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Mathematical model describing the drying curves of false banana´s fibre (Ensete ventricosum)

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Abstract. Drying processes play an important role in the preservation of agricultural products. They are defined as a process of moisture removal due to simultaneous heat and mass transfer. This study was focused on the analysis of drying curves of fibres of false banana (*Ensete ventricosum*). The fibres of *Ensete ventricosum*, originally from Ethiopian region Hawasa, were used in this experiment. Moisture content of freshly harvested fibres $M_c = 78.4 \pm 1.4$ % (w.b.) were determined. The fibres were dried at different air temperatures $T_d = 40, 60, 80$ and 100 ± 1 °C. To determine the drying curves the drying moisture balance (Radwag, MA 50.R, Poland) was used. Measured data were analysed by computer software Mathcad 14. Experimental drying curves at different temperatures and drying rate were determined. Basic mathematical model describing the loss of mass by drying of the Ensete fibres was represented. The model coefficients were statistically significant suggesting that the determined model could be used as a background for further research focused on Ensete fibre application.

Key words: drying kinetics, moisture content, drying rate.

INTRODUCTION

False banana fibre (*Ensete ventricosum*) belongs to the family *Musa*, and is a lucrative natural fibre with good mechanical and physical properties (Mizera et al., 2017). In general natural fibres are an interesting and environmentally friendly alternative to the replacement of synthetic material. The natural fibres are environmentally friendly, biodegradable and recyclable, and also they can help in the reduction of waste and environmental pollution (Kalia et al., 2013). Natural fibres are good substitute for synthetic polymeric fibres since they are available in fibrous forms at low cost (Aseer et al., 2013). The Ensete plant is a perennial herb that grows in Ethiopia and it is primarily intended for human consumption and animal feeding (Vincent et al., 2013; Herak et al., 2014). Over centuries the Ensete fibres have been extracted from the leaves of this plant as major material for the weaving, ropes and cord production, as well as for baskets production (Diriba et al., 2013; Yirmaga, 2013). Some of the mechanical properties of Ensete fibres have already been determined (Mizera et al., 2016a; Mizera et al., 2016b). For using of natural fibres as a construction material it is necessary to reduce their moisture content. Because of their relatively high moisture content fresh fibres have short shelf-life as they are sensitive to microbial spoilage and formation of mould. A decrease of moisture content reduces their biological activity as well the chemical and physical changes that occur during storage. Drying is one of the oldest methods of agriculture products preservation and improves the shelf life of agriculture products (Larrauri, 1999). Water loss from agriculture products is a very energy – intensive process and it is necessary to find the optimum drying conditions for economical operation (Agrawal & Methekar, 2017). Energy and time efficiency is one of the most significant design and operation parameters in drying processing (Mongpraneet et al., 2002; Sharma et al., 2005; Adak et al., 2017). For better understanding of drying processes is necessary to know the drying curves under various drying temperatures. Experimental data are usually transformed into mathematical drying models, which are routinely used in the design and analysis of dryers. In view on the fact that no literature was available on the drying characteristics of *Ensete ventricosum* fibres, the present study aims are to measure drying curves and to determine drying rate and basic mathematical model of drying under different temperatures.

MATERIALS AND METHODS

Materials

Samples of fibres produced from *Ensete ventricosum*, obtained from Hawassa region, Ethiopia were used for this experiment. Fibres were harvested at natural moisture content. The moisture content $M_c = 78.4 \pm 1.4\ \%$ (w.b.) of the freshly harvested fibres was determined using standard oven method, ASAE method (ASAE S410.1 DEC97, ASAE, 1998). Samples of *100 g* mass from a batch of Ensete fibres 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. After harvesting the fibres were packaged by vacuum atmosphere in polyethylene (PE) bag. Packed samples of fibres were transported using air transport to the laboratory of CULS Prague. All the fibres were stored in a refrigator at 5 ± 1 *°C* prior to the experiments.

Drying experiments

Drying of samples were carried out in the 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 (Fig. 1). To explore the effect of drying temperature on drying rate of fibres, drying experiments were carried out at temperatures of *40, 60, 80* and 100 ± 1 *°C*. The fibres were prepared for drying by chopping them into short fibres of approximately *25 mm* length. The randomly selected samples of weight $m_0 = 10 \pm 1$ *g* were inserted into the moisture balance and gradually dried. The weight loss changes per minute were recorded in the memory.

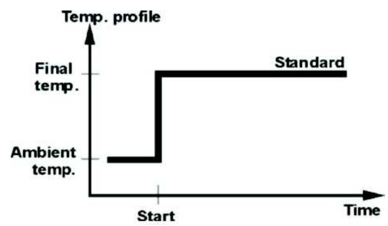

Figure 1. Drying profile: Standard for moisture balance Radwag

Mathematical modelling of drying curves

The measured values of weight loss 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). The determined models of drying curves were statisticaly verified by using ANOVA.

RESULTS AND DISCUSSION

Fig. 2 shows the moisture ratio as a function of drying time of Ensete fibres at the air temperature range of *40–100 °C*. The initial moisture content of freshly harvested Ensete fibres was observed to be $M_c = 78.4 \pm 1.4\%$ (w.b.), which is characteristic of most natural fibres (Faruk et al., 2012). Drying continued until the final moisture content was ca. *5%* (w.b.). Fig. 2 shows that, as expected, drying rate increases significantly as the drying air temperature increases. Drying time was estimated at *473, 112, 77* and *51 min* at *40, 60, 80* and *100 °C*, respectively. The results indicate that increasing drying air temperature can extensively enhance drying process. The drying time at air temperature of 40 °C was approximately four times longer that required at a drying air temperature of 60 °C. The drying time of Ensete samples at 80 °C was 43% shorter than the drying period at temperature of 60 °C. This phenome due to the fact that high temperature could enhance heat transfer between drying air and fibre samples (Wang et al., 2017).

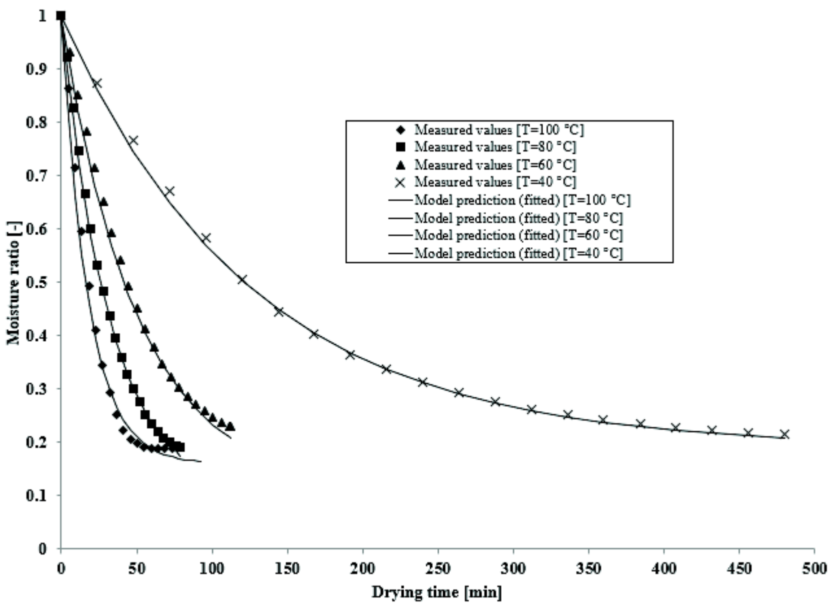

Figure 2. Comparison of measured values of moisture ratio and fitted models in the air temperature range of 40–100 °C.

The drying curves of the Ensete fibres at 4 drying temperatures with the model fit are presented in Fig. 2. Measured and calculated values for different drying curves were fitted by exponential curve using Marguardt Levenberg algorithm and it is described by Eq. 1.

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

where: d_0 – ratio of dry matter, -; d_1 – ratio of water, -; d_2 – slope of the tangent at zero time, min^{-1}.

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

Table 1. Estimated values of coefficients for Eq. 1

Temperature of drying	d_0 (-)	d_1 (-)	d_2 (min^{-1})
40	0.192	0.8169	-0.00793
60	0.1158	0.9001	-0.02
80	0.0962	0.9082	-0.031
100	0.1632	0.8665	-0.056

From statistical analysis ANOVA (Table 2) follows, that measured amounts of drying curves at diferent 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 Ensete fibres 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

Drying temperature (°C)	F_{rat} (-)	F_{crit} (-)	P_{value} (-)	R^2 (-)
40	$-1.147.10^{-14}$	4.085	1	0.999
60	$-1.523.10^{-14}$	4.073	1	0.998
80	$-1.798.10^{-14}$	4.085	1	0.999
100	$-1.963.10^{-14}$	4.073	1	0.994

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.

The variation of drying rate with moisture content is shown in Fig. 3. From the Fig. 3 is evident, that the drying rate decreased continuously with decreased moisture content. A trend of drying rate decrease showed no constant drying rate period for Ensete fibres. Different drying rate decrease is determined by the structure of the sample being dried and the mechanism of internal liquid migration (Simović et al., 2016). Some previous authors determined, that moisture diffusion represents the dominant physical mechanism affecting drying rate decrease during the drying of vegetable products (Singh & Gupta, 2007; Xiao et al., 2010).

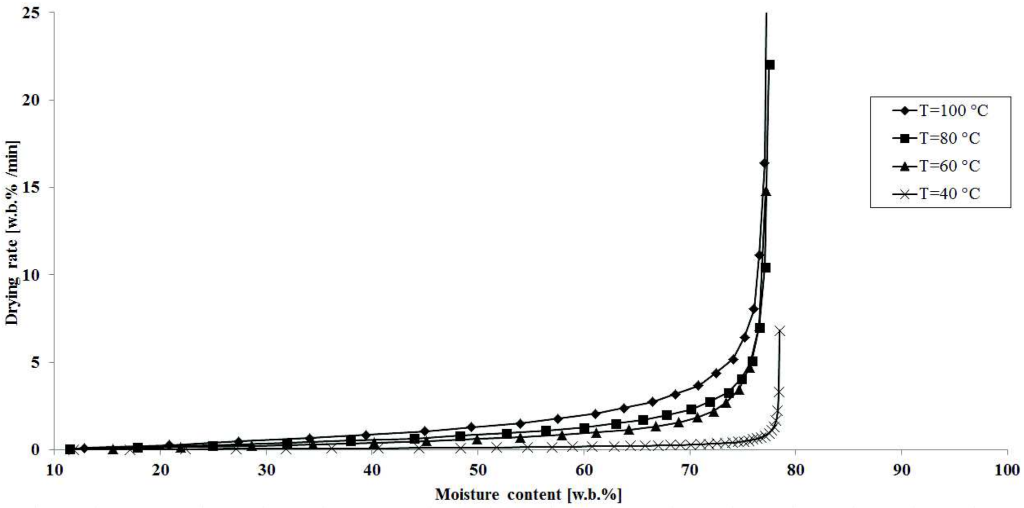

Figure 3. Drying rate versus moisture content at different air temperatures.

This effect can also be seen in the drying of Ensete fibres indicating that the absence of constant water supply to the sample surface lowered the drying rate, which is expressed through the rapid decline of drying rate values (Fig. 3). Similar values were measured also for other natural fibers (Stamboulis et al., 2001). Drying of coton fibres explored Soomro (2014). Drying is a very energy demanding process and also has a large effect on the mechanical and physical properties (Mohanty et al., 2005). Therefore it is very important to know the drying process of Ensete fibres and to determine the basic mathematical description. Modeling of drying process for agricultural products also published some authors (Karathanos & Belessiotis, 1996; Krokida et al., 2003).

CONCLUSIONS

This study has focussed on the drying process of Ensete fibres. Dependency between weight loss and drying time was observed and transformed into general mathematical model describing hot air drying of Ensete fibres. Results indicate that the fibres are very sensitive to the drying air temperature and air temperature enhance extensively drying process. The drying time at air temperature of 60 °C was approximately four times shorter that required at a drying air temperature of 40 °C, which can occur by drying with sunshine. The drying rate was also determined. Mathematical model in this study could by used for the development of further models which will describe drying process of Ensete fibres and it can help to design of technology for drying of Ensete ventricosum fibres.

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