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Air-drying and rehydration characteristics of date palm (*Phoenix dactylifera* L.) fruits

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Abstract

The influence of variety and drying temperature range of 50–80 °C on air-drying pattern of date palm fruits were investigated. Results indicated that drying took place in the falling rate period. Moreover, the effect of variety and rehydration temperature range of 15–45 °C, maintaining a fruit : water ratio of 1:25 w/w were also investigated. Moisture transfer during air-drying and rehydration were described by applying the Fick's diffusion model, and the effective diffusivities and activation energies were calculated. Arrhenius relation with activation energy range of 35.17–44.02 and 30.29–40.29 kJ/mol expressed the effect of temperature on the diffusivities during air-drying and rehydration, respectively.

Keywords: Date palm fruit; Air-drying; Rehydration; Effective moisture diffusivity; Activation energy

1. Introduction

Date palm (*Phoenix dactylifera* L.) is a monocotyledon of the family of the Palmae. Botanically, date fruit is a berry consisting of a single seed surrounded by a fibrous parchment like endocarp, fleshy mesocarp and the fruit skin (pericarp). Date fruits vary in shape, size and weight depending on variety and growing conditions. Usually dates are oblong though certain varieties may reach a near spherical shape. The moisture content of the fruit vary from 60% at the mature to about 25% at the dried stage (Barreveld, 1993), safe moisture content for storage of date is between 24% and 25%.

Date is grown extensively in the arid region of the Northern part of Nigeria from latitude 10 °N in the Sudan Savanna to Sahel regions, and may be found in the lower latitudes within the Savanna region (Omoti & Okolo, 2000). According to Okolo, Okwuagwo, and Ataga (2000), while the consumption of the fresh fruit in the fresh mature ripe stage is popular among the people of the Middle East and North Africa, Nigerians show preference for fruits at the dry and semi-dry stage probably because of lower astringency, sweet taste and easy storability. Drying of fresh dates is necessary because it contains high moisture (about 60%) which limits the shelf life. Matured date fruits are allowed to partially dry on the trees before they are harvested and further sun dried to enhance their keeping quality and storage. However, problems associated with sun drying are well documented (Doymaz, 2004, 2005; Guine & Castro, 2002). Dehydration in air driers at controlled temperatures and air flow will ensure appropriate level of moisture in dates and better preservation of the product quality. Reduction of moisture to very low level would result in fruits too hard to eat and inappropriate for some consumers, and may necessitate rehydration.

Rehydration is a complex process aimed at the restoration of previously dried materials in contact with water. It is generally accepted that the degree of rehydration is dependent on the degree of cellular and structural disruption. During dehydration, irreversible rupture and dislocation occur resulting in loss of integrity and hence a dense

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Nomenclature

a	major semi-axis of the data palm fruit (m)	R	gas constant (8.314 J/mol K)
b	minor semi-axis of the date palm fruit (m)	R_{eq}	equivalent spherical radius of the date palm fruit (m)
D_{eff}	effective moisture diffusivity (m^2/s)	R_s	radius of sphere (m)
e	eccentricity	S_p	surface area of date fruit (m^2)
E_a	activation energy (kJ/mol)	S_s	surface area of sphere of equal volume to date fruit (m^2)
M_e	equilibrium moisture content of dates (kg water/kg dry solids)	t	time of dehydration (or rehydration) (h)
M_0	moisture content of fresh dates (kg water/kg dry solids)	T_{abs}	absolute temperature (K)
M	instantaneous moisture content of dates (kg water/kg dry solids)	V	volume of date fruit (m^3)
MR	moisture ratio (dimensionless)	ψ	shape factor (S_s/S_p) (dimensionless)

structure of collapsed, greatly shrunken capillaries with reduced hydrophilic properties as reflected by the inability to rehydrate fully (Lewicki, 1998). Pre-drying treatments and drying induce changes in structure and composition of plant tissues (Lewicki, 1998), which results in impaired rehydration properties. Consequently, the objectives of this work are to investigate the effects of variety and temperature on moisture transfer during air-drying and rehydration of date palm fruit, and to compute effective moisture diffusivities and activation energies during air-drying and rehydration.

2. Materials and methods

Three varieties of date palm fruits (*Phoenix dactylifera* L.) namely: Red soft type, Tempo 2 and Tempo 3 (*Zabia*) were obtained from the Nigerian Institute for Oil Palm Research (NIFOR) Date Palm Research Sub-Station in Dutse, Nigeria. Fresh mature ripe date palm fruits were collected, sealed 100 μm low density polyethylene and kept at low temperature during transportation (8 ± 2 °C) and prior to use. Average moisture contents of Red soft type, Tempo 2 and Tempo 3 were 59%, 60% and 65% wet basis, respectively.

2.1. Drying pattern of date palm fruit

Fresh mature ripe date palm fruits were weighed and dried in Gallenkamp (Model OV-160) cross flow air oven drier at different temperatures of 50 °C, 60 °C, 70 °C, and 80 °C, and air velocity of 1.5 m^2/s and same orientation of product. Drying process started when constant temperature was achieved in the drier. During drying, pre-weighed dates (about nine fruits per run, 200 ± 3 g) samples were weighed at 10 min internal for the first hour, followed by 30 min for the next hour and subsequently at hourly intervals until three consecutive constant weights (equilibrium) were achieved. On attaining equilibrium, dry weight was determined according to the method of AOAC (1990). Equilibrium moisture content was calculated as the difference between equilibrium weight and bone dry weight divided by the bone dry weight. Drying data was expressed as moisture ratio versus drying time, and drying rate versus moisture content (dry basis). Drying rate was calculated as the amount of water removed per unit time (h). Effective moisture diffusion coefficient (D_{eff}) was determined by plotting ln MR as a function of time from the integrated form of Fick's equation (Eq. (3)), and activation energy as shown by Babalis and Belessiotis (2004) and Senadeera et al. (2003) were adopted (Eq. (4)).

2.2. Theoretical considerations

Fick's second law of the unsteady state diffusion, resulting by neglecting the effects of temperature and total pressure gradients, can describe the transport of water during the food dehydration process that take place in the falling rate period, if only radial diffusion is considered. This can be solved analytically, for the case of drying and rehydration of a spherical body with constant radius R, if we assume constant values of the diffusion coefficient D_{eff} throughout the drying process, uniform initial moisture distribution, and surface moisture equal to the equilibrium moisture content and symmetrical radial diffusion.

The experimental drying data for the determination of diffusivity coefficients were interpreted by using Fick's second diffusion model.

$$\frac{\delta M}{\delta t} = D_{eff}\left(\frac{\delta^2 M}{\delta x^2}\right) \quad (1)$$

$$\mathrm{MR} = \frac{M - M_e}{M_0 - M_e} = \exp(-kt) \quad (2)$$

For a thin layer, the solution of the above Eq. (1), with assumption of moisture migrating only by diffusion, negligible shrinkage, constant temperature and diffusivity coefficient and long drying (or rehydration) times, are given below (Eq. (3)) (Crank, 1975; Senadeera, Bhandari, Young, & Wijesinghe, 2003):

$$\mathrm{MR} = \frac{M - M_e}{M_0 - M_e} = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left(-n^2\pi^2\frac{D_{eff}t}{\psi R_{eq}^2}\right) \quad (3)$$