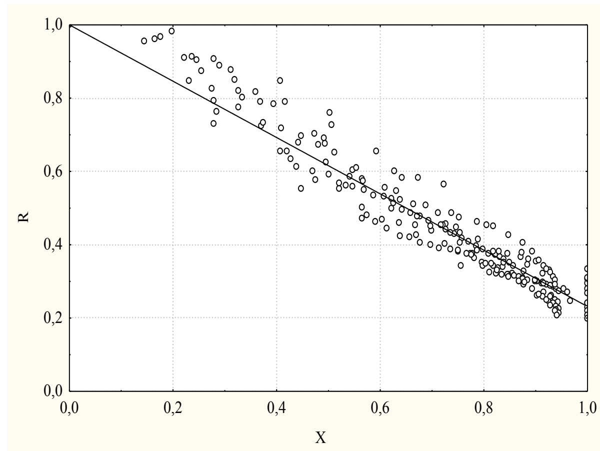

Fig. 3. Variation of dimensionless particle density of banana with dimensionless moisture

Figures 4 and 5 show observed versus predicted values for apple and banana.

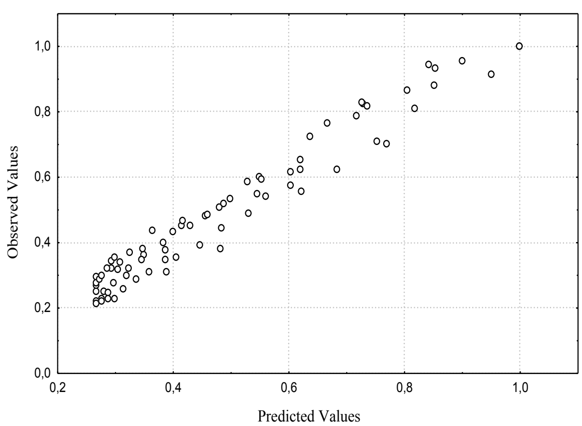

Fig. 4. Observed versus predicted values for apple

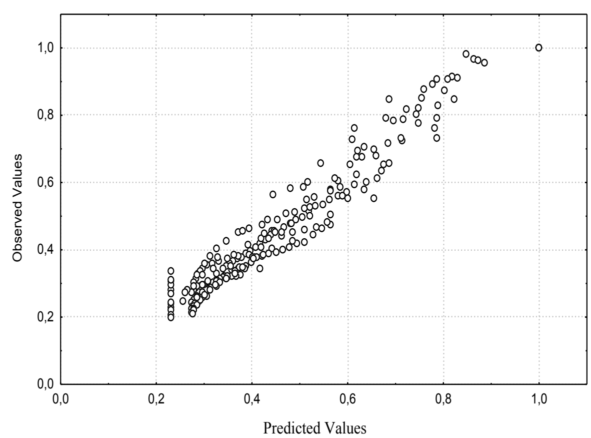

Fig. 5. Observed versus predicted values for banana

CONCLUSION

The particle density of apple and banana slices during convective drying was studied. For this purpose some experiments were conducted in a laboratory air-dryer. Some simple 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.

NOMENCLATURE

A - parameter
MRD - mean relative deviation
m (kg) - mass
n -degrees of freedom
R -dimensionless particle density
RSS - residual sum of squares
R - correlation coefficient
V (m^3) - volume
SE - standard error of the estimate
X - dimensionless moisture content
x (kg/kg d.b.) - moisture content
Y_{cal} - estimated value
Y_{exp} - experimental value
GREEK SYMBOLS
r (kg/m^3) - density
SUBSCRIPTS
0 - initial
a - air
ap - apple
ba - banana
p - particle
s - solid
s0 - initial solid
t - total
w – wáter

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