Describing of drying curves of green coffee beans using mathematical model

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Abstract. The most important processes in food processing include drying. Generally it is the removal of water from the material for further processing or storage. This study was focused on the analysis of drying process of green coffee beans (Coffee arabica). The green beans, originally from Indonesia, were used in this experiment. Moisture content of beans M_c = 28.1 ± 1.7 % (w.b.) were determined. The beans were dried at different air temperatures T_d = 40, 60, 80, 100 and 120 ± 1 °C. Drying tests were carried out on drying scales (Radwag, MA 50.R, Poland). The test was repeated three times for each temperature. Measured data were analysed by computer software Mathcad 14. Experimental drying curves at different temperatures were determined. The measured values of the drying curves of green coffee beans were fitted and a mathematical model was created. Model coefficients were determined and the proposed model was statistically analysed.

1. Introduction

Coffee is one of the most commonly consumed beverages in the world. Drying coffee plays a very important role in its processing. Drying is one of the oldest methods of agriculture products preservation and improves the shelf life of agriculture products [1]. Without drying, it is not possible to process or store fresh coffee. For storage of coffee beans is necessary to reduce their moisture content. Due to the drying requirements, it is necessary to keep coffee moisture around 11% [2]. Drying coffee is a very sensitive process that can affect quality [3]. For example, drying has an effect on the sugar content of coffee beans [4]. Removing the water is very energy intensive and therefore it is necessary to find optimal point drying [5]. One of the most important parameters in the design of drying lines is energy and time efficiency [6], [7], [8]. When designing dryers, it is necessary to know drying curves for different drying temperatures. The aim of this study is to determine the mathematical model describing the coffee bean drying curves for different drying temperatures.

2. Materials and Methods

2.1. Materials

Samples of coffee beans (*Coffee arabica L.*), obtained from Nord Sumatra region, Indonesia were used for this experiment. The moisture content Mc = 28.1 ± 1.7 % (w.b.) of

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the freshly coffee beans was determined using standard oven method, ASAE method (ASAE S410.1 DEC97, ASAE, 1998). Samples of 100 g mass from a batch of coffee beans were randomly selected for the moisture content determination. For measuring of mass of each sample m_s(g) an electronic balance (Kern 440–35, Kern & Sohn GmbH, Balingen, Germany) was used. All the obtained results were expressed as mean of three replicates. Beans samples were packaged by vacuum atmosphere in polyethylene (PE) bag. Packed samples of coffee beans were transported using air transport to the laboratory of CULS Prague. All the beans were stored in a refrigator at 5 ± 1 °C prior to the experiments.

2.2. Drying experiments

Drying experiments were carried out using drying moisture balance (Radwag, MA 50.R, Poland). Moisture balance is equipped with IR emiter heating module 400 W and was set to a standard drying profile. Samples of coffee beans weighing 15g were inserted into drying balance and air-dried at temperatures of 40, 60, 80, 100 and 120 ± 1 °C. The weight loss changes per minute were recorded in the memory. The test was repeated three times for each temperature.

2.3. Mathematical modelling of drying curves

The measured values of weight loss of coffee beans for different drying temperstures were analysed with computer program Mathcad 14 (MathCAD 14, PTC Software, Needham, MA, USA), (Pritchard, 1998) uses Levenberg-Marquardt algorithm for data fitting (Marquardt 1963). ANOVA was used for statistical verification of the obtained models.

3. Results and discussion

The figure (Fig. 1) shows the drying curves of coffee beans for different drying temperatures in range of 40 – 120 °C. The initial moisture content of freshly harvested coffee beans was observed to be Mc = 28.1 ± 1.7% (w.b.), which is normal value for coffee beans [9]. Drying continued until the final moisture content was ca. 11% (w.b.). The appropriate moisture content for storing the coffee is around 11% (w.b.) [10] Fig. 1 shows that, as expected, drying rate increases significantly as the drying air temperature increases. However, it is necessary to use the appropriate temperature when drying the coffee beans. It has been found that when drying above 45 ° C the coffee beans may be damaged [11]. Therefore optimum drying temperature is required for the highest quality coffee. The results indicate that increasing drying air temperature can extensively enhance drying process. This is due to the fact that high temperature could enhance heat transfer between drying air and coffee beans [12].

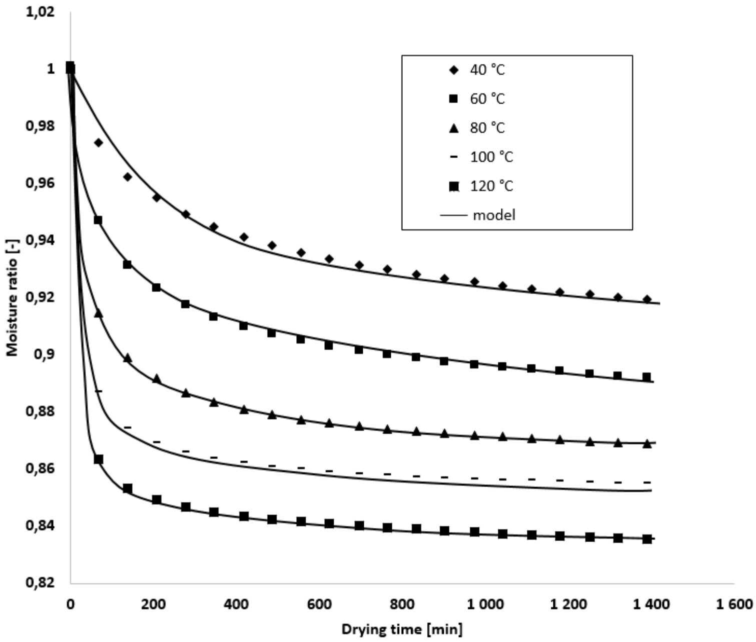

Figure 1. Measured values of moisture ratio of coffe beans and fitted models in the air temperature range of 40 – 120 °C

Individual measured drying values are shown in figure 1. Measured values for different drying air temperatures were fitted by exponential curve using Marguardt Levenberg algorithm and it is described by Eq. 1.

$$\vartheta\ (d,t) = d_0 + d_1(e^{d_2.t}) + d_3(e^{d_4.t}) \quad (1)$$

where: d_0, d_1,d_2, d_3,d_4 – coefficients of equation; t – drying time.

The values of coefficients d_0, d_1, d_2 d_3, $d_4$from Eq. 1 are presented in Table 1.

Table 1. Estimated values of coefficients for Eq. 1

Temperature of drying (°C)	d_0 (-)	d_1 (-)	d_2 (min^{-1})	d_3 (-)	d_4 (min^{-1})
40	0.914	0.031	-0.014	0.054	-0.00167
60	0.89	0.06	-0.022	0.05	-0.00219
80	0.869	0.091	-0.029	0.04	-0.0028
100	0.855	0.117	-0.037	0.028	-0.00321
120	0.835	0.142	-0.04	0.023	-0.00224

In table 2 a statistical evaluation of the obtained model was determined. From statistical analysis ANOVA (table 2) follows, that measured amounts of drying curves at different temperatures and results from the general exponential model (Eq. 1) were statistically significant at significance level 0.05, that is, the values of F_{crit} (critical value comparing a pair of models) were higher than the F_{rat} values (value of the F – test) for all the measured coffee beans and values of P_{value} (significance level at which it can be rejected the hypothesis of equality of models) (table 2) were higher than 0.05 which is also confirmed by very high coefficients of determination R^2.

Table 2. Statistical analysis of general model

Temperature of drying (°C)	F_{rat} (-)	F_{crit} (-)	P_{value} (-)	R^2 (-)
40	$1.703.10^{-11}$	4.085	1	0.998
60	$1.223.10^{-11}$	4.085	1	0.999
80	$1.811.10^{-11}$	4.085	1	0.999
100	$-7.214.10^{-12}$	4.085	1	0.993
120	$-5.857.10^{-12}$	4.085	1	0.996

F_{rat} - value of the F test, F_{crit} - critical value that compares a pair of models, P_{value} - hypothesis of the study outcomes significant level, R_2 – coefficient of determination

From the Fig. 1 is also visible that drying rate decrease showed no constant drying rate period for coffee beans. This fact is caused by the structure of the sample being dried and the mechanism of internal liquid migration [13]. Some previous authors found that moisture diffusion represents the dominant physical mechanism affecting drying rate decrease during the drying of natural products [14], [15]. Drying is a very energy-intensive process and has a significant effect on the quality of the final product [16]. It is necessary to know the mathematical description of drying curves for the construction of coffee dryers. Modelling of the drying process is examined by a number of authors [17], [18], [19].

4. Conclusion

This study was focussed on the drying process of green coffee beans. A change in weight was determined depending on the drying time and the drying temperature. This dependence was transformed into general mathematical model describing hot air drying of green coffee beans. The model of Eq. 1 provides valuable information about the moisture ratio during drying. This model may be used in the optimal design of coffee dryers.

5. Acknowledgment

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