Al-Azhar Journal of Agricultural Engineering 6 (2024) 38

Contents lists available at Egyptian knowledge Bank (EKB)

Al-Azhar Journal of Agricultural Engineering

journal homepage: https://azeng.journals.ekb.eg/

Full length article

Physical and mechanical properties of white mulberry fruits (Morus alba)

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ARTICLE INFO

Handling Editor - Dr. Mostafa H. Fayed

Keywords:
Physical properties
Mechanical properties
White mulberry

Agricultural Products Process Engineering

ABSTRACT

The aim of this work is to determine and recognize some physical and mechanical properties for white Mulberry fruits as remarkable role in developing and designing of machines as well as, its operations like harvesting, drying and grading. The current study included one variety of white mulberry (Morus alba) to determine its physical and mechanical properties. For each dimension, average values of length and width for white mulberry fruits were 28.48 and 11.88 mm, respectively. The highest value of repose angle was 27.3° for wood while, lowest value was 23.41º for glass. The white Mulberry fruits gave the lowest value of static coefficient of friction of 0.68 for glass while, highest value was 0.85 for wood. The results presented in this research can be used to evaluate the optimal lateral inclination angle of the hopper used in food processing machines such as drying, storage and mixing to allow easy sliding.

1. Introduction

The mulberry tree lives between 200 and 300 years. Morus alba Linnaeusincludes trees, shrubs and herbs. Asia, which has a warm climate, is home to most berries. Mulberry plants are characterized by the presence of milky juice in the buds. These plants are monoecious and dioecious, their flowers are discreet and odorless, while the small and sweet fruits are numerous: drupes or nuts.The leaves are alternate, simple, often lobed and serrated on the margin (Litwinczuk, 1993; Butt et al., 2008). The classification of the genus Morus is very complex. This is due to extensive hybridization in which hybrids are fertile. To date, more than 150 species of mulberry have been described, but only 10 to 16 species are generally recognized by botanists (Datwyler and Weiblen, 2004). Berries are distinguished by their many uses since ancient times. Berries are of great importance and desirable because of their good and attractive flavor, and they can be easily used in food in many forms of nutritional recipes. For example, they are used as juice or in the form of jam and may be added to some foods (Stasinski, 1957).

The seeds contain 25 to 35% yellow oil, which is why mulberry has been used as an oil crop (Sharma and Madan, 1994). Many studies have shown that the mulberry plant is of great importance in many industrial fields, such as the fields of energy, food and medical industries. Many active substances are found in the leaves and fruits of the mulberry plant, as mulberry fruits contain many nutritional elements such as vitamins, mineral salts, and antioxidants (Lochynska and Oleszak, 2011). Berries play a major role in improving human health characteristics. The high-quality protein found in the leaves and fruits of the mulberry plant ranges from 15-31%. Many studies have also proven that the fruits and leaves of the mulberry contain many acids and vitamins, such as folic acid and vitamin D. In addition to the presence of some minerals such as iron, zinc, magnesium, calcium, phosphorus, and potassium (Sharma and Madan 1994; Srivastava et al. 2006; Ercisli and

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https://azeng.journals.ekb.eg/article_249641.1007.html
Peer review under responsibility of Faculty of Agricultural Engineering, Al-Azhar University, Cairo, Egypt.
Received 19 November 2023; Received in revised form 06 December 2023; Accepted 08 December 2023
Available online 1 January 2024

Orhan 2007). Data on the physical & mechanical properties of agricultural crops are of great importance in pre-harvest and post-harvest operations such as sowing operations and serving the crop during cultivation, in addition to other operations such as cooling, freezing and drying. Knowledge of the physical & mechanical properties also helps in choosing the optimal methods for manufacturing the agricultural product during various manufacturing processes (Badr, 2016). The physical & mechanical properties of each material, such as size, shape, volume, surface area, density and coefficient of friction, are significant and essential engineering values in the design and control of machine structures, in analyzing and determining the efficiency of a machine or an operation (Nesvadba, et al., 2004 and Ismail et al., 2010). The main objective of this work was to determine physical & mechanical properties related to handling, storage and planting from the material and color surfaces for a specific variety of Egyptian white mulberry fruit.

2. Materials and methods

2.1. Raw Materials

The white mulberry fruit samples used in this study were obtained from some trees in a farm in Gharbia Governorate, as shown in Fig. 1.

Fig. 1. White mulberry fruit.

All experiments in the present research were carried out in 2022 in a laboratory of the Department of Agricultural Products Process Engineering, Faculty of Agricultural Engineering, Al-Azhar University.

2.2. Physical properties of white mulberry fruit

2.2.1. Properties of dimensional

Two main dimensions were recorded for each fruit, namely the length L "parallel to the longitudinal axis" and the width W "the diameter perpendicular to the longitudinal axis" in mm, as shown in Fig. 2. One hundred fruits of the Morus alba variety were sampled. Length and width in mm were measured with a digital caliper with an "accuracy of 0.01".

2.2.2. Fruit surface area

The surface area of the mulberry fruit under study is an important property that helps in calculations of manufacturing processes such as heat and mass transfer. For example, in the drying process, surface calculation helps in understanding heat transfer and moisture diffusion during the dehumidification process. Surface area is also useful in calculations for the rehydration process for dried products. The following equation was used to calculate the surface area (mm^2) according to (Matthews, 1991) as:

$$a_f = \frac{\pi}{4}(L.W) \quad mm^2 \qquad \text{... [1]}$$

Fig. 2. Length (L) and width (W) of the individual white mulberry fruit.

2.2.3. Mass of one thousand fruits

A random sample of one thousand mulberry fruits was obtained by counting fruits and using a digital electric scale, Sartorius: 1413-MP 8-1, made in Germany, with capacities of 500 g and 5000 g with an accuracy of 0.001 g and 0.01, respectively g weighed. The mass of each treatment was repeated three times.

2.2.4. Fruits bulk density "ρ_b", real density "ρ_r" and void ratio

The bulk *density* "*ρb*, kg/m^3" was evaluated using a 1000 ml graduated measuring cylinder. The volume was evaluated by placing one hundred mulberry fruits in the previous graduated measuring cylinder (Boumans, 1985; Kaleemullah, 1992). Each test was performed in three replicates. The density " *ρb* " of mulberry fruits was evaluated by dividing the mass of the number of fruits "*Mb*, kg" by their volume "*Vb*, mm^3".

$$\rho_b = \frac{M_b}{V_b} \qquad \text{... [2]}$$

The mulberry fruits real density "ρ_r, kg/m^3" was evaluated by measuring the actual volume of a known mass of a randomized sample of mulberry fruit. The actual volume of mulberry fruits was evaluated by the water displacing modality in a 250 mL graduated measuring cylinder; the time of immersion was about 10 seconds, which was too less to absorb water. The mulberry real density " ρ_r " is evaluated by the dividing the mass "*Mr, kg*" on the volume of displaced water "*Vr*, mm^3". The mulberry real density was carried out three times.

$$\rho_r = \frac{M_r}{V_r} \qquad \text{... [3]}$$

2.2.5. The void ratio of mulberry fruits "ε, %"

The ratio of voids between fruits or grains of agricultural products is the ratio of the volume of voids to the volume of solid particles in a porous medium. It is dimensionless quantitative. It can be calculated as follows:

$$\varepsilon = 1 - \frac{\rho_b}{\rho_r} \quad \text{... [4]}$$

2.2.6. The Moisture content "M.C % w.b" of mulberry fruits

The moisture content was recorded for fruits using (AOAC, 1995). Moisture content "M.C" wet basis for white mulberry fruits, "% w.b":

$$M.C = \frac{W_m}{W_m + W_d} \times 100 \quad \text{... [5]}$$

where: W_m and W_d are moisture mass in sample (g) and bone-dry mass in material (g) respectively.

2.2.7. The Repose angle "α" of white mulberry fruits

The angle "*α*" of the white mulberry fruits was determined between the horizontal level and the natural slope of the fruit pile. Various surfaces of selected materials were used for measurements, namely wood, galvanized, glass and sheet metal. The height and diameter of the pile platform were recorded, and the slope angle was evaluated using the following equation (Ismail, 1988; Kaleemullah, 1992; Soliman, 1994; Badr, 2016).

$$\alpha = tan^{-1}\left(\frac{2H}{Dp}\right) \quad \text{... [6]}$$

where: α = mulberry fruits repose angle (degree),
H = height of heap (mm), and
Dp = Diameter of the pile base (mm).

The angle of repose "*α*" for white mulberry fruits was carried out three replicates. It can be calculated as follows:

2.2.8. The coefficient "f_c" of Static friction of white mulberry fruits

The coefficient "f_c" of static friction between the fruits and the different surfaces of the selected materials was recorded, namely: wood, galvanized, glass and sheet surface. The coefficient "f_c" of static friction can be calculated as follows (Mohsenin, 1986):

$$f_c = \tan\theta \quad \text{... [7]}$$

where: θ = the angle of inclination between test surfaces and horizontal level.

The coefficient "fc" of Static friction of white mulberry fruits was recorded three times with the selected materials.

3. Results and discussions

The physical and mechanical properties of the studied white mulberry fruits were determined in a physical properties laboratory at the Faculty of Ag. Engineering, Al-Azhar University, Cairo, Egypt.

3.1. Dimensional characteristics

The average values of one hundred mulberry fruits for two main dimensions are shown in Table 1.

Table 1

The two-Major dimensions of white mulberry fruits.

Two-major dimensions	Max.	Min.	Ave.	S.D	C.V %
Length (mm)	37.35	22.15	28.48	2.89	10.15
Width (mm)	14.60	10.00	11.88	0.83	7.00

The recorded values of length "L" and width "W" in mm of one hundred randomly selected mulberry fruits. The maximum value of fruit length and width was 37.35 and 14.60 mm, respectively, while the minimum value of fruit height and width was 22.15 and 10.00 mm, respectively.

Figs. 3 and 4, show the frequencies "%" of length and width fruits. The highest frequency of values was 46% in the range between of length from 28.23 to before 31.27 mm, while the highest frequency of values was 46% in the range between of width from 10.93 to before 11.84 mm.

3.2. The surface area mulberry fruit

Table 2 shows the flat surface area of the mulberry fruits. The maximum value of the mulberry fruit flat area under this study is 428.29 mm^2, while the minimum value of fruit is 173.97 mm^2.

Table 2

Flat surface area of white Mulberry fruits.

Seed surfaces area (mm^2)	Max.	Min.	Ave.	S.D	C.V %%
Flat surface area (mm^2)	428.29	173.97	267.49	46.05	17.22

Fig. 5 shows that the highest frequency of mulberry fruit flat surface area was 39 % at the range from 224.86 to before 275.72 mm^2.

3.3. Mass of 1000 mulberry fruit, bulk "ρ_b" and real density "ρ_r", void ratio "ε" and moisture content "M.C"

The mass of fruit measurements of 1000 examined white mulberry fruits as well as "ρ_b" and "ρ_r" density; ratio of void "*ε*" and moisture content "*M.C*" were carried out in three replicates.

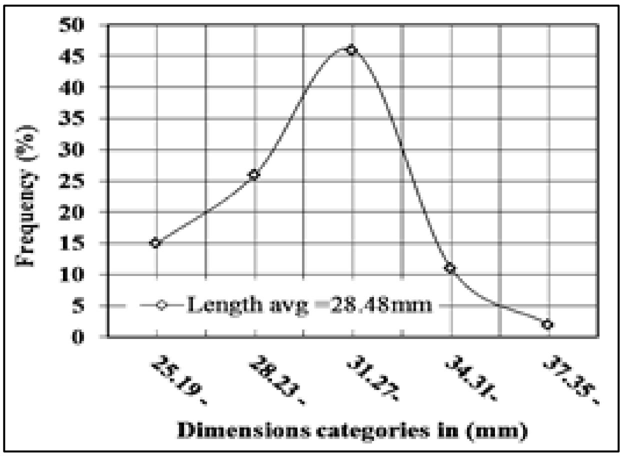

Fig. 3. Length of white Mulberry fruits categories.

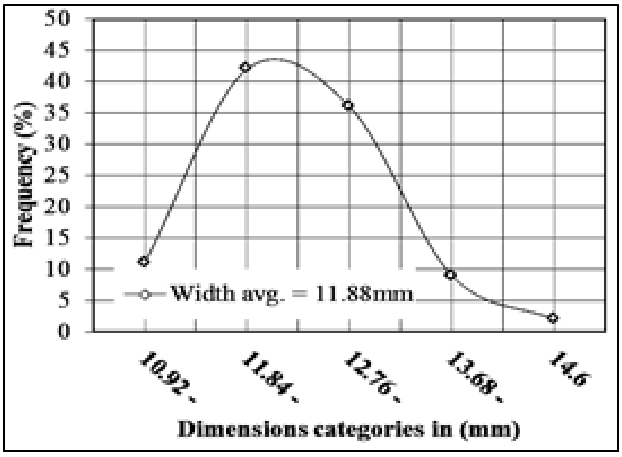

Fig. 4. Width of white Mulberry fruits categories (mm).

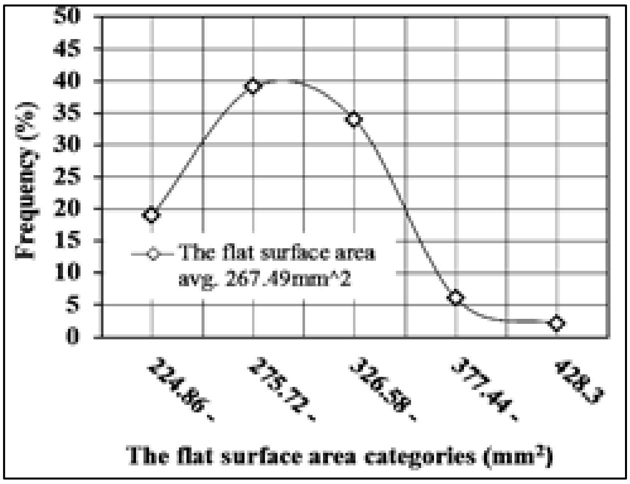

Fig. 5. The flat surface area (mm^2) of the individual Mulberry fruit.

Table 3 shows additional physical properties for mulberry mass, "ρ_b" and "ρ_r" density, "ε" and "M.C". It was found that the previous values were 2360.00 g, 1.18, 0.597 "g/cm3", 49.40% and 82.10% w.b for mass, "ρ_r" density, "ρ_b" density, "ε"and "M.C" respectively. When designing bins, silos and hoppers, the mass of thousand fruit is an important consideration. Fruit mass estimation is necessary to determine the mass required to plant a limited area and number of fruits in each hole. "ρ_b" and "ρ_r" density is important considerations when designing conversion, seeding, drying, aeration and storage systems. Apparent density is also taken into account when determining the side capacity and design dimensions of fruit containers in cleaning and sorting plants.

Table 3

The mass of one thousand fruits, real and bulk density, void ratio and moisture content.

Fruits	Mass (g)	Real density (g/cm^3)	Bulk density (g/cm^3)	Void ratio (%)	Moisture content (%)
	2360.00	1.180± 0.05	0.597± 0.02	49.40	82.10

3.4. Repose angle "α" and coefficient of friction "f_c"

The angle "α" for white mulberry fruits was 27.30°, 24.08°, and 23.41° for wood, galvanized plate, and glass, respectively, as shown in Fig. 6.

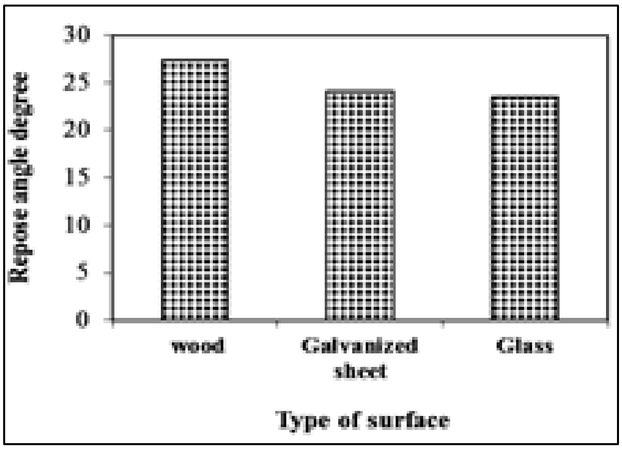

Fig. 6. Angle of repose for white Mulberry fruits on different material surface.

It is clear that the slope angle of white mulberry fruits decreased as the surface of the fruits became smoother.

The lowest values of the coefficient of static friction were found for glass, followed by galvanized plate, and the highest for wood, "0.68, 0.77 and 0.85" for the white Mulberry fruits variety, respectively. As in Fig. 7. The above data can be used to evaluate the optimal lateral inclination angle of the hopper used in food processing machines such as drying, storage and mixing to allow easy sliding.

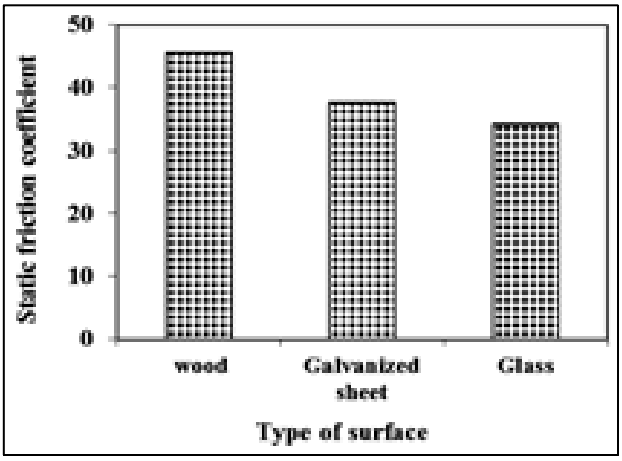

Fig. 7. Static friction coefficient for white Mulberry fruits on different material surface.

4. Conclusions

The most important results obtained in this study:

- The average values of length and width for white mulberry fruits were 28.48 and 11.88 mm respectively.
- The largest surface area of white mulberry fruits was 428.29 mm^2, and the average value was 267.49 mm^2.
- The values of 2360.00 g, 1.180 g/cm3, 0.597 g/cm^3 and 44.00% refer to the mass of 1000 white mulberry fruits, "ρ, ρ_b and ε, respectively.
- The moisture content of white mulberry fruits was 82.10 % w.b.
- The angle "α" for white mulberry fruits was 27.30°, 24.08° and 23.41° for wood, galvanized sheet and glass, respectively.
- The coefficient of friction of white mulberry fruits was 0.85, 0.77 and 0.68 with wood, galvanized plate and glass and respectively.

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بعض الخصائص الطبيعية والميكانيكية لثمار التوت الأبيض

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الملخص العربي

تهدف هذه الدراسة إلى توفير قاعدة معلومات لبعض الخصائص الطبيعية والميكانيكية لثمار التوت الأبيض لما تمثله هذه الخواص من أهمية فى كثير من العمليات التصنيعية المختلفة مثل عمليات التداول والتنظيف والتدريج والتجفيف والعصير التى قد تتم على ثمار التوت محل الدراسة كمراحل أولية فى العمليات التصنيعية المختلفة, وبغرض المساهمة فى تقليل الأضرار الميكانيكية التى تتعرض لها الثمار خلال عمليات التداول المختلفة. وكانت الخصائص الطبيعية المدروسة هى الطول (البعد الموازى للمحور الطولى للبذرة) والعرض (القطر العمودى على المحور الطولى للبذرة) للبذرة (مم) والكثافة الظاهرية والحقيقية (جرام/سم٣) ونسبة الفراغات البينية ووزن الألف حبة و والمحتوى الرطوبى وزاوية المكوث ومعامل الإحتكاك الإستاتيكى للبذور على ثلاثة أسطح مختلفة وهى الخشب والزجاج والصاج. **ويمكن تلخيص النتائج التي توصل إليها البحث فيما يلي:**

- **الخصائص البعدية:** كانت أعلى قيمة للطول (البعد الموازى للمحور الطولى للبذرة) ٣٧,٣٥مم و أقل قيمة ٢٢,١٥مم, وأعلى قيمة للعرض (القطر العمودى على المحور الطولى للبذرة) ١٤,٦٠ مم وأقل قيمة ١٠,٠٠مم وكان متوسط مساحة السطح للثمار ٢٦٧,٤٩ مم٢ .
- **وزن الألف حبة:** أظهرت النتائج أن وزن ألف حبة من ثمار التوت الأبيض كانت ٢٣٦٠,٠٠ جرام.
- **الكثافة الظاهرية** : سجلت ثمار التوت كثافة ظاهرية مقدارها ٠,٥٩٧ جرام/سم٣.
- **الكثافة الحقيقية:** سجلت ثمار التوت كثافة حقيقية مقدارها ١,١٨٠ جرام/سم٣.
- **المحتوى الرطوبى:** سجلت بذور الرمان محتوى رطوبى ٨٢,١٠ ٪ على أساس رطب.
- **زاوية المكوث الطبيعى للأسطح المختلفة:** سجلت ثمار التوت فى زاوية المكوث الطبيعى الإستاتيكى ٢٣,٤١° , ٢٤,٠٨° , ٢٧,٣٠° على أسطح الخشب والصاج والزجاج على التوالى.
- **معامل الإحتكاك الإستاتيكى للأسطح المختلفة:** سجلت ثمار التوت فى معامل الإحتكاك الإستاتيكى ٠,٨٥ , ٠,٧٧ , ٠,٦٨ على أسطح الخشب والصاج والزجاج على التوالى.