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Physical Properties of The Mature-Green Golden Apple (*Spondias Cytherea Sonnerat*)

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ABSTRACT

Some physical properties of golden apple (Spondias cytherea Sonnerat) at green-mature stage were determined in this work. The mean wet basis moisture content of the fruit was 89.38 ± 0.48 %. The fruit has an average length, width and thickness of 46.92 ± 2.77 mm, 31.81 ± 1.90 mm and 31.88 ± 1.98 mm, respectively. In terms of its geometric mean diameter, sphericity, aspect ratio and surface area, the reported average values were 36.22 ± 1.84 mm, 77.29 ± 3.30 %, 67.93 ± 4.40 % and 4132.06 ± 417.48 mm^2, respectively. The mean value for mass, volume, true density, bulk density and porosity of the fruit were 26.868 ± 3.963 g, 26100.00 ± 3871.55 mm^3, 1055.14 ± 12.19 kgm^{-3}, 646.28 ± 58.02 kgm^{-3} and 38.75 ± 5.46 %, respectively. The average value of static friction coefficient for the fruit against four types of structural surface were found to be ranging from 0.419 ± 0.049 for galvanized steel sheet to 0.475 ± 0.041 for rubber surface. The data obtained in this study may be useful to facilitate the design of machines and tools for postharvest handling and processing of the fruit.

Keywords: *golden apple; ambarella; kedondong; Spondias cytherea Sonnerat; physical properties*

1. INRODUCTION

Malaysia is a country that is rich in the diversity of tropical fruit trees including golden apple. The golden apple (*Spondias cytherea Sonnerat*) tree species or commonly known among the locals as Ambarella or *kedondong* is still underutilised and has great commercial potential [1]. Golden apple is a member of the Anacardiaceae family [2]. It is believed to be the native plant of the South Pacific Islands, located in the regions of Melanesia and Polynesia. Today, golden apple trees are also cultivated in many parts of the world including Asia, Africa, Central and South America as well as in the Caribbean region [3].

The golden apple tree is considered a medium size tree. It can reach 15 – 25 metres of height when fully grown. The tree has pinnately compound leaves. Flowering and fruiting of the tree happen throughout the year. Its fruit contains a fibrous pit and is edible. The fruit is a good source of fibre-rich diet and high in mineral contents such as calcium, magnesium and phosphorus [4]. The nutrient compositions of the fruit were reported in other studies [3], [5]. Golden-yellow ripe fruit can be consumed either raw or cooked. Occasionally, it is turned into juices, sparkling beverages, jams and preserves [6], [7]. The green unripe fruits can be used to

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make pickles and jellies. Besides that, it can also be added to soups and stews as a natural flavouring.

The agro-based industry and agro-processing sector have become an important component in Malaysia's agriculture development plan to increase farmers' income and to produce more processed food from various crops. In line with Industrial Revolution 4.0, the smart farming approach is going to be adopted to transform and modernise the local agricultural sector. One of the strategies under this initiative is the acquisition and utilisation of more technologies by farmers to enhance their productivity and boost their earnings. However, in the golden apple fruit processing industry, the biggest challenge is the limited technology available to handle and process the fruit due to the lack of information on the physical properties of the fruit.

At present, the methods employed in the handling, processing and storing of the fruits are still traditional, time-consuming and labour intensive. The inappropriate fruit handling techniques also cause postharvest losses to producers. According to a study [8], the estimated total postharvest losses caused by physical damages during harvesting, transporting and washing of the fruits is as high as 8.4%. The mature-green golden apples are prone to all sorts of physical damage in every stage of the postharvest handling system [9]. The main type of physical damage during the harvesting stage is the punctures in the fruits caused by the harvester's fingernails.

According to another study conducted in Grenada [10], the estimated losses during harvest are as high as 50%. The losses were due to improper harvesting technique by shaking the branches of the tree and causing the fruits to drop and land on hard surfaces resulting in cracks in the fruits. Besides that, transporting the fruits in underfilled or overfilled containers is another source of spoilage. During the process, compression, bruising and abrasions may occur to the fruits. These will induce secondary fungal and bacterial infections which in turn destroy the fruits. Findings from other studies [11], [12] also suggest that the lack of logistics at the packing plant, inappropriate packing line facilities, the use of different sanitation protocols, untrained operators at the packing plant and limited infrastructure were the major factors that contributed to losses during the packing stage.

Therefore, to reduce postharvest losses and to increase productivity, there is a need to design equipment and machines to facilitate the proper handling, processing and storing of the golden apple fruit. Hence, the determination of the physical properties of the fruit is of paramount importance for the development of machines and equipment that are suitable for proper postharvest handling of the fruit.

In recent years, there have been many studies conducted on the physical properties of the different types of fruits and nuts. Among the studies reported were for the apples, plum, doum palm, musk lime, red avocado, wood apple, pear, okra fruits, ginkgo, walnut, hazelnut, and jujube fruits [13] – [26]. As of the time this study was conducted, there were limited physical properties reported for the golden apple and most of the works focused on the chemical properties of the fruit [4], [27].

The aims of this study were 1) to determine the geometric and gravimetric properties of mature-green golden apple fruit such as linear dimensions, sphericity, geometric mean diameter, surface area, true and bulk density, and 2) to study the frictional properties of the fruit by measuring the coefficient of static friction of the fruit against selected structural surfaces.

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2. MATERIALS AND METHODS

For this study, the fresh mature-green golden apple fruits were procured from a superstore in Butterworth city of Penang state, Malaysia. Figure 1 shows samples of the fruits. The procedures to investigate the physical properties of the fruits were performed in a Physics laboratory under the Department of Applied Sciences at Universiti Teknologi MARA, Penang Branch, Malaysia. The procedures were conducted for a period of five days with the temperature and relative humidity range of 21.2 – 25.1 ^{o}C and 70 – 90 %, respectively. Before the start of the experiment, the fruits underwent a sorting process to get rid of the damaged and immature fruits. Then the fruits were cleaned manually to ensure that the samples were free from dirt and dust.

Figure 1. Mature-green golden apple fruits

The AOAC standard method [28] was used in this study to determine the moisture content of the fruits. Five samples were selected randomly from the fruits. The samples were heated in an air-ventilated oven at the temperature of 80 ^{o}C over a period of three days. Equation (1) was used to calculate the moisture content (wet basis) of the sample.

$$MC(\%) = \frac{M_i - M_f}{M_i} \times 100\% \quad (1)$$

where $MC(\%)$ is the moisture content (wet basis), M_i is the initial mass of the sample before heating and M_f is the final mass of the sample after heating for three days.

2.1 Geometric properties

One hundred samples were picked randomly among the golden apple to determine the average size of the fruit. A digital vernier calliper (Model CD-6BS) manufactured by Mitutoyo Corporation of Japan with a resolution of 0.01 mm was used to measure the length (L), width (W) and thickness (T) of the samples. Based on these principal dimensions, the geometric mean diameters (D) of the fruits were computed according to Equation (2) [29-32].

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$$D = (LWT)^{\frac{1}{3}} \quad (2)$$

The value obtained from dividing the surface area of a sphere having the same volume as the fruit by the actual surface area of the fruit is called sphericity (*S*). In this study, Equation (3) was used to calculate the sphericity [30].

$$S = \frac{(LWT)^{\frac{1}{3}}}{L} \quad (3)$$

In order to analyse the shape of the fruit, the value of aspect ratio (R) was determined from Equation (4) [33]:

$$R = \frac{W}{L} \times 100\% \quad (4)$$

The estimation of the surface area (A) of the golden apple was done based on its geometric mean diameter. Equation (5) [34] shows the formula used in this study to estimate the surface area of the fruit.

$$A = \pi D^2 \quad (5)$$

2.2 Gravimetric Properties

Individual mass of 100 samples of the golden apple was measured using a RADWAG PS200/2000/C/2 electronic balance (RADWAG, Poland) with 0.001 g accuracy. The average mass of the fruit was then calculated for the 100 samples.

Water displacement method [35] was used to determine the true volume (*V*) for 10 samples of fruit separately. In order to prevent the sample from absorbing water during the process, each fruit was first coated with a layer of table glue and dried in air. Later, the sample was fully submerged into water in a measuring cylinder and the volume of water displaced was recorded as the true volume of the fruit. Based on its mass and true volume, the true density (ρ_T) for each sample was calculated according to Equation (6).

$$\rho_T = \frac{m}{V} \quad (6)$$

where *m* = mass of fruit (kg) and *V* = true volume of fruit (m^3).

The ratio of the total mass of samples in a container to the volume of the container is known as the bulk density [36]. In this study, the bulk density of the golden apple was determined by pouring the samples of the fruit from a fixed height into an empty container until the container is filled up with the fruit [37]. Next, the samples on the top level were removed and the mass of the remaining samples in the container was determined. Equation (7) was then used to compute the bulk density (ρ_B) of the fruit.

$$\rho_B = \frac{m_B}{V_B} \quad (7)$$

where m_B = total mass of samples in container (kg) and V_B = volume of container (m^3).

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Porosity (P) is the percentage of the empty space in a bulk fruit that is not occupied by the fruit. The calculation of the porosity of the bulk golden apple was performed using Equation (8) [38].

$$P = \frac{\rho_T - \rho_B}{\rho_T} \times 100\% \quad (8)$$

2.3 Frictional Properties

To analyse the static friction of golden apples on different types of structural surfaces, the following materials were used as the sliding surface, namely glass block, rubber strip, plywood and galvanised steel sheet. Individual sample of the fruit was first placed on the sliding surface in a horizontal position. Then one end of the surface was raised slowly using a screw until the sample began to slide.

The angle between the inclined surface and the horizontal was subsequently measured to determine the coefficient of static friction. Equation (9) shows the expression used to calculate the coefficient of static friction (μ_s).

$$\mu_s = \tan\theta \quad (9)$$

where θ = angle between the inclined surface and the horizontal when the sample begins to slide.

All the recorded data were analysed using Microsoft Excel 2007, MINITAB v.14 and Statistical Package for Social Sciences, SPSS v.17. Descriptive statistics such as mean, standard deviation (SD) and coefficient of variation (CV) were computed. Analysis of variance (ANOVA) for the data was followed by LSD (at 0.05) to run the multiple comparisons.

3. RESULTS AND DISCUSSION

The wet basis moisture content of the mature-green golden apple fruits was found to be in the range of 88.75 – 89.98% with a mean value of 89.38%. This finding is very similar to the reported average value of 90.5% by another study for green mature stage golden apple [4]. It is important to emphasise that the value reported by that study [4] are the mean of three samples whereas the value reported in this study are the mean of five samples.

The moisture content can be used as an indication of the storability of the fruit. The higher the moisture content, the shorter the storage life of the fruit. This is due to the rapid growth of mould on the fruit. In comparison, it is found that the moisture content of the golden apple fruits is similar to the moisture content of Santa Maria pear which is reported as 88.56% [39], but it is slightly higher than that of the moisture contents of Redspar and Delbarstival apples which are reported as 82.80% and 81.16%, respectively [18].

The descriptive statistics of various physical properties of golden apple fruit samples at a mean moisture content of 89.38% (wet basis) were summarised and presented in Table 1.

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Table 1. Some physical properties of golden apple fruits

Physical property	Unit of measurement	Mean value	Minimum value	Maximum value	Standard deviation	Coefficient of variation
Moisture content	%	89.38	88.75	89.98	0.48	0.54
Length	mm	46.92	41.77	53.85	2.77	5.91
Width	mm	31.81	26.51	35.82	1.90	5.99
Thickness	mm	31.88	26.54	36.12	1.98	6.21
Geometric mean diameter	mm	36.22	31.69	40.87	1.84	5.07
Sphericity	%	77.29	68.96	84.75	3.30	4.27
Aspect ratio	%	67.93	57.01	77.62	4.40	6.48
Mass	g	26.868	18.77	35.783	3.963	14.75
Surface area	mm^2	4132.06	3154.48	5247.88	417.48	10.10
Volume	mm^3	26,100.00	21,000.00	32,000.00	3,871.55	14.83
True density	kgm^{-3}	1,055.14	1,035.00	1,079.58	12.19	1.16
Bulk density	kgm^{-3}	646.28	562.68	724.08	58.02	8.98
Porosity	%	38.75	31.02	46.14	5.46	14.09

The histograms in Figure 2 show the distribution of the raw data of length, width and thickness. It was found that the data obtained for the three dimensions follow the normal distribution. Our findings indicated that 80% of the golden apple fruits have a length ranging from 44.19 to 50.23 mm, and 80% of the width ranging from 29.30 to 33.96 mm, whereas 60% of the fruits have a thickness ranging from 31.33 to 34.52 mm. The histograms also displayed similar distributions between the width and thickness. It shows that the width of the fruit is equal to its thickness. Therefore, the cross-section of the fruit is considered to be round. Based on the distribution of the length, it's obvious that the length of the fruit is larger than its width and thickness. Thus, the fruit is oval and round in a cross-section.

The mean values of length, width and thickness for golden apple fruit were found to be 46.92 ± 2.77 mm, 31.81 ± 1.90 mm and 31.88 ± 1.98 mm, respectively. These results are in agreement with the previous study in which the reported mean values for length and diameter of the fruit were 48.50 ± 3.70 mm and 35.50 ± 1.70 mm, respectively [4]. Based on the result of the analysis of variance, it was found that there was no significant difference between the mean width and the mean thickness of the fruits ($p > 0.01$), but the mean length of the fruit is significantly larger than the other two dimensions ($p<0.01$). This result suggests that the shape of the fruit is a prolate spheroid. It was interesting to note that all the three dimensions of the golden apple fruits were similar to that of Stanley plums fruit but lower than those of Golab, Redspar and

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Delbarstival apples [13], [14] thus indicating that golden apple fruit is not as big as compared to the Golab, Redspar and Delbarstival apples.

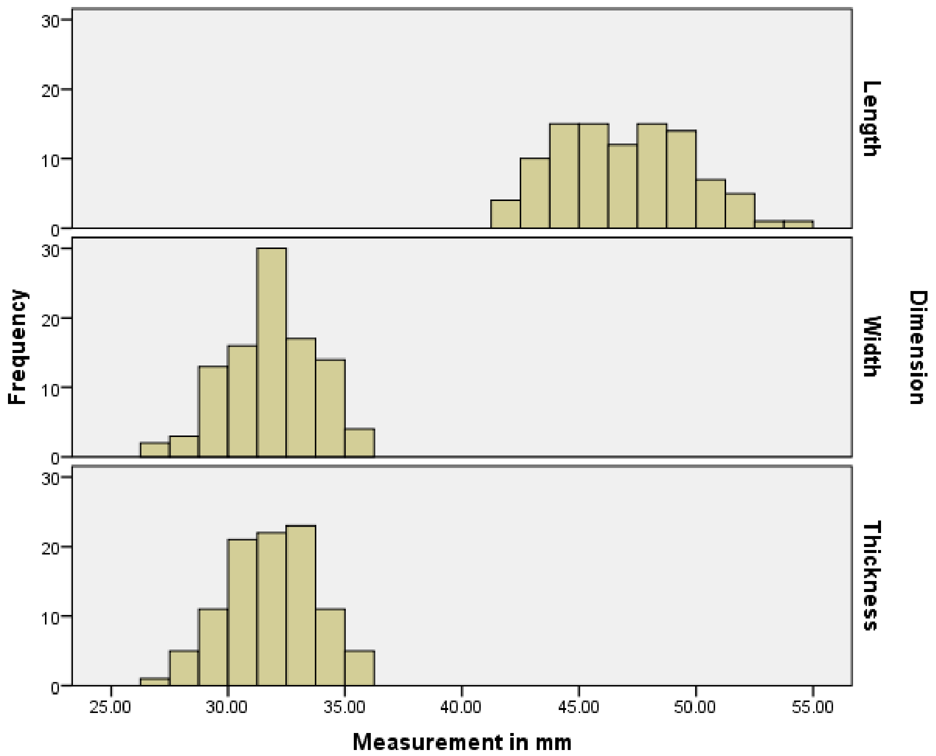

Figure 2. Frequency distributions of golden apple fruit dimensions (length, width and thickness)

The dimensions of golden apple fruit obtained in this study are useful in determining the aperture size of machines that could be designed to perform fruit separation from foreign materials [30]. In addition, these dimensions are also useful in determining the size of machine components to estimate the number of fruits that can be retained at one time, and also to estimate the slicing disc space and the number of cut slices from an average fruit size.

The calculated geometric mean diameter of golden apple fruit ranged between 31.69 to 40.87 mm with a mean value of 36.22 ± 1.84 mm, while the calculated surface area ranged between 3154.48 to 5247.88 mm^2 with a mean value of 4132.06 ± 417.48 mm^2.

The mean sphericity and aspect ratio of the fruits were found to be 77.29 ± 3.30 % and 67.93 ± 4.40 %, respectively. Both the sphericity and aspect ratio values were similar to kumquat fruits which has the reported values of 75.5% and 65.1%, respectively [40], but lower compared to *Citrus microcarpa* fruits with the values of 98.67% and 100.23%, respectively [17], and doum palm fruits with the values of 85.19% and 80.56%, respectively [16]. Since, the sphericity index of all the sample fruits is less than 90%, the fruit is regarded to belong to the oblate group. On the other hand, it is found that both the sphericity and aspect ratio are greater than 50%, therefore the fruit is expected to have a tendency to roll with some sliding. These parameters are important in designing the hopper to handle the fruits.

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The histogram in Figure 3 shows that the distribution of the mass is following a normal distribution. About 80% of the fruits have mass ranging from 22.17 to 30.68 g. The mean mass of the golden apple fruit was 26.868 ± 3.963 g. This result is comparable to the mean value of 24.4 ± 7.43 g as reported by another study [4]. However, the average value reported by that study [4] was based on 10 samples of fruit whereas the mean value reported in this study was based on 100 samples of fruit.

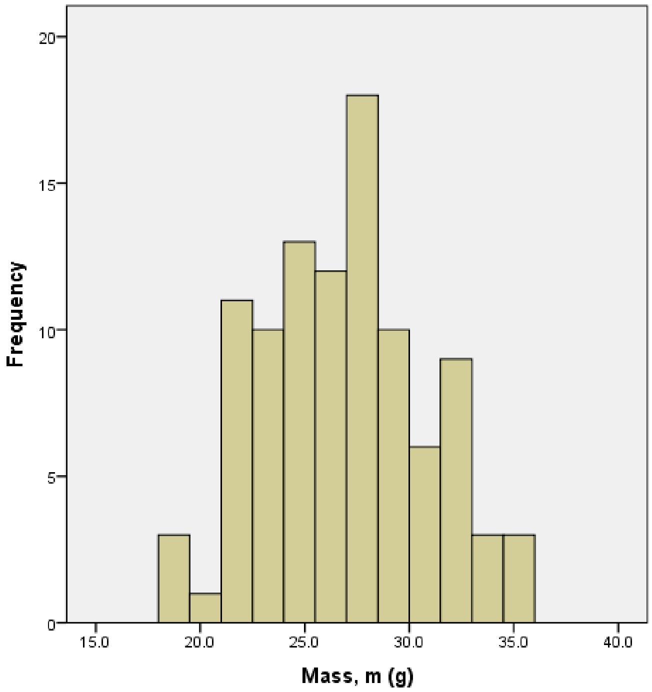

Figure 3. Frequency distributions of golden apple fruit mass

The volume of golden apple fruit determined from 10 samples was found to be in the range of 21000 to 32000 mm^3 with the mean volume of 26100.00 ± 3871.55 mm^3. The result agrees with the mean value of 24000 ± 2550 mm^3 as obtained in their findings [4]. The mean value of true density and bulk density of the fruits were 1055.14 ± 12.19 kgm^{-3} and 646.28 ± 58.02 kgm^{-3}, respectively. The true density and bulk density of the fruits were found to be higher than that of Tabarze apricot fruits [41]. Besides that, it was also observed that the bulk density of golden apple fruits is similar to that of Stanley plums [15]. This may be due to the fact that the size of both fruits was quite similar. This parameter is important in determining the storage capacity of the fruits. The average porosity of the golden apple fruits was 38.75 ± 5.46 %. This value was found to be in the same order as Stanley plums fruits [15], and okro fruits [42] but lower than that of Tabarze apricot fruits and Pear (Deveci) variety [41]. The porosity of fruit is important because it shows the resistance of the fruits to airflow during the drying process.

The coefficient of static friction of golden apple fruits against four types of the structural surface obtained in this study is shown in Table 2. The low value of the coefficient of static friction may be attributed to the smoother surface of the fruit. It was found that the fruit had the highest coefficient of static friction on rubber, followed by plywood, glass and lastly the galvanised steel sheet. The result of variance analysis performed on the coefficient of friction data for various surfaces indicated that there is a significant difference in the coefficient of static friction

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for rubber as compared to the other three types of surfaces ($p<0.01$), but there is no significant difference of the coefficient among plywood, glass and steel sheet surfaces ($p>0.01$).

The coefficients of static friction for golden apple fruits were lower than the values reported for Tabarze apricot fruits [41] but greater than that of the *Citrus microcarpa* fruits [17]. This property is of paramount importance in determining the steepness of the storage container, hopper or any other loading and unloading devices.

Table 2. Coefficient of static friction of golden apple fruit on four types of structural surface

Structural surface	No. of observation	Mean value	Minimum value	Maximum value	Standard deviation	Coefficient of variation
Galvanized steel sheet	25	0.419	0.325	0.510	0.049	11.68
Glass	25	0.434	0.176	0.554	0.072	16.61
Plywood	25	0.445	0.364	0.532	0.047	10.59
Rubber	25	0.475	0.384	0.554	0.041	8.60

4. CONCLUSION

The average moisture content (wet basis) obtained in this study for the mature-green golden apple fruit was 89.38%. The mean values of its length, width, thickness and geometric mean diameter were 46.92, 31.81, 31.88 and 36.22 mm, respectively. The average values of its mass, volume, sphericity, aspect ratio, bulk density, true density and porosity were 26.868 g, 26100 mm^3, 77.29%, 67.93%, 646.28 kgm^{-3}, 1055.14 kgm^{-3} and 38.75%, respectively. The fruit has the highest coefficient of static friction on the rubber surface with a mean value of 0.475 and the lowest average value of 0.419 on the galvanised steel surface. The findings in this study are useful in facilitating the design of machines and equipment that are suitable for proper postharvest handling of the golden apple fruit.

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