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Dimensional specific physical properties of fan palm fruits, seeds and seed coats (*Washingtonia robusta*)

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A b s t r a c t. In this study some physical properties of fan palm (*Washingtonia robusta*) fruits, seeds and seed coats were determined using dimensional, bulk and single kernel physical analysis. The moisture content of whole fruits, seeds and seed coats was 12.0, 9.86 and 13.87% (d.b.), respectively. The sphericity values showed that seed shape (0.86) is close to a sphere, similar as the fruit shape (0.83), both of which were close to a scalene ellipsoid shape. The surface area values of fruits and seeds were obtained as 163.27 and 80.25 mm^2, and volume values were obtained as 190.96 and 66.32 mm^3, respectively. Bulk densities of fruits, seeds and seed coats were 559, 783 and 272 kg m^{-3}, and the corresponding true densities were 1143, 1147 and 864 kg m^{-3}, whereas the corresponding porosities were 48.87, 54.12, and 31.52%, respectively. The values of the static coefficient of friction and the angle of repose of fruits, seeds and seed coats of palm fruits were studied on aluminium, canvas, galvanised iron, plywood, PP knitted bag, PVC and stainless steel surfaces. As expected, seed coat has higher values of coefficient of static friction on the all surfaces than fruit and seed.

K e y w o r d s: palm fruit, physical properties, density, coefficient of friction, angle of repose

INTRODUCTION

Palm trees represent the third most important plant family (*Arecaceae*) with respect to human use, and numerous edible products are obtained from palms, including the familiar date palm fruits, coconut palm nuts, and various palm oils (Johnson, 1998). Most of palm products such as palm date, coconut and oily palm seeds are available commercially and valuable for trading. Fan palm (*Washingtonia* spp.) fruits are not used commercially all over the world. The genus *Washingtonia* is commonly cultivated as ornamental avenue plants and landscape foliage. It has two species, namely *Washingtonia filifera* and *Washingtonia robusta*. The California fan palm (*Washingtonia filifera*) and the Mexican fan palm (*Washingtonia robusta*) are relatively similar (Anonymous, 2010). Both species are cultivated as ornamental trees, widely planted particularly in California and northwest Mexico, and also in the Mediterranean region, southern Europe, some parts of Australia and other warm areas of the world, including Turkey. Fan palms are very popular street trees of coastal areas of Turkey, including the Mediterranean, Aegean, Marmara and Black Sea Regions.

Fan palm trees produce a dozen or so such date clusters at 2-9 kg each, flowering occurs in May and June, and the leaves die at the end of the summer-growing season but remain attached to the trunk. Fan palm has small, hard and ovoid/elliptical black fruits like berry or drupe, about 4-6 mm wide and 8-10 mm long (Star *et al.,* 2003). Fruits have a very large, brown seed surrounded by thin and sweet pulp, that taste likes dates (Turner and Wasson, 1997). Fruits of fan palms are used by Native Americans, eaten raw or cooked, and dried for later use (Watson and Preedy, 2009) or ground up as flour for making breads and cakes. They also use soaked fruits to produce a sweet beverage and make jelly from the berries (Facciola, 1990).

Despite extensive literature search, detailed information on the physical properties of fan palm fruits seeds and seed coats (*Washingtonia* spp.) is not available. Since the palm fruit seed coat has a high soluble sugar content, and seed has a high oleic acid content oil, it can be an appropriate candidate for the production of bio-ethanol (Mazmancı, 2011; Nehdi, 2011). Suitable post harvest technologies

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for palm fruit need to be identified, as physical properties play an essential role in the design of planting, harvesting, handling, operation, transportation, storing and processing equipments. In this study, some physical properties of edible fruits of palms with fan-shaped leaves (fruit, seed and seed coat) were investigated for linear dimensions, geometric mean diameter, thousand fruit/seed weight, fruit/seed volume, fruit/seed surface area, bulk density, true density, porosity, coefficient of static friction against six structural surfaces, and dynamic angle of repose.

MATERIAL AND METHOD

Mature and sun dried palm fruits were hand-picked from trees and gathered together from Mersin, Turkey (36°45`N-34°30`E at an altitude of 5 m a.s.l.). The fruits were cleaned manually and all foreign material, such as dirt, smashed and broken seeds, was removed. During analysis to obtain palm seeds, palm fruits were broken up by hand and seeds freed from seed coat. Fruits, seeds and seed coat were separately packed in hermetic plastic vessels and stored at 5°C until use. Before starting each test, the required quantity of samples were taken out of the refrigerator and allowed to warm up at room temperature.

Experiments were replicated three times and the average values were reported. The palm fruits, seeds and seed coat were smashed with a hammer, ground using a blender and sieved through a 30 mesh stainless steel screen. The residue was blended again until all the ground powder passed through the screen to obtain uniform powder. Moisture contents of samples were determined using the AOAC Official Method 930.15 (135°C for 2 h) (AOAC, 2005), the results are expressed in percentages.

The size and shape of grain kernels can affect post harvest processing. To completely specify the form of irregular shaped grain kernels, an infinite number of dimensional measurements are required. From a practical point of view, measurement of three mutually perpendicular axes is typically sufficient for a quantitative description of grain kernel (Mohsenin, 1986). Samples of a hundred seeds were randomly selected to determine the average size of the palm fruit and seed. Measurements of the three major perpendicular dimensions, namely length (L), width (W) and thickness (T) of the fruit, and length (l), width (w) and thickness (t) of the seed were carried out using a digital caliper (Mitutoyo, 150 mm/6'' Absolute Digital Digimatic Vernier Caliper, Japan) with an accuracy of 0.01 mm. The unit mass of single fruit, seed and seed coat (g) was recorded by using an electronic balance (AND GR-200 model analytical balance, Japan) with accuracy of ± 0.001 g. The Sneed and Folk triangular diagram method was used to obtain shape indices of palm fruits and seeds. This method of representing particle shape employs a triangular diagram in which ratios of the three orthogonal axes of the particle are plotted. Particles are envisaged as lying in the continuum between blocks (or spheres), slabs (discs, oblate) and rods (prolate) which mark the corners of the plotted diagram (Graham and Midgley, 2000). The geometric mean diameter, sphericity, aspect ratio, bulk density, true density and porosity values of the samples were calculated according to Mohsenin (1986).

Fruit and seed volume (V) and surface area (S) were calculated using the formula given by Jain and Bal (1997):

$$V = \frac{\pi}{6}\frac{B^2L^2}{(2L-B)}, \quad (1)$$

$$S = \frac{\pi B L^2}{2L-B}, \quad (2)$$

where: diameter of the spherical part of the seed (mm), L is length – the maximum diameter (circumference diameter), W is width – medium diameter (circumference diameter), T is thickness – minimum diameter.

$$B = (WT)^{1/2}. \quad (3)$$

To determine the weight of one-thousand fruit and seed, eight sub-samples consisting of 100 seeds and fruits were randomly drawn from the bulk sample and weighed on an electronic balance (AND GR-200 model analytical balance, Japan) with 0.001 g accuracy, and then the weight obtained was extrapolated to 1000 seeds (Coşkuner and Karababa, 2007).

For the determination of percentage shell mass, 100 g samples of fruits were taken and peeled manually. The peeled samples were then weighed and the average percentage of shell and seed were then calculated as outlined by Bart-Plange and Baryeh (2003) for cocoa bean.

The coefficient of static friction (μ) was obtained with respect to six surfaces: aluminium, canvas, galvanised iron sheet, plywood, polypropylene (PP) knitted bag, PVC and stainless steel surfaces. These are common materials used for transportation, storage and handling operations of grains, pulses and seeds, construction of storage and drying bins. A hollow metal cylinder with 50 mm diameter and 50 mm high, open at both ends, was filled with the seeds at the desired moisture content and placed on an adjustable tilting table made of wood. The hollow cylinder was pulled up slightly to avoid contact between it and the friction surface. The tilting surface was raised gradually by means of a screw device; the angle of tilt (α, degree) at which the cylinder with seeds just began to slide down was recorded as the angle of static friction between the experimental materials (palm fruits, seeds and seed coat) and the friction surface. Adjustable tilting table method has been used for other grains and seeds by other researchers to obtain the coefficient of static friction (Singh and Goswami, 1996).

$$\mu = \tan\alpha . \quad (4)$$

The angle of repose indicates the cohesion among the individual units of a material. The higher the cohesion, the higher is the angle of repose. The angle of repose of palm fruits and seeds was measured in two ways with the:

– filling method, to determine the angle of static repose, and
– emptying method, to determine the angle of dynamic repose.

For the filling method, a Hele-Shaw cell was built and used (Schlumberger, 2008). The sample was poured onto the cell through a fixed hopper in order to foster a constant feeding rate, and thus the formation of a natural slope. The slope angle, namely the angle of static repose, was read using a protractor.

The emptying angle of repose (θ, degree) was obtained using a plywood box with dimensions of 300x300x300 mm, having a removable front panel. The box was filled with whole fruit, seed and seed coat, the front panel was then quickly removed allowing the seeds to flow out in natural slope. The angle of repose was calculated by measurements of materials free surface depths at the end of the box, midway along the sloped surface and horizontal distance from the end of the box to this midpoint. This method has been used by previous researchers to determine the angle of dynamic repose (Bart-Plange and Baryeh, 2003; Jain and Bal, 1997; Singh and Goswami, 1996).

All experiments were replicated three times, unless stated otherwise, and the average values were reported. Spreadsheet software of Microsoft Excel (2003) was used to analyse the mean, minimum and maximum values of measurements of the three major perpendicular dimensions of palm fruits and seed, reporting their standard deviations, skewness and kurtosis, and the linear correlation coefficient (R) was computed using the least square method. The statistical evaluation was calculated using the Windows STATISTICA release 5.0 (Statsoft, 2005).

RESULTS AND DISCUSSION

To the best of our knowledge, there have been no published research studies about physical properties of palm fruit and seed such as size distribution, diameter, length, density and weight. The moisture content of fruit used was 12.0% while that of the seeds was 9.86% and that of the seed coat was 13.87% (d.b). According to the results obtained, the fractions of fan palm fruit are seed (46.28%) and seed coat (53.72%). Fruit fractions gave us an overall idea about the composition of seed and seed coat which have an effect on the sugar and oil yield of the product.

Results from the 100 measurements taken for the axial dimensions, geometric mean diameter and sphericity for palm fruit and seeds are presented in Table 1. The results showed that the length, width and thickness of the fruit ranged between 7.99-10.73, 6.38-8.47 and, 5.69-7.46 mm, respectively, while the geometric mean diameter and sphericity ranged between 6.66-8.77 and 0.77-0.89 mm, respectively. The results revealed that the length, width and thickness of the seed ranged between 5.10-7.36, 4.82-6.18 and 3.96-5.02 mm, respectively, while geometric mean diameter and sphericity ranged between 4.60-6.11 and 0.81-0.92 mm, respectively. The sphericity values for palm fruit and seed fell within the range of 0.32-1.00 as reported by Mohsenin (1986) for most agricultural particles.

Table 1. Axial dimensions (n=100) of fan palm fruits and seeds at moisture contents of 12.0 and 9.86% (d.b.)

Dimensions	Fruit			Seed		
	Mean	Skewness	Kurtosis	Mean	Skewness	Kurtosis
Unit mass (g)	0.25 (0.04)	0.185	-0.413	0.12 (0.02)	1.089	2.698
Length (mm)	9.23 (0.60)	0.159	-0.447	6.20 (0.38)	0.685	1.672
Width (mm)	7.41 (0.39)	0.026	-0.056	5.49 (0.24)	0.435	0.977
Thickness (mm)	6.57 (0.37)	0.303	0.077	4.45 (0.17)	0.536	1.284
Geometric mean diameter	7.66 (0.40)	0.246	-0.270	5.33 (0.23)	0.653	2.290
Sphericity	0.83 (0.03)	-0.017	-0.290	0.86 (0.02)	-0.028	-0.035
Volume (mm^3)	190.96 (29.97)	0.532	0.119	66.32 (8.15)	0.975	2.475
Surface area (mm^2)	163.27 (16.99)	0.390	-0.070	80.25 (6.64)	0.820	2.318
Aspect ratio	80.49 (3.75)	0.065	-0.587	88.65 (3.20)	-0.391	0.473

Standard deviation in parentheses.

a

b

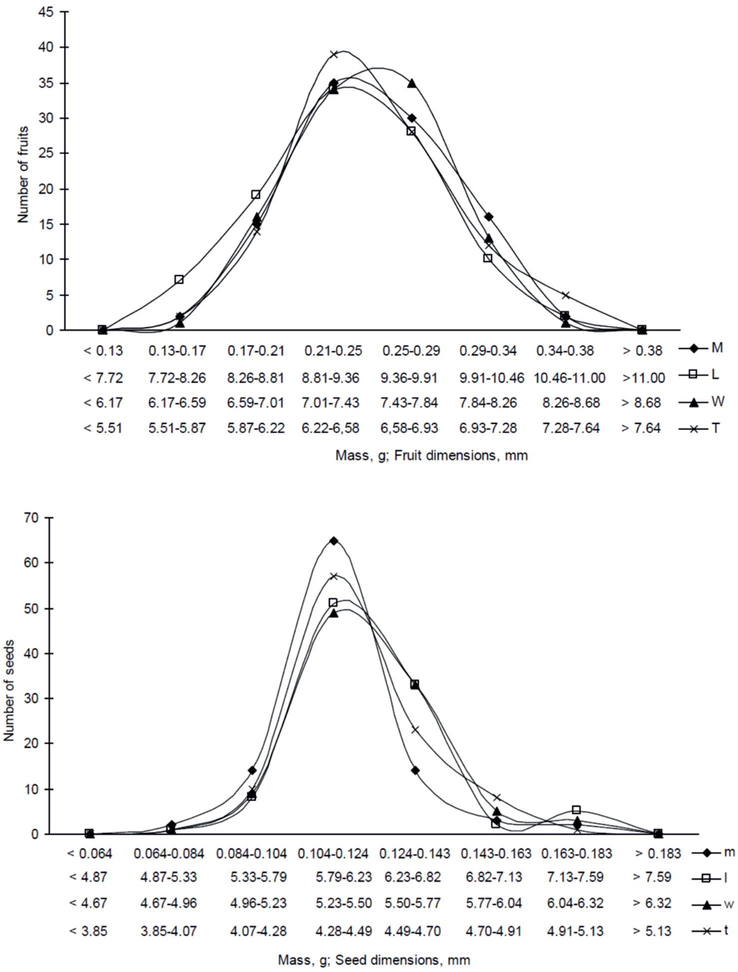

Fig. 1. Frequency distribution for single weight and axial dimensions of the palm: a – fruits and b – seeds.

The frequency distribution curves were plotted for palm fruits and seeds for length, width, thickness and mass at the class intervals of 0.55, 0.42, and 0.36 mm 0.04 g, and of 0.45, 0.28, and 0.21 mm 0.02 g, respectively (Fig. 1). The skewness and kurtosis analysis for the frequency distribution curve for the 100 readings taken for each dimension is presented in Table 2. The curves show normal distribution for all the parameters with peaks within the mean values, which agrees with earlier results by Irtwange and Igbeka (2002) for two African yam bean accessions, Taşer *et al.* (2005) for vetch seed and Akaaimo and Raji (2006) for *Africana propis* seed. This is an indication that the axial dimensions are relatively uniform and are useful information in the design of separation and size reduction systems. Skewness characterises the degree of symmetry of distribution within its mean. Positive skewness indicates a distribution with an asymmetric tail extending towards more positive values (skewed to the right) and vice versa for negative. Skewness values were found higher than zero '0' for a single fruit weight, seed weight, length, width and thickness parameters, which means that tails of normal distribution graphics extend to the right side, and it is shown that most of the values are higher than the means, too. Kurtosis characterises the relative peakedness or flatness of distribution compared to normal distribution and kurtosis for normal distribution is 3. The distributions with kurtosis value for both fruit and seed properties presented in Table 1 and Fig. 2 are called a platykurtic. It means distribution compared to normal distribution and its central peak is lower and broader, while its tails are shorter and thinner. This indicates that the sample weight is uniformly distributed. This information is important in selecting storage and handling containers.

As can be seen from Table 1, the aspect ratio of palm fruit and seed were 80.49 and 86.65%, respectively. Low aspect ratio indicates the tendency to be oblong in shape (Omobuwajo *et al.*, 1999). However, with an aspect ratio of over 70%, the palm fruits and seed are more likely to roll than to slide. A similar trend had been reported previously (Ixtaina *et al.*, 2008; Mpotokwane *et al.*, 2008). Considering the low aspect ratio (which relates the materials width to length) and sphericity, it may be deduced that those

T a b l e 2. Palm fruit and seed dimensions ratio at 12.0 and 9.86% moisture content (d.b.), respectively

Particulars	Ratio	Minimum – maximum	Coefficient of correlation* (R)
L/W	1.25 (0.058)	1.12 – 1.39	0.71
L/T	1.40 (0.075)	1.23 - 1.63	0.63
L/M	37.84 (4.955)	27.82 - 54.56	0.68
W/M	30.39 (3.707)	22.51 - 42.82	0.85
T/M	26.96 (3.361)	19.66 - 38.92	0.81
l/w	1.13 (0.045)	1.04 - 1.26	0.81
l/t	1.39 (0.063)	1.22 - 1.56	0.68
l/m	54.21 (4.602)	42.54 - 69.38	0.90
w/m	48.08 (4.608)	35.72 - 65.14	0.93
t/m	39.03 (4.064)	28.30 - 53.51	0.81
L/l	1.49 (0.070)	1.33 - 1.66	0.72
W/w	1.35 (0.039)	1.26 - 1.45	0.83
T/t	1.48 (0.062)	1.33 - 1.62	0.66
M/m	2.15 (0.179)	1.79 - 2.58	0.84

Standard deviation in parentheses, *values are significant at 5% level.

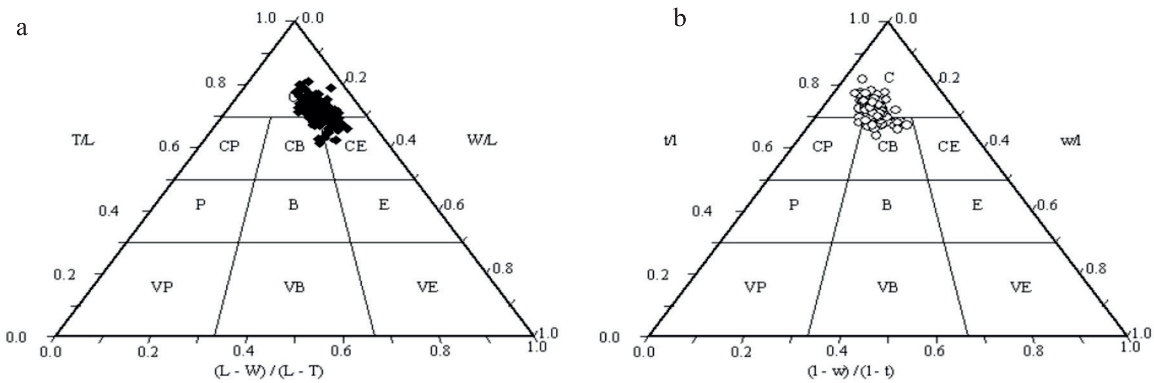

Fig. 2. Sneed and Folk descriptive particle shape classes of palm: a – fruits and b – seeds at moisture content of 12.0 and 9.86% (d.b.), respectively. C – means compact, P – platy, B – bladed, E – elongate, V – very.

materials would slide on their flat surfaces rather than roll. This tendency to either roll or slide is very important in the design of hoppers, because most flat seeds slide easier than spherical seeds which roll on structural surfaces (Ixtaina *et al.*, 2008). Furthermore, the shape indices indicated that the palm fruit and seed may be treated as a scalene ellipsoid for an analytical prediction of its postharvest processes. All the aspect ratios of fan palm fruit and seeds are found to be higher than those of African breadfruit (47.8), Chia seeds (62.7-65.2) and chickpea (75.6) and lower than bambaraa (84.6) (Ixtaina *et al.*, 2008; Mpotokwane *et al.*, 2008; Omobuwajo *et al.,* 1999; Tabatabaeefar *et al*., 2003).

The relationship and correlation coefficients between palm fruit and seed dimensions at 12.0 and 9.86% moisture content are shown in Table 2. The coefficients of correlation with 98 degrees of freedom show that the *W*/*M* and *T/M* ratios are highly significant as compared to *L*/*W, L*/*T* and *L*/*M* ratios for fruit dimensions. This indicates that the width and thickness of fruit are closely related to its mass but less associated with length. For seed dimension, *l/m* and *w/m* ratios have the highest correlation coefficients. This also indicates that the length and width of seeds are closely related to their mass but less associated with thickness. The coefficients of correlation (R) showed that all the ratios were found to be highly significant for fruit and seed dimensions ratios at 5% significance level. We can conclude that length and width are closely related with mass of palm fruit and seed and less with their thickness.

Sixty two percent of palm fruits had a length ranging from 8.81 to 9.91 mm, 26% less than 8.81 mm, and 12% greater than 9.91 mm at 12.0% (d.b.) moisture content. On the other hand, 84% of palm seeds had a length ranging from 5.79 to 6.82 mm, 9% less than 5.79 mm, and 7% greater than 6.82 mm at 9.86% (d.b.) moisture content (Fig. 1).

Basically, agricultural materials can be classified into four different shapes: disc (slabby in appearance, but not elongated); equidimensional (neither slabby appearance nor elongated); blade (slabby appearance) or rod (elongation, but not slabby in appearance) shaped (Uthus *et al*., 2005). Using the plot of (*L-W*)/(*L-T*) versus (*T/L*) values, we can prepare material classification chart depending on axial dimensions of materials and we can estimate dimensional shape (Fig. 2). So, axial dimensions of materials give us not only the size of materials but also their shape properties. As presented in Fig. 1, dimensional evaluations of randomly selected one hundred palm fruits and seeds are located different places on the shape indices chart. Fruits contain 64% compact shape, 25% compact-elongate shape, and the rest are compact-bladed (11%). On the other hand, palm seeds contain 71% compact shape, 26% compact-bladed and 3% compact-platy.

The volume determines the shape of materials and the axial dimensions give an indication of the size. The difference in axial dimensions of seed with relatively low sphericity (0.65) shows that seed will not rotate easily during handling. The higher sphericity value for fruit or seed, the closer its shape is to a sphere. The closer the sphericity to 1.0, the higher the tendency to roll about any of the three axes and the closer the ratio of thickness to width to 1.0, the higher the tendency to rotate with reference to the major axis (Akaaimo and Raji, 2006). Fan palm fruits and seeds have nearly similar and higher sphericity values (0.83 and 0.81, respectively) (Table 1) than fruit, nut and kernel of oil palm (below than 75%) (Akinoso and Raji 2011), ginkgo nuts (69.70%) and kernels (71.86%) (Ch'ng *et al.,* 2013), almond nut (62.96%) and kernels (52.14 %) (Mirzabe *et al.* 2013), cumin (36.2%) and caraway (34.64%) (Zare *et al.,* 2013), and lower than Gbafilo (Chrysobanusicaco) fruits and kernels (0.84 and 0.82, respectively) (Davies and Zibokere, 2011).

Mean values of palm fruit and seed mass were measured to be 0.25 g and 0.12 g, respectively (Table 1). The summary of the gravimetric and frictional properties of palm fruits, seeds and seed coats is presented in Table 3. Average values of one thousand weight (g) of fruits, seeds and seed coats are 250, 115.70 and 134.30, respectively. These values show that palm fruits have 46.28% seed and 53.72% seed coat. The bulk density of fruit, seed and seed coat are 559, 783 and 272 kg m^{-3}, respectively. This indicates that bulk density of the fruit is 28.60% lower than that of seed. This shows that fruits need more space per unit mass than kernels. The true density values of the fan palm fruit, seed and seed coat are 1143, 1447 and 864 kg m^{-3}, respectively. The true density of the fan palm fruit and seed are higher than the density of water (1 000 kg m^{-3}). The true density of seed is higher than that of fruit and seed coat. This illustrates that separation of seed coats from seeds after removing of seed coat could be done by blowing air (winnowing) instead of floating in water. As the seed coat can absorb water easily in a few seconds, the separation of seed coats from seeds will not be possible. According to most of the researchers, it was generally observed that the bulk density of nuts was always lower than that of kernels (Kashaninejad *et al.,* 2006). This pattern was similar to that reported in a study on pistachio nuts and kernels (Kashaninejad *et al*., 2006), ginko nuts and kernels (Ch'ng *et al.,* 2013). This is probably due to the shell, in which the nut is bigger in size than the kernel, hence a decrease in the total mass per unit volume occupied by the nut (Kashaninejad *et al.,* 2006). The information about the bulk density of nuts is indeed useful in determining nut storage capacity (Ch'ng *et al.,* 2013). Physical properties of agricultural materials are important factors for consideration when designing storage facilities and processing. Many of the physical properties, like bulk and true densities, porosity, coefficient of friction, gravimetric and dimensional properties, vary with moisture content and vary according to the variety and different parts of the fruits. But the data accumulated to date are insufficient to make this certain. Relationships between fruit or seed composition and physical properties such as seed volume, bulk density and true density are suspicious (Daun *et al.*, 2011).

The porosity of fan palm fruit, seed and seed coat are found to be 48.87, 54.12, and 31.52%, respectively. Since the porosity depends on the bulk as well as true density, the degree of variation in porosity depends on these factors only. The porosity of the bulk of seed coat and bulk of fruits is lower than that of the seeds. This demonstrates that aeration of the bulk seed coat is easier than of the bulk of fruit and the bulk seed.

The angle of repose of bulk materials is the angle which the surface of a normal, freely formed pile makes to the horizontal and it is an indicator of the material ability to flow. Depending on the characteristics of materials, the angle ranges from 0 up to 40°. Normally, materials are classified depending on the angle of repose values obtained at certain moisture content, as follows: very free flowing (0°-19°), free flowing (20 to 29°), average flowing

T a b l e 3. Gravimetric and frictional properties of palm fruits, seeds and seed coat

Properties	Number of observation	Fruit	Seed	Seed coat
One-thousand weight (g)	8	250	115.70	134.30
Bulk density (kg m^{-3})	3	559	783	272
True density (kg m^{-3})	20	1 143	1 447	864
Porosity (%)	3	48.87	54.12	31.52
Angle of repose (°)				
Filling	3	32	34	43
Emptying	3	26	30	37
Coefficient of friction				
Aluminum	3	0.459	0.351	0.532
Canvas	3	0.481	0.397	0.700
Galvanized iron	3	0.424	0.371	0.524
Plywood	3	0.495	0.438	0.577
Polypropylene knitted bag	3	0.344	0.319	0.466
PVC	3	0.445	0.424	0.577
Stainless steel	3	0.404	0.364	0.452

(29 to 39°) and sluggish (40° and up). Angle of repose values of palm fruits, seeds and seed coats are presented in Table 3. The values were higher when applying the filling method than when applying the emptying method. The filling and emptying angle of repose values of the whole palm fruit, palm seed and seed coat varied between 26 and 43°. It was noticed that the angle of repose of whole fruits, using both methods, was higher than that of seeds. The highest angle of repose values were obtained for palm seed coat with both methods. These values are higher than previously reported on African star apple and chia seed (Ixtaine *et al.*, 2008; Oyelade *et al.*, 2005). The rough outer surface and the shape of the seeds are apparently responsible for the relatively higher values of repose angle, and thus the hardiness of the seeds to slide on each other.

The values of the coefficient of friction on aluminium, canvas, galvanised iron, plywood, polypropylene knitted bag, PVC and stainless steel were determined for whole palm fruit, seed and seed coat (Table 3). Plywood had the highest coefficient of friction (0.495), followed by canvas (0.481), aluminium (0.459), PVC (0.445), galvanised iron (0.424), stainless steel (0.404) and polypropylene knitted bag (0.344) for whole palm fruit. Similarly, plywood had the highest coefficient of friction (0.438), followed by PVC (0.424), canvas (0.397), galvanised iron (0.371), stainless steel (0.364), aluminium (0.351) and polypropylene knitted bag (0.319) for palm seed. For palm seed coat, canvas had the highest coefficient of friction (0.700), followed by both plywood and PVC (0.577), aluminium (0.532), galvanised iron (0.524), polypropylene knitted bag (0.466) and stainless steel (0.452). As shown in Table 3, palm seed coat had the highest and palm seed had the lowest values of the coefficient friction on different surfaces. The coefficient of static friction was the lowest against polypropylene knitted bag and stainless steel. This may be due to the smoother and polished surface of stainless steel sheet compared to the other sheets used. The coefficient of friction on material surface is important in selecting appropriate materials for different units of machinery, especially for components requiring flow of the seeds. The design of the container for storage, like a silo, and for loading and unloading during handling, such as a hopper is dependent, on the understanding of the friction properties. The angle of internal friction is required to calculate the lateral pressure which causes bending of the wall in storage bin as well as gravity flow in hoppers (Akaaimo and Raji, 2006).

CONCLUSIONS

1. Fan palm (*Washingtonia robusta*) fruits and seeds have a geometric shape which could be approximated by scalene ellipsoid.

2. The relations between lengths, width, thickness, geometrical mean, volume, surface area, sphericity, aspect ratio, bulk and true density, and porosity enables the reliable correlation of geometrical dimensions to the unit mass. These correlations can be used for post harvest processes like cleaning and sorting of fan palm fruit and seeds into fractions that also reflect quality classes in terms of sugar and oil content. These parameters can be used for the theoretical determination of seed volume and sphericity.

3. One thousand fruit weight was 250 g, on average, for whole fruits, and 115.70 g for seeds. The bulk densities were 559, 783 and 272 kg m^{-3} for whole fruits, seeds and seed coats, respectively. The true densities were 1143, 1447 and 864 kg m^{-3} for whole fruits, seeds and seed coats, respectively. Porosity values were found to be 48.87, 54.12 and 31.52 for whole fruits, seeds and seed coats, respectively.

4. In brief, this paper deals with the physical properties of Washingtonia robusta whole fruits and seeds, contributing to the knowledge about this species and providing useful data for its industrial processing. The data obtained are useful for the development of handling systems and for the design of equipment and processing machines, and it has not been present in the available literature.

Conflict of interest: The Authors do not declare conflict of interest.

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