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Physical and mechanical properties and mass modeling of Oak marble galls (*Andricus kollari*) based on geometric attributes

Mostafa Bahrami, Ali Nejat Lorestani, Farzad Jaliliantabar* and Rashid Gholami

Agricultural Machinery Department, Faculty of Agriculture, Razi University, Kermanshah, Islamic Republic of Iran

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Some physical and mechanical Properties of Oak marble galls (*Andricus kollari*) were investigated in this study. Physical characteristics such as: dimensions, Arithmetic mean diameter, geometric mean diameter, projected area, sphericity, bulk and true density, mass, volume, porosity and mechanical characteristics such as, coefficient of friction and slide angle, rolling angle, rupture force, deformation at rupture and energy consumed to rupture. These properties were found at specific moisture contents about 6.33% wet basis. The average of length, width and thickness were equal 18.03, 17.61 and 16.73 mm, respectively, while the average sphericity was 96.88 %. True density, bulk density and porosity were 1.03 g/mL, 0.5 g/mL and 0.51%, respectively. The coefficient of friction on glass, plywood, and galvanized iron surfaces was 0.13 to 0.26, 0.31 to 0.38 and 0.43 to 0.57, respectively. The mechanic properties were determined in terms of average rupture force, specific deformation and rupture energy along X- and y -axes. These properties are necessary for the design of equipments for harvesting, processing, and transportation, separating and packing. Also, in this paper the mass of Oak marble galls was modeled with physical properties. There are some situations in which it is desirable to determine relationships between physical attributes. Models for predicting the mass of Oak marble galls from their dimensions and projected area were selected. Models includes: Exponential, Linear, Logarithmic, polynomial, and Power. Also two linear models for whole three diameters and all three projected areas ware picked. According to the results, the best model for prediction the mass of Oak marble galls were based on CPA of the Oak marble galls with determination coefficients of 0.904. At last, mass model based on PA_1 from economical standpoint is recommended.

Key words: Oak, Physical, Mechanical, *Andricus kollari*

* Corresponding author: Farzad Jaliliantabar; e-mail: fjaliliantabar@gmail.com

Introduction

Oak marble galls (*Andricus kollari*) herbal products (shown in the Figure1), and spherical shape of the holes caused by insects to lay eggs on fresh branches of oak trees occurs. This product contains tree sap (gum) and the amount is 50 to 70 percent Oak tanned leather of all materials, more tannin. Oak used in the leather industry, composite manufacturing, dyeing and medical benefits to treat burns. Oak types and colors are different. The gall of some oak species (such as Pedunculate Oak) is achieved. Oak marble gall extract is used in deodorants because of tannic acid's anti-bacterial properties .This product can be found wherever there are oak (such as Iran).

Fig. 1. Oak marble galls

The physical properties of biomaterials are essential is in the design and development of specific equipment and structures for transporting, handling, processing and storage and also for assessing the behavior of product quality (Kashaninejad *et al*., 2005).The dimensions and shape are important in designing separating, harvesting, sizing and size reduction machines (Dash *et al*., 2008).

Many researches have been conducted to find physical properties mechanical of various types of agricultural products such as, Post harvest chemical and physical-mechanical properties of some apricot varieties cultivated in Turkey(Hacıseferogullar *et al*., 2007), Mechanical Behavior of Hazelnut under Compression Loading(uner *et al.*, 2002) Physical Properties of Shelled and Kernel Walnuts as Affected by the Moisture Content (Altuntas and Erkol, 2010), Physical and mechanical properties of Oak fruits(Jaliliantabar *et al*., 2011).

Relationships among physical characteristics; for instance, fruits are often graded by size, but it may be more economical to develop a machine, which grades by weight. Therefore, the relationship between weight andthe major, minor and intermediate diameters is needed (Khoshnam *et al*., 2007; Naderi-Boldaji *et al*., 2008) Recent researches in the field of fruit sorting focused on automated sorting strategies (eliminating human errors). It provides more efficient and accurate sorting systems which either improve the classification success or speed up the process (Polder *et al*., 2003; Kleynen *et al*., 2003; Seyedabadi *et al*., 2011). Fruits are often classified based on the size, mass, volume and projected areas. Electrical sizing mechanisms are more complex and expensive. Mechanical sizing mechanisms work slowly. Therefore it may be more economical to develop a machine, which grades fruits by their mass. Besides, using mass as the classification parameter is the most accurate method of automatic classification for more fruits. Therefore, the relationships between mass and length, width and projected areas can be useful and applicable (Khoshnam *et al*., 2007; Stroshine and Hamann, 1995; Marvin *et al*., 1987; Seyedabadi *et al*., 2011).

Many studies have been reported on the mass modeling of products, such as orange (Tabatabaeefar *et al*., 2000) apple (Tabatabaeefar and Rajabipour, 2005) kiwi fruit (Lorestani and Tabatabaeefar, 2006) apricot (NaderiBoldaji*et al*, 2008) fava bean (lorestani and ghari, 2011) cantaloupe (Seyedabadi *et al*., 2011).

There are no detailed in studying of physical and mechanical properties and mass modeling of Oak marble galls. The aims of this study were to determine the most suitable model for predicting Oak marble galls mass by its physical attributes and study some physical properties of Iranian Oak marble galls to form an important database for other investigators.

Materials and methods

The oak marble galls were procured from the local market of herbal medicines in Kermanshah - Iran which was prepared to investigate the physical properties of the sample, then fifty samples were normal and there was no break in them. Then the samples were transferred to the laboratory, physical and mechanical properties of Agriculture, Razi University in Kermanshah.

Moisture content determination

To determine moisture content, oak marble galls was kept in the oven for 24 h at 104 ℃. Moisture content (m.c.) of product was derived from Equation (1) (Lorestani and Tabatabaeefar, 2006).

$$m.c = \frac{M_0 - M}{M_0} \quad (1)$$

Where: M and M0 are last and initial (before placed in the oven) mass of product.

Size and shape

A vernire caliper was used to measure the axial dimensions of randomly selected 50 Oak marble galls: Length, width and thickness. From the average of axial dimensions the geometric mean diameter Dg and Arithmetic mean diameter Da. (Altuntas and Mehmet, 2007)

$$Da = \frac{(A+B+C)}{3} \quad (2)$$

$$Dg = (ABC)^{0.333} \quad (3)$$

Where: Da, Arithmetic mean diameter in mm.Dg, geometric mean diameter in mm. A, the is the longitudinal axis through the hilum in mm. B, longest axis normal to a in mm, and C, longest axis normal to both a and b in mm. The sphericity was determined using (Mohsenin, 1970):

$$\varphi = \frac{Dg}{a} \quad (4)$$

Projected area

projected areas (PA_1, PA_2 and PA_3) in three perpendicular directions of the Oak marble galls were measured by a ΔT area-meter, MK2 model device with 0.1 cm^2 accuracy and criteria projected area (CPA) is defined as follow(Lorestani and Ghari, 2011).

$$CPA = \frac{PA_1 + PA_2 + PA_3}{3} \quad (5)$$

WherePA_1, PA_2 and PA_3 are first, second and third projected area (mm^2).

Weight and volume

Oak marble galls weight with electronic scales were measured with an accuracy of 0.001 g. Oak marble galls volume by water displacement method (WDM)and using a graduated cylinder has been determined (Jaliliantabar *et al.*, 2011). The WDM is one of the most common and simple means of measuring the volume of large objects such as fruits and vegetables (Mohsenin, 1970). The procedure is as follows: the fruit is first weighed on a scale and then dipped into water with a sinker rod. The weight of the displaced water is then calculated by subtracting the weight of the water-filled container from the weight of the container when it contains the fruit. The resulting value is then used to calculate the volume of the fruit by using (Omid *et al*., 2010):

$$\text{Volume(ml)} = \frac{\text{weight of displaced water(g)}}{\text{water density}\left(\frac{\text{g}}{\text{ml}}\right)} \quad (6)$$

Bulk and true densities

The bulk density was determined by filling an empty 160 ml graduated cylinder with the seed and weighed The weight of the seeds was obtained by subtracting the weight of the cylinder from the weight of the cylinder and Oak marble galls. To achieve uniformity in bulk density the graduated cylinder was tapped 2 times for the Oak marble galls to consolidate.

The volume occupied was then noted. The process was replicated four times and the bulk density for each replication was calculated from the following relation:

$$\rho_b = \frac{W_s}{V_s} \quad (7)$$

where: the ρ_b is the bulk density in g/ml W_s is the weight of the sample in kg; and V_s is the volume occupied by the sample in mm^3. The true density ρ_t was defined as the ratio between the mass of Oak marble galls and the true volume of the Oak marble galls, and determined using the water method.

Porosity

This was calculated from the values of bulk and true densities using the following relationship (Mohsenin, 1970)

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \quad (8)$$

Where: the ρ_t is the true density in $Kg.m^{-3}$ and ε is the porosity.

Coefficient of friction and Slide angle and rolling angle

Coefficient of static friction of Oak marble galls on three surface including plywood, galvanized steel, and glass was determined by automatic machine. So I was stuck in the top two Oak marble galls in 15 replications for each surface. Rolling angle of Oak marble galls on one surface including wood was determined by automatic machine.

Mechanical properties

To determine the mechanical properties of Oak marble galls, a biological material test device was used. This device has three main components, which are moving platform, a driving unit and a data acquisition (load cell, PC card and software) system as shown in Fig. 2. The Oak marble galls was placed on the moving platform considering the variation of loading position at the 5 mm/min speed and pressed with a plate fixed on the load cell until the Oak marble galls ruptured. Force-deformation curves were recorded. The mechanical behavior Oak marble galls were expressed in terms of rupture force, specific deformation, and rupture energy required for initial rupture. 15 samples in each test were used. The two compression axes (X, Y,) for Oak marble galls were used to determine the specific deformation, Elasticity modulus, rupture force and rupture energy (Fig. 2). The X-axis (force Fx) is the longitudinal axis through the hilum (A), while the Y-axis (force Fy) is transverse axis (Altuntas *et al*., 2007).


Fig. 2. Biological material test device

After measuring the size, mass, volume and projected areas, Excel 2007 and SPSS 19.0 programs were used for regression.

In order to estimate mass models of Oak marble galls, the following models were considered (lorestani and ghari, 2011).

Single variable regression of Oak marble galls mass based on Oak marble galls dimensional characteristics: length (A), width (B), thickness (C), and geometric mean diameter (Dg).

Single variable regressions of Oak marble galls mass based on Oak marble galls projected areas and criteria projected area.

Single variable regression of Oak marble galls mass based on measured volume.

Single variable regression of Oak marble galls mass based on surface area. In all cases, the results which were obtained from experiments were fitted to Exponential, Linear, Logarithmic, polynomial, and Power models which are presented as following equations, respectively:

$$M = b_0 e^{b_1 X}$$
$$M = \mathrm{b}_0 X + b_1$$
$$M = b_0 Ln(X) + b_1$$
$$M = b_0 \mathrm{X}^2 + b_1 X + b_2$$
$$M = b_0 \mathrm{X}^{b_1}$$

Where M is mass (g), X is the value of a parameter (independent parameter) that we want to find its relationship with mass, andb_0,b_1 and b_2 are Oak marble galls fitting parameters which are different in each equation. Also two linear models for whole three diameters and all three projected areas ware selected. The general forms of these models are shown in the following equation.

$$M = b_0 A + b_1 B + b_2 C + b_3$$
$$M = b_0 PA_1 + b_1 PA_2 + b_2 PA_3 + b_3$$

Where length (A), width (B), thickness (C) in mm and PA_1, PA_2 and PA_3 are first, second and third projected area (mm^2). b_0 , b_1, b_2 and $b_3$are constant.

One evaluation of the goodness of fit is the value of the coefficient of determination. For regression equations in general, the nearer R^2 is to 1.00, the better the fit (Stroshine, 1998; lorestani and ghari, 2011).

Results and discussion

Physical properties

Some physical properties are given in Table 1. These properties were found at specific moisture contents about 6.33% wet basis. This property such as the average size of the dimensions A, B and C as given in (Table. 1) equals 18.03, 17.61 and 16.73, respectively while the average sphericity was 96.88% and True density, bulk density and porosity were 1.03$^{g}/_{mL}$, 0.5 $^{g}/_{mL}$and 0.51, respectively while data pertaining to mean length, width, Thickness, geometric mean, coefficient of sphericity, projected area, mass, volume of Oak marble galls as shown in Table 1.

Table 1. Several physical properties of Oak marble galls

Properties	Min	Max	Average	Sd*	C.V.(%)**
A (mm)	13.7	22.13	18.03	1.94	10.78
B (mm)	13.83	23.39	17.61	1.80	10.22
C (mm)	12.89	19.92	16.73	1.62	9.71
D_g (mm)	13.64	21.51	17.44	1.69	9.70
D_t(mm)	13.65	21.57	17.46	1.69	9.72
φ%	86.35	104.49	96.88	3.81	3.93
V (mL)	1.14	4.23	2.46	0.64	25.94
$PA_1(mm^2)$	129	304.5	209.41	38.51	18.39
$PA_2\ (mm^2)$	133.8	294.7	210.01	37.73	17.96
$PA_3(mm^2)$	22.9	293.6	199.16	45.09	22.64
$CAE\ (mm^2)$	131	297	206.19	38.26	18.55
M (g)	1.21	4.06	2.53	0.64	25.31
$\rho_t\ (^g/_{mL})$	0.55	1.43	1.03	0.13	13.21

*Standard deviation **Coefficient of variation

The importance of these and other characteristics axial dimensions in determining aperture sizes and other parameters in machine design have been discussed by Mohsenin (1986).

The dimension properties was reported for shelled walnut by Altuntus and erkol (2010) approximately 72% of the shelled walnuts had a lent ranging from 42.79 mm to 45.46mm, about 78% of the samples a width ranging from 35.96 mm to 37.58 mm, about 75% a thickness ranging from 34.21 mm to 36.21.also the dimension properties was reported over one variety of hazelnut by Uner *et al*. (2009) the nut size had a length 19.76 mm, width 16.53 mm, thickness 14.46mm.

The geometric mean of the axial dimensions is useful in the estimation of the projected area of a particle moving in the turbulent or near- turbulent region of an air steam. This projected area of the particle is generally indicative of its pattern of behavior in a flowing fluid such as air, as well as the ease of separating extraneous materials from the particle during cleaning by pneumatic means (Heidarbeigi, 2008).

Mechanical Properties

Coefficient of static friction and sliding angle of Oak marble galls on three surface including plywood, galvanized steel, and glass were shown in the

Table. 2. The average values of static coefficient of friction against plywood, galvanized iron sheet and glass sheet were 0.43, 0.34 and 0.21, respectively. The static coefficient of friction is used to determining the angle at which chutes must be positioned in order to achieve consistent flow of material through it. (Heidarbeigi. *et al*., 2008) The min, max and average values of rolling angle against plywood sheet were 9.62, 29.82 and 18.29, respectively.

The force required to initiate Oak marble galls rupture at compression axes is presented in Table 3 for X-axes and Table 4 for Y-axes. It can be observed from the Tables 3 and 4, that the average force required to initiate break of Oak marble galls along the Y-axes as more than X-axes was 236.44N .while in the last research by (Jaliliantabar *et al*., 2011) the rupture force of oak fruit was more than 500N. Elasticity modulus and other mechanical parameters were shown in the Tables 3 and 4.

Table 2. Coefficient of friction and slid angle

Sheets	Properties	Min	Max	Average	Sd*	C.V. (%)**
Plywood	Coefficient of friction	0.43	0.57	0.43	0.07	16.28
	Slide angle (deg)	18.91	30.47	24.04	3.36	14.00
Galvanized iron	Coefficient of friction	0.31	0.38	0.34	0.021	6.10
	Slide angle (deg)	17.42	20.98	19.36	1.01	5.26
Glass	Coefficient of friction	0.13	0.26	0.21	0.03	17.00
	Slide angle (deg)	7.61	19.92	16.73	1.62	9.71

*Standard deviation **Coefficient of variation

Table 3. Mechanical properties of X-axes

Properties	**Min**	**Max**	**Average**	**Sd ***	**C.V. (%) ****
W to f break Nmm	22.24	152.59	89.40	44.21	49.45
E mod GPa	1.13	6.73	3.76	1.83	48.63
Dl at f break mm	0.4	1.1	0.79	0.22	28.38
F break N	93.8	308	201.78	80.29	39.79

*Standard deviation **coefficient of variation

Table 4. Mechanical properties of Y-axes

Properties	Min	Max	Average	Sd *	C.V. (%) **
W to f break Nmm	67.09	209.28	108.22	44.31	40.95
E mod GPa	0.947	5.91	3.88	1.57	40.62
Dl at f break mm	0.6	1.3	0.91	0.24	26.57
F break N	164	352	236.44	64.41	27.24

*Standard deviation **Coefficient of variation

Table 5. The best models for prediction the mass of Oak marble galls with some physical characteristics

Dependent parameter	**Independent parameters**	**The best model**	**Constant values of model**			$\mathbf{R^2}$
			b_0	b_1	b_2	
M (g)	A (mm)	Power	0.005	2.109	-	0.736
M (g)	B (mm)	Power	0.002	2.361	-	0.812
M (g)	C (mm)	Power	0.002	2.464	-	0.833
M (g)	D_g (mm)	Exponential	0.185	0.148	-	0.866
M (g)	V (mL)	polynomial	-0.053	1.149	0.039	0.761
M (g)	$PA_1 (mm^2)$	Power	0.002	1.332	-	0.896
M (g)	$PA_2\ (mm^2)$	Power	0.001	1.369	-	0.894
M (g)	$PA_3 (mm^2)$	Power	0.002	1.327	-	0.872
M (g)	$CAE\ (mm^2)$	Power	0.001	1.368	-	0.904

Mass modelling

The best regression models obtained for prediction the mass of Oak marble galls with some physical are shown in Table 5. For mass modeling reported by Lorestani and Ghari (2011) of Fava bean The best model for prediction the mass of Fava bean was based on third projected area which perpendicular to Length direction of Fava bean and it was Power form as: $M = 0.006\ \mathrm{PA3}^{1.071}$, $R^2 = 0.657$.Another research showed that apricot mass model obtained based on the minor diameter ($M = 2.6649\ C - 66.412$, $R^2 = 0.954$) is recommended (Naderi-Boldaji *et al*., 2008) and for mass modeling reported by Seyedabadi *et al*. (2011) The model to predict the mass of cantaloupe based on the estimated volume of cantaloupe (oblate spheroid shape) was found to be most appropriate for sorting systems: $M = 2.198 V_{obl}^{0.884}$, $R^2 = 0.986$; where $V_{obl} = \frac{4}{3}\pi \left(\frac{a}{2}\right)^2 \left(\frac{b}{2}\right)$

For prediction of the mass of Oak marble galls based on projected areas including PA_1, PA_2 and PA_3 and criteria projected area (CPA). The best model was Power for CPA with $R^2 = 0.904$:

$$M = 0.001\mathrm{CPA}^{1.368} \quad R^2 = 0.904$$

According to the results, for prediction of the mass of the Oak marble galls based on geometric mean diameter D_g, Exponential model was the best model with$R^2 = 0.866$:

$$M = 0.185e^{0.148D_g} \quad R^2 = 0.866$$

This model is not economical because for calculating the geometric mean diameter (D_g) we must measure three dimensions of Oak marble galls and it is time consuming and costly.

For mass modeling of Oak marble galls based on volume, the best model was polynomial with $R^2 = 0.761$:

$$M = -0.053V^2 + 1.149V + 0.039 \quad R^2 = 0.761$$

The best model was power for CPA with $R^2 = 0.904$ because one evaluation of the goodness of fit is the value of the coefficient of determination. For regression equations in general, the nearer R^2 is to 1.00, the better the fit. But this model is not economical because for calculating the CPA we must measure three second projected areas of Oak marble galls and it is time consuming and costly. So we suggest the power model based on PA_1 for prediction the mass of Oak marble galls because we need one camera and it is applicable and economical method. This model is power with$R^2 = 0.896$

$$M = 0.002{PA_1}^{1.332} \quad R^2 = 0.896$$

The Regression linear models obtained for prediction the mass of Oak marble galls based on whole three diameters and all three projected areas are shown:

$$M = 0.092A + 0.118B + 0.143C + -3.619 \quad R^2 = 0.861$$

$$M = -3.504 \times 10^{-5}PA_1 + 0.015\,PA_2 + 0.001\,PA_3 + -0.815 \quad R^2 = 0.878$$

But these models are not economical too. According to the results the Power model could predict the relationships among the mass and some physical properties of Oak marble galls for determination coefficient.

Conclusion

According to the results, the mean values of properties which were studied in this research (length, width, thickness, geometric mean diameter, volume, mass ,projected areas and criteria projected area) are 18.03mm, 17.61mm, 16.73mm, 17.44mm, 2.46cm^3, 2.53g, 209.41mm^2, 210.01 mm^2, 199.16 mm^2, and 206.19 mm^2 respectively.

The average values of static coefficient of friction against plywood, galvanized iron sheet and glass sheet were 0.43, 0.34 and 0.21, respectively.

The average values of rupture force, specific deformation, Elasticity modulus, energy required for initial rupture on X-axes were 201.78 N, 0.79 mm, 3.76 GPa, 89.40Nmm and on Y-axes were 236.44 N, 0.91mm, 3.88 GPa, 108.22Nmm, respectively.

The best model for prediction the mass of Oak marble galls based on CPA was Power:$M = 0.001CPA^{1.368} \quad R^2 = 0.904$

At last, economical model based on projected area was Power:$M = 0.002{PA_1}^{1.332} \quad R^2 = 0.896$

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