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Mathematical modelling of thin layer drying kinetics of plum in a tunnel dryer

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Abstract

Drying kinetics of plum (control, blanching and blanching in 1% KMS solution as pretreatments) in a tunnel dryer was studied at 55, 60 and 65 °C air temperatures. Drying of plum slices occurred in falling rate period. It was found that treated plum slices dried faster. Six thin layer drying models were fitted to the experimental moisture ratio data. Among the mathematical models investigated, the logarithmic model satisfactorily described the drying behaviour of plum slices with high r^2 values. The effective moisture diffusivity (D_{eff}) of plum increased as the drying air temperature increased. The D_{eff} values were higher for treated samples than the control.

Keywords: Diffusivity; Drying; Models; Plum; Pretreatments; Tunnel dryer

1. Introduction

Plum (*Prunus domestica*) is an important temperate zone fruit crop. Plums are rich in sugars and carotenes. Plum fruits can be used as fresh dessert fruit, dried or cooked. Dried plums are rich in minerals and vitamins, and are mildly laxative. The dried plum is often added to cathartic decoctions to improve their flavour. Plums, which contain high moisture (86–90%, wet basis), are highly perishable and hence drying and storage are considered important.

Traditionally fruits and vegetables are dried in open sunlight, which is weather dependable and also prone to microbial and other contamination (Mathioulakis, Karathanos, & Belessiotis, 1998). To achieve consistent quality dried product industrial dryers should be used. Industrial dryers are rapid and provide uniform, hygienic dried product (Abdelhaq & Labuza, 1987; Doymaz & Pala, 2002; Karathanos & Belessiotis, 1997). The drying rate can also be enhanced by pretreatments like blanching and sulphitation (Dabhade & Khedkar, 1980; Doymaz, 2004a). Pretreatments help in color retention and improve storage stability by the preservative effects.

The drying kinetics of food is a complex phenomenon and requires simple representations to predict the drying behaviour, and for optimizing the drying parameters. Thin layer drying equations were used for drying time prediction for generalization of drying curves (Karathanos & Belessiotis, 1999). Extensive research in drying behaviour of pre-treated fruits was reported (Doymaz, 2004a, 2004b; Mahmutoglu, Pala, & Unal, 1995; Saravacos, Marousis, & Raouzeos, 1988; Verma & Gupta, 2004). But, no detailed studies were found in literature on drying kinetics of plum slices. The objectives of this study were: (i) to study the drying kinetics of plum in a tunnel dryer as affected by various pretreatments and (ii) to evaluate a suitable thin layer drying model.

2. Materials and methods

2.1. Experiment

Freshly harvested plums (*variety: Sutlej purple*) were purchased from local market, Ludhiana for the study.

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Nomenclature

χ^2	reduced chi-square
a, b, c, n	empirical constants in drying models
D_{eff}	effective moisture diffusivity, m^2/s
k	drying constant
KMS	potassium meta bisulphite
L	thickness of slice, m
M	moisture content at time t, kg moisture kg^{-1} dry matter
MBE	mean bias error
M_e	equilibrium moisture content, kg moisture kg^{-1} dry matter
M_0	initial moisture content, kg moisture kg^{-1} dry matter
MR	dimensionless moisture ratio
MR_{exp}	expected moisture ratio
MR_{pre}	predicted moisture ratio
N	number of observations
r^2	coefficient of determination
RMSE	root mean square error
t	drying time, h
z	number of drying constants

The initial moisture content of plum was 986.17% d.b. and was determined by the AOAC method no. 934.06 (AOAC, 2000). Plum fruits were sliced uniformly (average thickness: 3.5 ± 0.5 mm) and were dried on the same day.

The drying experiments on plum were performed in a laboratory model cross-flow tunnel dryer (NSW-600, Narang Scientific Works, New Delhi). The overall dimensions of the dryer are $3.06 \times 1.10 \times 2.15$ m and it consisted of a tunnel, electrical heater, fan and a temperature controller (30–110 °C, dry bulb temperature).

The control (untreated), blanched (50 °C for 2 min) and blanched with 1% potassium meta bisulphite solution (KMS) of plum slices were used to conduct the drying experiments at 55, 60 and 65 °C (±1 °C). The speed of the tunnel was fixed at 0.004 m/s. The dryer was allowed to run for 30 min to reach the set drying air temperature conditions. Plum slices (150 g) were uniformly spread in rectangular aluminium trays (size: $310 \times 210 \times 30$ mm) and kept in the tunnel for drying. Moisture loss was recorded at 30 min interval by a digital balance of 0.01 g accuracy (Scaltec instruments, Germany). The drying was continued till there is no large variation in the moisture loss. Experiments were conducted in triplicate.

2.2. Drying models

Moisture ratio of samples during drying was expressed by the following equation:

$$MR = \frac{(M - M_e)}{(M_0 - M_e)} \quad (1)$$

As the M_e value is very small compared to M_0 and M values, the M_e value can be neglected and the moisture ratio can be expressed as

$$MR = M/M_0 \quad (2)$$

To select a suitable model for describing the drying process of plum slices, drying curves were fitted with six thin layer drying equations. The moisture ratio models that are evaluated are presented in Table 1.

The non-linear regression analysis was analysed using SPSS (Statistical Package for Social Science) 11.5.1 software package. Coefficient of correlation, r^2 was one of the main criteria for selecting the best model. In addition to coefficient of correlation, the goodness of fit was determined by various statistical parameters such as reduced chi-square, χ^2, mean bias error, MBE and root mean square error, RMSE. For quality fit, r^2 value should be higher and χ^2, MBE and RMSE values should be lower (Demir, Gunhan, Yagcioglu, & Degirmencioglu, 2004; Erenturk, Gulaboglu, & Gultekin, 2004; Pangavhane, Sawhney, & Sarsavadia, 1999; Sarsavadia, Sawhney, Pangavhane, & Singh, 1999; Togrul & Pehlivan, 2002). The above parameters can be calculated as follows:

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{exp} - MR_{pre})^2}{N - z} \quad (3)$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(MR_{exp} - MR_{pre}) \quad (4)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{exp} - MR_{pre})^2\right]^{1/2} \quad (5)$$

Table 1
Mathematical models given by various authors

Equation	Name	References
$MR = \exp(-kt)$	Newton	Liu and Bakker-Arkema (1997) and O'Callaghan et al. (1971)
$MR = \exp(-kt^n)$	Page	Zhang and Litchfield (1991)
$MR = \exp(-(kt)^n)$	Modified Page	Overhults et al. (1973)
$MR = a\exp(-kt)$	Henderson and Pabis	Henderson and Pabis (1961) and Chhinnman (1984)
$MR = a\exp(-kt) + c$	Logarithmic	Yaldiz et al. (2001)
$MR = 1 + at + bt^2$	Wang and Singh	Wang and Singh (1978)