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Some Physical Properties of Strawberry (Kurdistan Variety)

Hadi Samimi Akhijahani and Jalal Khodaei

Department of Mechanical Engineering of Agricultural Machinery,
Faculty of Agriculture, University of Kurdistan, Sanandaj, Iran

Abstract: A range of physical properties of strawberry (Kurdistan variety) were determined as a function of moisture content. As the moisture content was increased from 24.85 to 90.20% d.b. the average length, width, thickness and the geometric mean diameter of strawberry varied from 18.22 to 24.27, 11.01 to 22.23, 7.24 to 19.66 and 11.36 to 21.97 mm, respectively. In the same moisture content range, the study showed that sphericity, surface area and thousand fruit mass, bulk and true density were increased from 0.62 to 0.91, 405.80mm^2 to 1516.62mm^2, 554.21g to 3668.70g, 316.00kg/m^3 to 551.80 kg/m^3, 624.33kg/m^3 to 1545.24 kg/m^3, respectively. In addition, as the moisture content was increased from 24.85 to 90.20% d.b. the terminal velocity of strawberry was increased from 11.88 to 20.47 m/s. The static coefficient of friction was linearly increased with an increase in the moisture content for all contact surfaces (Plywood, aluminum, rubber and galvanized iron). The research indicated that the plywood surface had maximum static coefficient of friction. Crushing strength of strawberry fruit was decreased from 103 to 24N, with increasing moisture content from 24.85 to 90.20% d.b. respectively.

Key words: Moisture content · Engineering properties · Strawberry · Terminal velocity

INTRODUCTION

Strawberry fruit is known as a medicinal and ornamental plant in the world. This fruit is used in medicine to cure rheumatism, heart and stomach cancer, blood purification and as mouth scent. It has some vitamins such as *E*, *C*, *B* and some protectors such antioxidant [1]. In Iran strawberry is generally produced in the western part of country, Kurdistan province, in more than 3800 ha with an annual fresh production of 40,000 tons that mostly supply the market in the dry form of products. The Kurdistan variety of strawberry, as shown in Figure 1, is beautiful, delicious and red in color [1].

The moisture dependent characteristics of physical properties of agricultural products affect the adjustment and performance of processing machines. A range of moisture content usually exists within which optimum performance of the machine could be achieved [2]. The effect of moisture content on the physical properties of strawberry is important in the design of handling and processing equipment such as packaging machines and dryers.

Fig. 1: Strawberry fruit (Kurdistan variety)

Many studies have been reported on the physical properties of fruits, grains and seeds, such as Juniperus drupacea fruits [3], bambara groundnuts [4], hackberry [5], fababeans [6], apricot pit [7], sunflower seeds [8], pumpkin seeds [9], chickpea seeds [10], cactus pear [11] and caper fruit [12].

Strawberry is a sensitive fruit that may be easily destroyed subject to a small force; therefore, its preservation and handling is very difficult. Mehmet *et al.* (2006) investigated the chemical composition, physical properties and mineral contents of strawberry (Arbutus *unedo* L.) fruit in Turkey, but little information

Corresponding Author: Hadi Samimi Akhijahani, Department of Mechanical Engineering of Agricultural Machinery, Faculty of Agriculture, University of Kurdistan, Sanandaj, Iran.
Tel: +98 871 6620552, Fax: +98 871 6620552, E-mail: hsamimia@gmail.com.

is known about the physical properties of strawberry fruit and its relationship with moisture content [13]. Since no research have been reported yet on the physical properties of the strawberry fruit and their relationship with moisture content, this study was carried out in order to investigate these properties.

MATERIAL AND METHOD

The strawberry used in this study was obtained from the local market during May and June, 2010 in Kurdistan province, Iran. The fruits were manually cleaned to remove all foreign matter, burst and immature fruits. The remaining fruits were packed in hermetic glass vessel and were stored in refrigerator to prevent undesirable effect at determined temperature of about +5°C until use. Initial moisture content of fresh strawberry fruits was obtained using oven method. A sample of 20g in four replicates was dried in a hot oven at 75 ± 2°C for 24 hours until the mass did not change between the two weighing intervals [14]. Initial moisture content was about 90.28% (d.b.) using a precision balance with an accuracy of 0.01 g, having capacity of 400 g. The required fruits were taken randomly from the vessels and dried down to the desired moisture content (MC) by the oven method before tests [4]. For the determination of all MCs, four replicates were applied to get an average value of MC for any sample. Weight loss on drying to a constant final weight was recorded as moisture content based on the developed method AOAC (1984) and using the following equation [15]:

$$MC = \frac{M_o - M_s}{M_o} \times 100 \qquad (1)$$

where, MC is moisture content (d.b.), M_o is initial mass and M_s is the final mass of strawberry fruit (g). Moisture content of strawberries had fallen down to 81.32, 66.33, 50.42 and 24.85 (d.b.) respectively. The physical properties of the fruits were determined at the above moisture contents.

A digital vernier caliper (*In size model*) with the sensitivity of 0.01 mm was used to measure the axial dimensions of randomly selected 100 strawberry fruits; length, width and thickness. Geometric mean diameter (D_g), sphericity (ϕ) and surface area (S) were calculated using the following equations [16, 11]:

$$D_g = (LWT)^{1/3}$$
$$\phi = D_g / L$$
$$S = \pi D_g^2$$

where L is the length, W is the width and T is the thickness of the fruit (Figure 2).

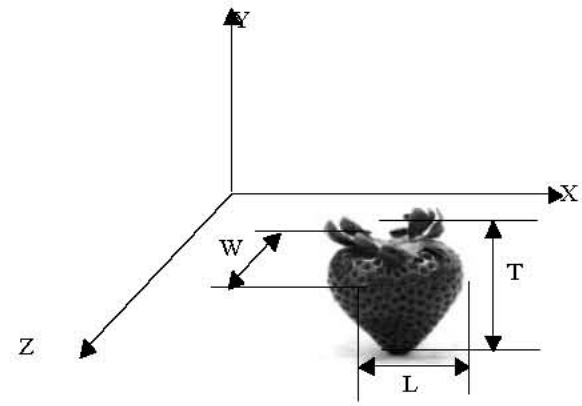

Fig. 2: Three major dimensions of strawberry`

The mass of strawberry fruit was determined using one hundred randomly selected fruits and converted to a 1000 fruits basis. Fruit unit mass (M_f) and 1000 fruit mass (M_{1000}) were measured using an electronic digital balance with 0.01g sensitivity [17].

The strawberry fruit's volume (V) and its density (ρ_f), as a function of moisture content, were determined, using the liquid displacement method. Toluene (C_7H_8) was used, rather than water, because it was not absorbed by the fruits. Also, its surface tension is low, so that it fills even shallow dips in a fruit and its dissolution power is low [17, 18, 13].

The bulk density (ρ_b) was determined with a hectoliter tester calibrated in kilogram per hectoliter [19]. The strawberries were dropped down into a bucket from a height of approximately 15 cm. The extra strawberry was removed by sweeping the surface of the bucket. The fruits were not compacted in any way [17 and13].

The porosity ϵ was calculated from the values of bulk and true densities using the following relationship:

$$\varepsilon = 1 - \rho_b / \rho_f$$

where ρ_b is bulk density and ρ_f is fruit density in kg/m^3 respectively [16, 20].

The terminal velocities of strawberry fruit at different moisture contents were measured using an air column device. For each test, a sample was dropped into an air stream from the top of the air column. Airflow rate was then gradually increased until the fruit became suspended in the air stream. The air velocity which kept the fruit in suspension was measured using an electronic anemometer (*YK-2005AM*) model having at least count of 0.1 m/s. Each sample consisted of 20 fruits selected randomly at the same moisture content. Three replications were taken for each sample [21, 22].

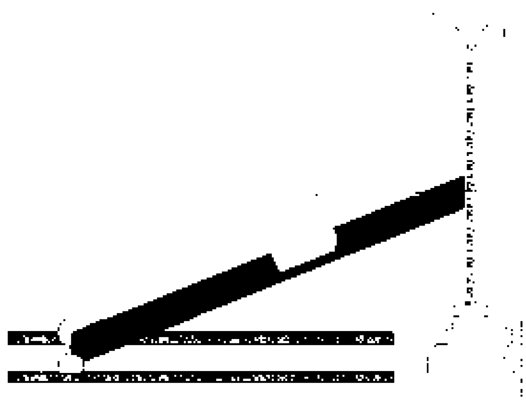

Fig. 3: Apparatus for measuring static coefficient of friction

The coefficient of static friction was determined with respect to different surfaces: Plywood, aluminum, rubber and galvanized iron. A hollow metal cube (Figure 3) opened at both ends was filled with the fruits placed on an adjustable surface such that the metal cube did not touch the surface. The surface was then raised gradually until the filled cube just started to slide down. The vertical and horizontal height values were the ruler when the fruit started sliding over the surface, the tangent value of the created angle gives the coefficient of static friction [7 , 23].

Crushing strength of strawberry was measured using an Instron Universal Testing Machine (Model Santam STM-5), that is equipped with a 25 kg compression load cell and integrator, with speed of load 5 mm/min was used for this test. The measurement accuracy was 0.001 N in force and 0.001 mm in deformation. The fruit was placed on the stationary lower plate along its natural rest position and pressed with the moving plate for the various moisture contents [24]. The individual fruit was loaded between mentioned parallel plates of the machine and compressed at the present condition.

RESULT AND DISCUSSION

Fruit Dimensions: The mean and standard errors of the axial dimensions of strawberry at different moisture contents are given in Table 1. According to the results, three axial dimensions were increased significantly ($P<0.05$) with moisture content in the moisture range of 24.85 to 90.20% d.b. when the moisture content of strawberry increases, the average length, width and thickness of fruits increases from 18.22 to 24.27 mm, 11.01 to 22.23 mm 7.24 to 19.66 mm, respectively (table1). ANOVA results showed that the differences among moisture levels were statistically significant ($P<0.01$) for length, width and thickness. Similar results of increase are reported for soybean [19], lentil seeds [25], sunflower seed [8], raw cashew nut [26], chickpea [10], safflower [27], cactus pear [11], caper fruit [12], jatropha fruit [24].

The Geometric Mean Diameter, Sphericity and Surface Area: Results show that geometric mean diameter, sphericity and surface area increase linearly with the increase in moisture content ($P<0.01$) (table1). The geometric mean diameter, sphericity and surface area were 11.36mm, 0.62 and 405.08 mm^2 at moisture content of 25.85% d.b. and 21.97mm, 0.91 and 1516.62mm^2 at moisture content of 90.20% d.b. respectively. Similar results have been reported for caper fruit [12], jatropha fruit [24]. The effect of moisture content on the seed sphericity is presented in Figure 4. The relationship between sphericity and moisture content was found to be linear and can be expressed using the following equation with a coefficient of determination of 0.87:

$$\phi = 0.004MC + 0.46$$

Thousand Fruit Mass: The thousand fruit mass of strawberry in g was increased from 554.21 to 3668.7 g as the moisture content was increased from 24.85 to 90.20% d.b. (Figure 5). This is expressed by the following equation:

Table 1: Axial dimensions of strawberry fruits at different moisture contents

Moisture content, % w.b.	Axial dimensions, mm: Length	Width	Thickness	Geometric mean(mm)	Sphericity (decimal)	Surface areas (mm^2)
24.85	18.22(3.09)*	11.01(1.81)	7.24(2.21)	11.36	0.62	405.08
50.42	18.11(2.21)	12.29(2.12)	8.25(1.55)	12.24	0.67	471.08
66.33	19.54(2.66)	13.62(2.73)	10.02(2.88)	13.88	0.71	604.88
81.32	21.12(3.44)	16.44(3.09)	14.35(2.85)	17.08	0.89	916.98
90.20	24.27(3.09)	22.23(3.51)	19.66(2.85)	21.97	0.91	1516.62

*Values in parentheses are standard deviation

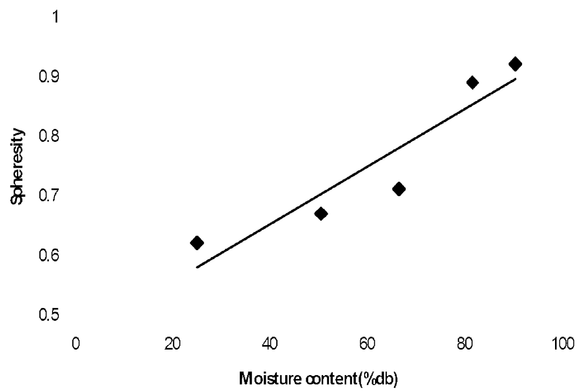

Fig. 4: Variation of the sphericity of strawberry fruit with moisture content

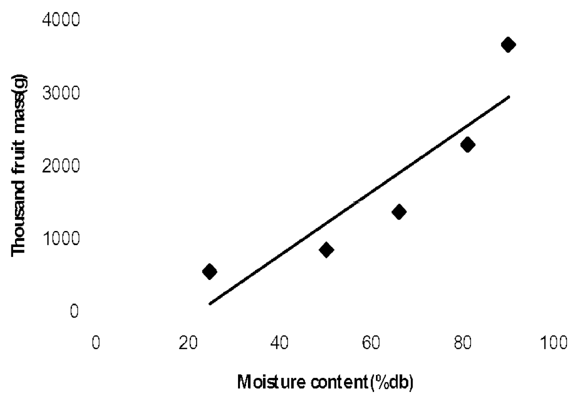

Fig. 5: Effect of moisture content on the thousand fruit mass

$$TFM = 43.65MC - 984.9$$

With a coefficient of determination of 0.81. Similar trends found for cotton seed [28], hemp seed [22] and jatropha fruit [24].

Surface Area: As seen from Table 1 and Fig 6, the surface area of strawberry fruit increases exponentially from 405.08 to 1516.62mm^2 (statistically significant at $P<0.01$), when the moisture content increases from 25.85% to 90.20% d.b (Figure 6). A similar trend has been reported for caper (*Capparis ssp.*) fruit [12]. The variation of moisture content and surface area (S) can be expressed mathematically as follows:

$$S = 0.616\ e^{0.083MC} + 422.97$$
with the value of R^2 equals 0.99.

Bulk and True Density: As the moisture content increased from 24.85 to 90.20% d.b. the bulk density increased from 316.00 to 551.80kg.m^{-3} (Figure 7).

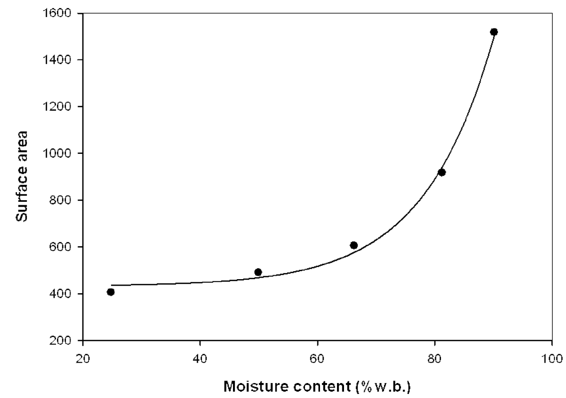

Fig. 6: Variation of the surface area of strawberry fruit with moisture content

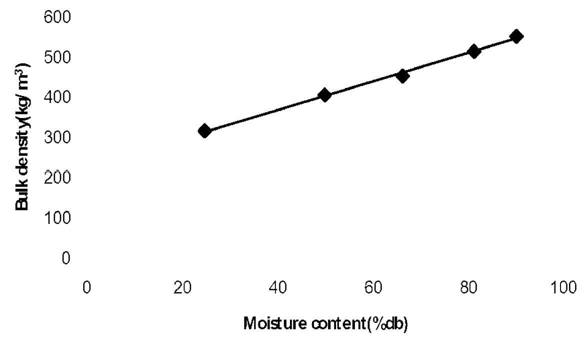

Fig. 7: Effect of moisture content on bulk density of strawberry fruit

The variation of bulk density was linear with the moisture content and can be expressed as follows:

$$\rho_b = 3.57\ MC + 224.3$$
with the value of R^2 equals 0.99.

The true density of the fruit was measured at different moisture contents and was linearly increased by increasing the moisture level and the true density of strawberry, varied from 624.33 to 1545.24 kgm^{-3}. The increase ($P < 0.01$) in true density value with the increase in moisture content might be attributed to the relatively lower true volume as compared to the corresponding mass of the fruit (Figure 8). The moisture dependence of the true density, ρ_t, is described by a linear equation as follows:

$$\rho_t = 12.95MC + 235.4$$
with the value of R^2 equals 0.89.

Different results were reported in some previous studies i.e. bulk density increases for apricot pit (Gezer *et al*. 2002) and cactus pear [11] and decreases for

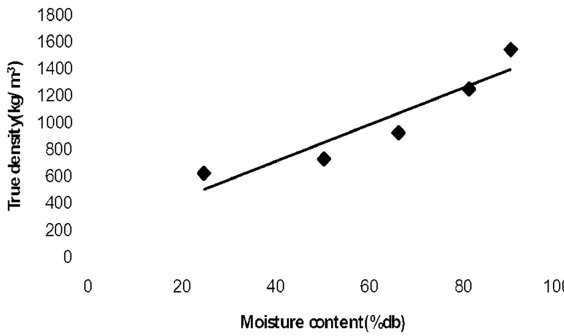

Fig. 8: Effect of moisture content on true density of strawberry fruit

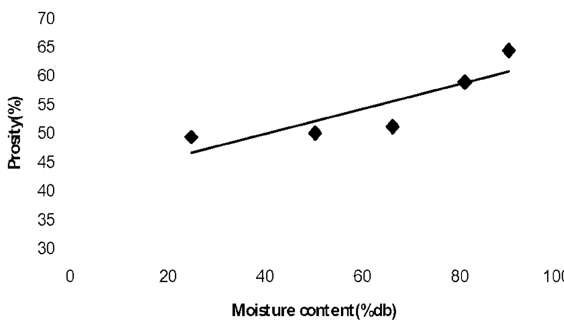

Fig. 9: Porosity variation with fruit moisture content

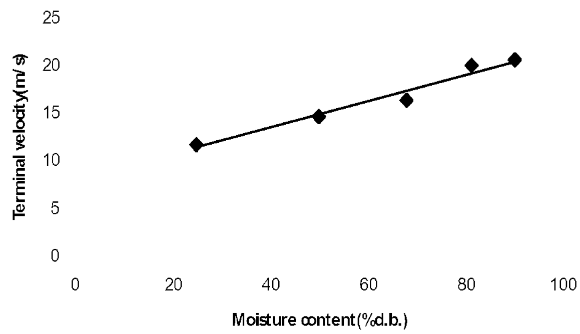

Fig. 10: Effect of moisture content on terminal velocity of strawberry fruit

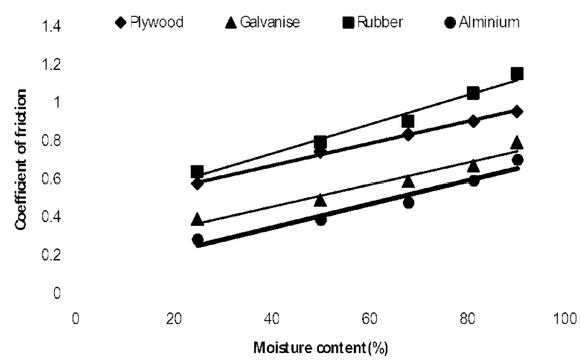

Fig. 11: Coefficient of friction variation with fruit moisture content

soybean [19], hackberry [5], chickpea seeds [10] and jatropha fruit [24] and for fennel seed [29].

Porosity: Figure 9 reveals that the porosity increases with the increase in fruit moisture content from 49.38% at 24.85% d.b. fruit moisture content to 64.28% at 90.20% fruit moisture content. The relationship between porosity and fruit moisture content were linear and can be expressed using the following equation with the coefficient of determination of 0.77:

$$\epsilon = 0.217MC + 41.11$$

An increase in porosity with moisture content was reported for chickpea seeds [10] and green gram [30], whereas the results for cactus pear fruit [11] and jatropha fruit [24] showed the decreasing of porosity by increasing the moisture content.

Terminal Velocity: The terminal velocity of strawberry was increased from 11.68 to 20.47 ms^{-1} by increasing moisture content from 24.85 to 90.20% d.b. respectively (Figure 10). As moisture content increased, the terminal velocity was found to increase linearly that expressed the following equation:

$$V_t = 0.138MC + 7.862 \quad R^2=0.97$$

The results are similar to that reported for green gram [30]. The increase in terminal velocity with increase in moisture content can be attributed to the increase in mass of an individual fruit per unit frontal area presented to the air stream [18].

Static Coefficient of Friction: From 24.85 to 90.20% d.b. the static coefficient of friction increased linearly with increase in moisture content for all contact surfaces (Figure 11). The reason for the increased friction coefficient at higher moisture content may be due to the presence of water in the fruit offering a cohesive force on the surface of contact [11]. The static coefficient of friction of strawberry fruit varied from 0.95 to 0.57, 1.15 to 0.64, 0.79 to 0.39 and 0.71 to 0.278 respectively for plywood, rubber, galvanized iron and aluminum sheets. At all moisture contents, the maximum friction is offered by Rubber. Similar results were found for *Juniperus drupacea* fruits [3], bambara groundnuts [4], beans and peanuts [31], hackberry [5], chick pea seeds [10] and cactus pear [11].

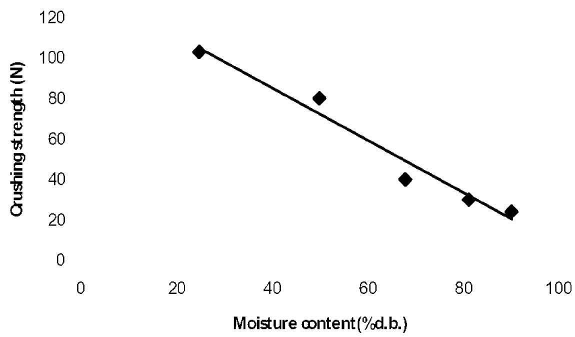

Fig. 12: Effect of moisture content on Crushing strength of strawberry

The relationship between the coefficient of friction and moisture content can be expressed for different structural surfaces using the following equations:

f_{rub}= 0.007MC + 0.422R^2= 0.97, for rubber surface;
f_w= 0.005MC + 0.438 R^2=0.99 , for plywood surface;
f_{gis}= 0.005MC + 0.219R^2=0.95, for galvanized iron surface;
f_{als}= 0.006MC + 0.094R^2=0.95, for aluminum surface.

Crushing Strength: The crushing strength of the strawberry fruit decreased linearly from 103 to 24N (P < 0.05) by increasing moisture content from 24.85-90.20% d.b (Figure 12). A similar decreasing trend in crushing strength has been reported for jatropha fruit [24]. The decrease in the crushing strength can be attributed to the fruit becoming softer at higher moisture contents [24]. The relationship between crushing strength, Cs and the moisture content, M, of the fruit can be expressed using the followed equation:

$$Cs = 136.9 - 1.296M$$

with a value for R^2 of 0.96.

CONCLUSION

Some physical properties of strawberry (Kurdistan variety) studied in this research and the results can be summarized as:

- In the moisture range of 25.85 to 90.20% d.b. the length, width, thickness and geometric mean diameter of the strawberry increased from 18.22 to 24.27, 11.01 to 22.23, 7.24 to 19.66 and 11.36 to 21.97 mm, respectively.
- Thousand Fruit mass, sphericity, bulk and true density, porosity and coefficient of friction on rubber, plywood, aluminum, galvanized iron sheet surface increased linearly, while the surface area of strawberry increases exponentially by increasing moisture content.
- The static coefficient of friction is necessary to design conveying machine and hopers used in planter machines. The differences between all the values of static coefficient of friction are statistically significant at P < 0.01.
- Crushing strength of strawberry decreased linearly with increasing moisture content at P<0.05.

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