Some Physical Properties of Dry Mulberries (*Morus alba* L.)

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ABSTRACT

This study was to present basic principles of physical properties of dried mulberry fruits in order to facilitate the design of some machines for its processing. Several physical properties of dry mulberries were evaluated as functions of moisture content. The average length, width, thickness, geometric mean diameter, sphericity, unit mass and volume of fruit were determined to be 17.60, 9.45, 9.40, 11.58 mm, 66.24%, 0.813 g and 1.25 cm^3, respectively. In the moisture range from 3.64% to 41.36% for rewetted fruit, the bulk density increased from 431.92$kgm^{-3}$to 542.98 kgm^{-3}, the true density increased from 1073.85kgm^{-3} to1271.78kgm^{-3} and the projected area increased from 0.934cm^2 to 1.325 cm^2; however, porosity decreased from 59.77% to 57.30%. In the moisture range from 3.64% to 41.36%., the static coefficient of friction varied from 0.16 to 0.50 for dried mulberries over different material surfaces.

Introduction

Mulberries belong to the genus Morus of the Moraceae family. About 12 species of mulberry are cultivated worldwide and can be classified as foliage, fruit, or timber or for ornamental use (Bellini *et al*., 2000; Machii *et al.,* 2000). Mulberry fruits are consumed fresh and are generally dried or are processed to pekmez, pestil, köme, alcohol or vinegar.

Physical properties of agricultural materials affect how they are processed, handled, stored and consumed and are required in the design of planting, harvesting and post-harvest operations, such as cleaning, conveying and storage (Mosoumi and Tabil, 2003; Kotwaliwale *et al*., 2004, Wilhelm *et al.,* 2004). Size and shape are most common used when describing fruits. Shape and physical dimensions are important in sorting and sizing of fruits, and determine how many fruits can be placed in shipping containers or plastic bags. Quality differences in fruits can be detected by density differences. When fruits are transported hydraulically, the design fluid velocities are related to both density and shape. Volumes and surface areas of solids must be known for accurate modeling of heat and mass transfer during cooling and drying. Porosity, which is the percentage of air space in particulate solids, affects the resistance to air flow through bulk solids. Air flow resistance, in turn, affects the performance of systems designed for force convection drying of bulk solids and aeration systems used to control the temperature of stored bulk solids. Knowledge of frictional properties is needed for design of handling equipment (Jahromi *et al.,* 2008). There are many studies regarding the physical properties and mechanical behaviors of different fruit species (Aydın, 2002; Aydın and Özcan, 2002; Çalışır and Aydın, 2004; Çalışır *et al.,* 2005; Gezer *et al.,* 2002); However, no published literature was found on the physical properties and mechanical behaviors of dried mulberries, despite an extensive search.

The aim of this study was to determine the physical properties and mechanical behaviors of mulberries. The properties and behaviors to be studied included the following: length, width, moisture, thickness, geometric mean diameter, sphericity, unit mass, volume, bulk density, true density, porosity and projected area, which is the ratio of the mass of a sample of a mulberry to its total volume (a moisture-dependent property).

Material and Methods

Dried mulberries (*Morus alba L.*) were used for all experiments in this study. The crop was collected during the 2008 season (midsummer), and the mulberries were cleaned in a cleaner air screen to remove foreign matter (dust, dirt, stones and chaff). Subsequently, the berries were dried under sunlight.

Mulberry samples of the desired moisture levels were prepared by adding calculated amounts of distilled water followed by thorough mixing and subsequent sealing in separate polyethylene bags. The samples were kept at 278 K in a refrigerator for 7 d for the moisture to distribute uniformly throughout the samples. Before the test began, the required quantities of dry mulberries were allowed to warm to room temperature (Deshpande *et al.,* 1993; Çarman, 1996). All physical properties of the mulberries were assessed at moisture levels of 3.46, 11.36, 21.36, 31.36 and 41.36%., with ten replications at each level. In this study, 20 materials in each test were used. To determine the average size of the dried fruit, a sample of 100 mulberries was randomly selected. Measurement of the three major perpendicular dimensions of the mulberry was carried out with a micrometer to an accuracy of 0.01 mm.

The geometric mean diameter (Dp) of the dried fruit was calculated using the following relationship (Mohsenin, 1970): $Dp = (LWT)^{1/3}$

where L is the length, W is the width and T is the thickness (Fig. 1).

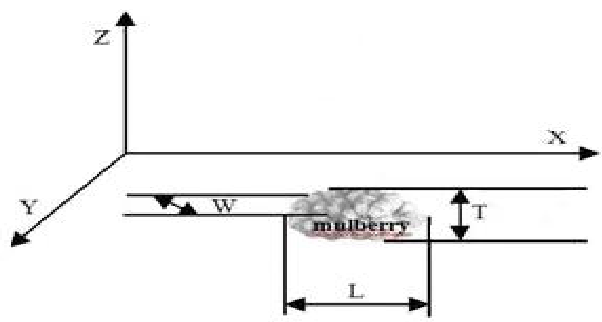

Figure 1. Representation of three axes and three perpendicular dimensions of dried mulberries.

(**The dimensions associated with this figure include the following:*
X-axis*, the longitudinal axis through the hilum, containing the major dimension (length, L);*
Y-axis*, the transverse axis, containing the major dimension (width, W) at right angles to the longitudinal axis; and*
Z-axis*, the transverse axis, containing the minimum dimension (thickness, T)*)).

According to Mohsenin (1970), the degree of sphericity F is expressed as follows:

$\Phi = [(LWT)^{1/3} / L]\ 100.$

This equation was used to calculate the sphericity of the dried mulberry fruit in the present investigation. To obtain the mass, each mulberry was weighed by a chemical balance reading to 0.001 g. Mulberry volume was determined using a liquid displacement method. Toluene (C7H8) was used in place of water because the mulberries absorb less of it. Also, its surface tension is low, so it fills even shallow dips in a mulberry, and its dissolution power is also low (Sitkei, 1986; Öğüt, 1998). Bulk density is a moisture-dependent property that involves the ratio of the mass of a sample of the fruit to its total volume. The bulk density was determined with a weight-per-hectoliter tester, which was calibrated in kilograms per hectolitre (Deshpande *et al.,* 1993). Mulberries were poured into the calibrated bucket up to the top (from a height of about 15 cm), and excess mulberries were removed by a leveling stick. The mulberries were not compacted in any way. The porosity of mulberries at various moisture contents was calculated using the method of Mohsenin (1970) as follows:

$\varepsilon = [(P_t - P_b) / P_t] \times 100$

where ε is the porosity in%, P_b is the bulk density in kg m^{-3}& P_t is the true density in kg m^{-3}.

The projected areas of mulberries were measured by placing them under a thin transparent paper and using a plan-meter equipped with a magnifying glass (Makanjuola, 1972). The terminal velocities of mulberries of different moisture contents were measured in free fall by means of an instrument developed by Keck and Goss (1965). The terminal velocities of mulberries of different moisture contents were measured using an air column. For each test, a small sample was dropped into an airstream from the top of an air column, from which air was blown to suspend the material in the airstream. The air velocity near the location of the mulberry suspension was measured five times by an electronic anemometer with an accuracy of 0.1 m s^{-1} (Joshi *et al.,* 1993).

The coefficients of friction of mulberries at different moisture contents were measured using a friction device. This device, which was developed by Tsang-Mui- Chung *et al.* (1984) and was later improved by Chung and Verma (1989), has three main components, which include a stationary sample container with a support shaft, a driving unit with a rotating disc and a data acquisition system. The samples were placed on the rotating surface of the device, and the torque necessary to restrain the sample was measured by the data acquisition system. This torque was used to determine the static and dynamic coefficients of friction using the following equation (Chung and Verma, 1989):

$\mu = Tm/(wq)$

where μ is the coefficient of friction, Tm is the measured torque, q is the length of the torque arm and w is the sample weight on the rotating surface. The maximum value of torque, which was obtained as the disc started to rotate, was used to calculate the static coefficient of friction, and the average value of the torque during the rotation of the disc was used to calculate the dynamic coefficient of friction.

Results

Dimensions of Dried Mulberry Fruit

Table 1 shows dimensional characteristics of dried mulberry fruit. The average values of length, width, thickness, geometric mean diameter, sphericity, mass and volume were calculated to be 17,60 mm, 9,45 mm, 9,40 mm, 11.58 mm, 66,24%, 0,81g and 1,25cm^3 respectively.The importance of dimensional characteristics is in determining the aperture size of machines, particularly in separation of materials as discussed by Mohsenin (1986).

Table 1. Dimensional characteristics of dried mulberries

Properties	Dried fruits
Length, mm	17.60 ± 1.96
Width, mm	9.45 ± 0.78
Thickness, mm	9.40 ± 0.83
Geometric mean diameter, mm	11.58 ± 0.67
% ,Sphericity	66.24 ± 5.11
Mass, g	0.81 ± 0.07
Volume, cm^3	1.25 ± 0.69

Bulk Density

The values of bulk density of dried mulberry fruits at moisture levels of 3.64–41.36% varied from 431.92 kg m^{-3}to 542.98 kg m^{-3}, which indicated an increase in bulk density with an increase in moisture content (Fig. 2). The bulk density of dried mulberry fruit was found to have the following relationship with moisture content:

$P_b = 3.8095M_c + 438,66$ ($R^2 = 0.9721$)

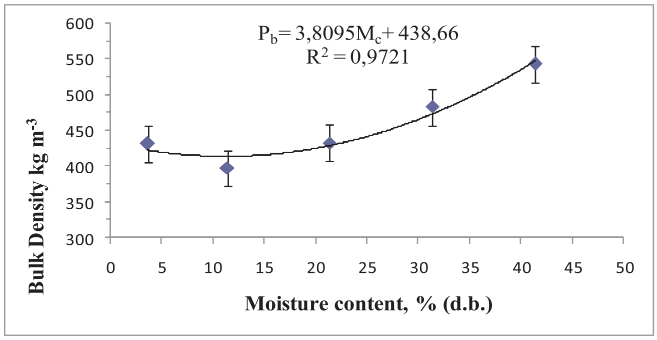

Figure 2. Effect of moisture content on bulk density

True Density

The true density of dried fruit at different moisture levels in the experimental range varied from 1073.85 to 1271.78 kg m^{-3} and indicated that bulk density increased as moisture content increased (Fig. 3). The true density of dried mulberry fruit was found to have the following relationship with moisture content:

$P_t = -3.5599M_c + 1093.8$ ($R^2 = 0.9671$)

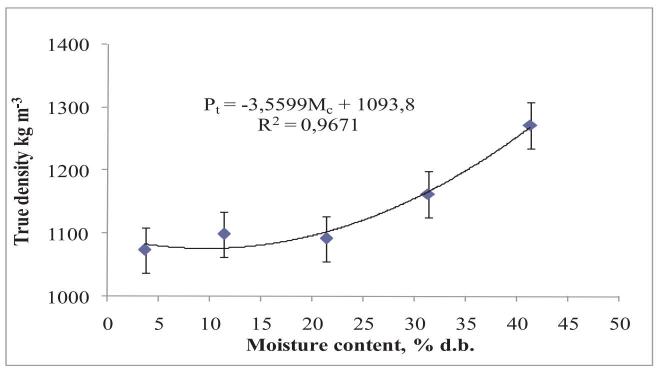

Figure 3. Effect moisture content on true density

Porosity

Because porosity depends on bulk as well as true density, the magnitude of variation in porosity depends on these factors only. The porosity of mulberries was found to slightly decrease with increasing moisture content (3.64–41.36%), as shown in Fig. 4.The relationship between the porosity and moisture content is as follows:

$\varepsilon = 0.252M_c + 59.75$ ($R^2 = 0.718$)

Projected Area

The projected area of mulberry fruit (Fig. 5) increased by about 1.344 cm^2, while the moisture content of mulberries increased from 3.64% to

31.36%. The project area of dried fruit was found to have the following relationship with moisture content:

$P_a = 0.03740M_c + 0.601$ ($R^2 = 0.8841$)

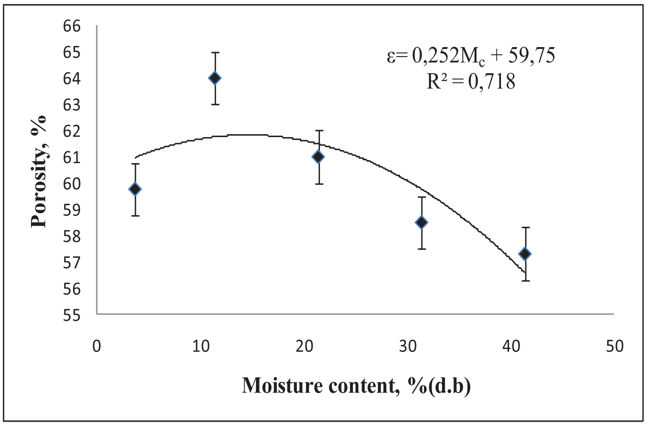

Figure 4. Effect of moisture content on true density

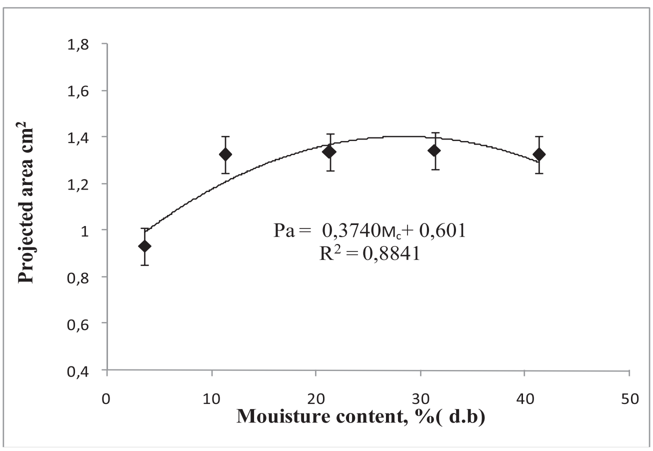

Figure 5. Effect of moisture content on projected area

Static Coefficients of Friction

The static coefficients of friction for mulberries, determined against rubber, plywood and galvanised metal surfaces, are presented in Fig. 6. At all moisture contents, both the static and dynamic coefficients of friction were greatest for mulberries compared to all other materials.

Terminal Velocity

The experimental result for the terminal velocity of dried mulberry fruit at various moisture levels is plotted in Fig. 7. As moisture content increased, the terminal velocity was found to increase linearly. The increase in terminal velocity with increasing moisture content can be attributed to an increase in the mass of an individual fruit per unit frontal area presented to the airstream.

$Vt = 0.010M_c + 9.995$ ($R^2 = 0.917$)

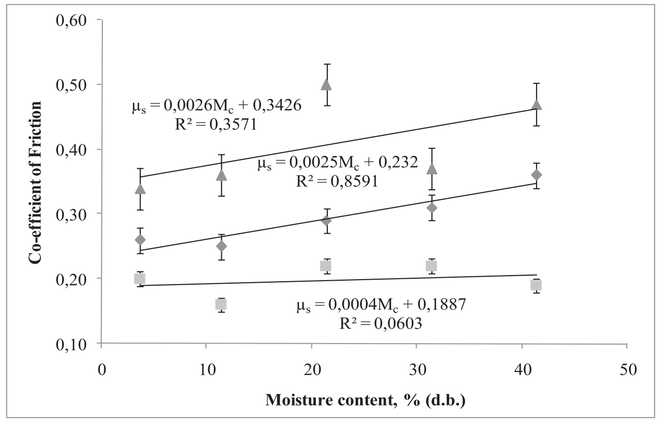

Figure 6. Effect of moisture content on coefficient of friction (▲: *Plastic* ♦: *Plywood* ■: *Galvanised Metal*)

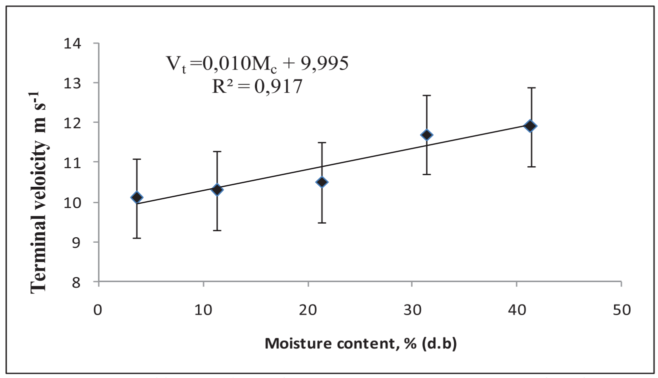

Figure 7. Effect of moisture content on terminal velocity

Conclusions

1. The average length, width, thickness and geometric mean diameter of dried mulberries were 17.60, 9.45, 9.40 and 11.58 mm, respectively, at 3.64% moisture content. The average units mass and volume were 0.813 g and 1.25 cm^3, respectively.
2. The bulk density of mulberries at different moisture levels varied from 431.92 to 542.98 kg m^{-3}, while the porosity decreased from 59.77% to 57.30% as the moisture content increased from 3.64% to 41.36%.
3. The true density of dried mulberries at different moisture levels varied from 1073.85 to 1271.78 kg m^{-3}.
4. The static coefficients of friction of dried mulberries increased with moisture content.
5. The terminal velocity of mulberries increased linearly from 10.1 to 11.9 m s^{-1} as moisture content increased from 3.64% to 41.36%.

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