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Modelling bulk density, porosity and shrinkage of quince during drying: The effect of drying method

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Abstract

The effect of drying method on bulk density, substance density, porosity, and shrinkage of quinces at various moisture contents was investigated. Samples were dehydrated with four different drying methods: conventional drying in fluid bed and tray driers, infrared assisted air drying, osmotic dehydration combined with conventional air drying and freeze drying. All the properties except substance density were affected by drying method. Bulk density of freeze dried materials decreased with decreasing moisture content while for all other dehydration processes, bulk density and porosity increased with decreasing moisture content. Freeze dried materials developed the highest porosity whereas the lowest was obtained using osmotic dehydration. Freeze dried samples had limited shrinkage. Simple mathematical models were used to correlate the above properties with the material moisture content. For the substance density, a single non-linear equation gave accurate predictions irrespective of drying methods. Although differences in shrinkage with the drying method were detected, the same model as a function of moisture content could be used for all drying methods but with different coefficients.

Keywords: Bulk density; Shrinkage; Porosity; Substance density; Quince; Drying methods

1. Introduction

Dehydration of foods is one of the most common processes used to improve food stability, since it decreases the water activity of the material, reduces microbiological activity, and minimizes physical and chemical changes during its storage (Mayor & Sereno, 2004). Drying is a complex process involving simultaneous heat and mass transfer and it can result in significant changes in the chemical composition, structure, and physical properties of food material. Loss of water and heating cause stresses in the cellular structure of the food leading to change in microstructure (e.g. formation of pores) and shrinkage. The development of pores and shrinkage depend upon the variation in moisture transport mechanisms and the external pressure. The strength of the solid matrix can also be affected (e.g. ice formation, case hardening, permeability of crust, and matrix reinforcement) (Rahman, 2003). Thus, the drying method and conditions applied has a significant effect on product characteristics affected by porosity, shrinkage, and bulk density.

Several drying methods have been proposed in the literature so that high quality products are produced efficiently. Conventional air drying (fluid bed drying or tray drying) is one of the most frequently used operations for food dehydration. Final products are characterised by low porosity and high apparent density values. Significant colour changes often occur during air drying (Krokida, Maroulis, & Marinos-Kouris, 1998), while the final product often has poor rehydration capacity (Maroulis, Tsami, Marinos-Kouris, & Saravacos, 1988). Osmotic dehydration minimizes the heat damage on colour and flavour, prevents enzymatic browning and thus limits the use of SO_2 and increases nutrient retention during subsequent air drying (Ponting, Walters, Forrey, Jackson, & Stanley, 1966). During osmotic dehydration apparent density increases, while

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Nomenclature

a_i	numerical constants of empirical equations for bulk density
b_i	numerical constants of empirical equations for shrinkage
dm	dry matter
m	mass, kg
M_{exp}	measured value of data
M_{cal}	estimated value through fitting of the models
S	shrinkage coefficient
R^2	correlation coefficient
RMS	root mean square
V	volume, m^3
W	moisture content, wet basis %
X	moisture content, kg water/kg dry matter

Subscripts

a	air
b	bulk
d	solid
0	initial
s	substance
t	total
w	water

Greek symbols

ε	porosity
ρ	density, kg/m^3

porosity of final product decreases due to solids gain (Krokida & Maroulis, 1997). Freeze drying is one of the most advanced dehydration methods, which provides a dry product with porous structure and little or no shrinkage, superior taste and aroma retention, and better rehydration properties (Krokida et al., 1998). Infrared assisted air drying has been investigated as a potential method for obtaining high quality dried foodstuffs including fruits, vegetables, and grains. Final products are characterised by low porosity and high apparent density values like conventional drying (Baysal, Icier, Ersus, & Yıldız, 2003).

Experimental data reported in previous studies showed that shrinkage and porosity could be related mainly as a function of moisture content for a wide variety of food products (Lozano, Rotstein, & Urbicain, 1983; Suzuki, Kubota, Hasegawa, & Hosaka, 1976). General empirical shrinkage models have been proposed for fruits and vegetables by Kilpatrick, Lower, and Van Arsdel (1955), Lozano, Rotstein, and Urbicain (1980, 1983) and Suzuki et al. (1976). Lozano et al. (1980) described the shrinkage behaviour of apples as a function of moisture content during conventional drying with a linear model. However, it was concluded that non-linear empirical models could describe the shrinkage behaviour more adequately for fruits and vegetables in most studies (Lozano et al., 1983; Mayor & Sereno, 2004; Ratti, 1994).

Porosity is especially important in the reconstitution of the dried products, effectively controlling the speed of rewetting as well as taste and appearance. Information on pore formation and their characteristics in foods during processing is also essential in estimating transport properties (i.e., thermal conductivity and diffusivity, mass diffusivity) and characterising the quality of a dried product (Rahman, 2001). Porosity in fruits and vegetables increases during drying depending on the initial moisture content, composition, and size, as well as on the type of drying (Saravacos, 1967). Lozano et al. (1983) developed a general equation to model the porosity for all foodstuffs valid for all moisture contents. However, this general equation failed to accurately predict the porosity of some foodstuffs (for example, pear and carrots).

Bulk density may vary with water content in the dried food product, and is dependent on the rate of shrinkage, which in turn is strongly affected by the drying method (Van Arsdel & Copley, 1964). Rahman and Potluri (1990) reported that the bulk density of squid flesh during air drying correlated well with the model developed by Lozano et al. (1983), while Marousis and Saravacos (1990) and Nelson (1980) found that a polynomial (third and fourth degree) model fitted their density data on corn, wheat and starch materials, respectively. Madamba, Driscol, and Buckle (1993) found that a second order polynomial model fitted well for fruit and vegetables bulk density data. A linear relationship of bulk density with moisture content was reported for fish (Balaban & Pigott, 1986).

In food systems, shrinkage is rarely negligible and it is necessary to take it into account when predicting moisture content profiles in the material undergoing dehydration. Modelling, design, and control of drying operations require changes in physical dimensions of the product, moisture content, shrinkage, porosity, bulk density, and volume. For such purposes, attempts at modelling shrinkage, porosity and bulk density during drying have been made by several researches for different fruits and vegetables like apple, banana, carrot, potato and garlic. However, no information has been reported on modelling shrinkage, porosity, and bulk density of quince during drying. High dietary fibre content of nearly 12% (dry basis), makes dried quinces an excellent ingredient for cereals, cakes and deserts. The objective of this study was to examine the effect of different drying methods on shrinkage, porosity, and bulk density of quinces and to propose simple mathematical models to predict these properties as a function of moisture content.