ENGINEERING PROPERTIES OF SOME ARABIAN COFFEE VARIETIES

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Abstract

The aim of the research was studied some engineering properties of Arabian coffee seeds (Himy, Esmaely and Ma'arepy) varieties to analyze the behavior of the product to design threshing and grading machines. Three categories of the coffee grains were used to measure the main dimensions (length, width, thickness), mass, density, porosity, angle of repose and coefficient of friction. The overall means of volume, geometric diameter, arithmetic diameter, cross-section area and spherisity were determined. The highest frequency length, width and thickness of the coffee been seeds were 10, 7 and 7 mm, respectively. The medium categorize (from 7 - 10 mm) was denser than both small and large sizes of coffee bean as the porosity of that size was lower than those of both small and large sizes. The angle of repose increased with the decrease of coffee bean sizes as the relation with coffee bean seeds spherisity. The coefficient of friction decreased with the increase of coffee bean size at all surfaces. The maximum coefficient of friction was occurred on plywood surface followed by galvanized steel, tin plate, and glass for all categories of the coffee bean seeds.

INTRODUCTION

Coffee is an extremely important crop in many tropic countries Brazil, Yaman, …etc. Coffee growing started since 14^{th} century, the Yemenis highlands can be considered as secondary center of origin of *Cafe Arabia* (Eskes and Mukred, 1989). In Yemen, coffee grows on valleys and at terraces. Coffee quality is a function of the characteristics of the cultivars grown which are then modified by the effected of the environment. Coffee bean seeds size is the reflection on both these factors and the field husbandry practices. While the quality is already determined at harvesting and may be not subsequently improved. The coffee fruit comprises the pulp which houses the parchment, surrounded by a layer of mucilage. The fruit of the Arabica coffee in which the pulp is removed from the ripe fruit by a pulping process, the mucilage and washing processes and the parchments are dried on the estate where they are grown. The dried parchment and cherry are further processed by hulling, sorting and grading. Coffee as a beverage is made from hot water extraction of soluble from the ground roasted coffee beans. Though the beverage has no nutritive value, it is consumed for the stimulating effect primarily due to it has 1.1-2.2% caffeine.

Many researches have been carried out on the physical and engineering properties of the agricultural products (Mohsenin, 1970; and El-Raie et al., 1996). The information on size, density, and crushing strength are required for the development of the grading system for barriers and for the pulpers (Gosh, 1969). The physical properties such as size, friction angle, angle of repose, crushing strength and bulk density are important in the design of the handling system, grading and hulling (Chandrasekar and Viswanathan, 1999).

Even though caffeine does not take part in any reaction, it should also contribute to bitterness, besides its known pharmacological effects (Macrae, 1985). Thus, evaluation of trigonelline, chlorogenic acids and caffeine, in both green and roasted coffee, could be of relevance in establishing coffee quality. Furthermore, a few studies have proposed the use of these substances for determination of the degree of roast (Stennert and Maier, 1996), as genotype selection criteria and for species differentiation (Martín et al., 1998; and Ky et al., 2001). The quality of coffee is commonly evaluated according to criteria such as bean size, color, shape, processing method, crop year, flavor and presence of defects (Banks et al., 1999). The term defect is employed in commercial practice in reference to the presence of defective (black, sour or brown, immature, insect-damaged or bored, broken, etc.) beans and also of extraneous matter (husks, twigs, stones, etc.) in a given coffee sample (Franca et al., 2004). The presence of defects is quite relevant in establishing coffee quality, for they are associated to problems during harvesting and pre-processing operations. This is accounted for as type classification, according to which coffee is categorized depending on the number of defects present in a 300 g sample. Each type of defect is counted as an equivalent to one black bean. For example, two sour beans or five insect-damaged beans correspond to one black bean, which is equivalent to one defect. Defective coffee beans are usually not commercialized in international markets, for they affect the quality of the beverage when roasted with non defective beans. Currently, these defective beans comprise a figure of about 20% of the total coffee production in Brazil, and they are separated from the non defective beans prior to commercialization. Since they also represent an investment in growing, harvesting and handling in the coffee production chain, coffee producers have adopted the practice of dumping them in the Brazilian internal market. The majority of the roasting industry in Brazil has been using these defective beans in blends with healthy ones, and, overall, a low grade roasted and ground coffee is consumed in the country.

The specific objective of this research was to determine the engineering properties of some Arabian coffee varieties. Such as dimensions, shape index, coefficient of friction, geometric mean diameter, spherisity, surface area, volume, density, porosity, and repose angle, to design the threshing, sorting, grading and packaging machines.

EXPERIMENTAL PROCEDURES

The coffee bean seeds used in the present study was obtained from a local market of Arabian coffee varieties. The study was carried out on three common varieties namely, Himy, Esmaely and Ma'arepy. The coffee bean seeds were cleaned manually by hand removal of all foreign matters such as stones, dirt and broken seeds. They were divided into three categories (< 7 mm, from 7-10 mm and > 10mm) based on seeds minimum diameter. These categories were used to measure dimensions (length, width and thickness), mass, bulk density, angle of repose and coefficient of friction. Shape index and coefficient of contact surface of coffee bean seeds were estimated. The overall mean of volume, geometric diameter, arithmetic diameter, frontal, and cross-sectional areas, and spherisity were also determined.

Apparatus and Procedure:

Main dimensions:

One hundred coffee bean seeds were randomly selected from the remainder of the 10 kg sample. The three main dimensions, length L, width W, and thickness T, of each of the 100 coffee bean seeds were measured with a caliper reading to 0.01 mm. The geometric mean diameter, arithmetic diameter, volume, frontal surface and cross-sectional areas of the coffee bean seeds were calculated using the relationships given by Mohsenin (1970), as follows:

$$\text{Sphericity} = 100\ \frac{(\text{LWT})^{0.333}}{\text{L}},\% \qquad (1)$$

$$\text{Volume} = \frac{\pi}{6}\ \text{LWT},\ \text{mm}^3 \qquad (2)$$

$$\text{Geometric diameter} = (\text{LWT})^{0.333},\ \text{mm} \qquad (3)$$

$$\text{Arithmetic diameter} = \frac{(\text{L}+\text{W}+\text{T})}{3},\ \text{mm} \qquad (4)$$

$$\text{Frontal surface area} = \frac{\pi}{4}\ \text{LW},\ \text{mm}^2 \qquad (5)$$

$$\text{Cross-sectional of area} = \frac{\pi}{4}\ \frac{(\text{L}+\text{W}+\text{T})^2}{3},\ \text{mm}^2 \qquad (6)$$

Shape index:

Shape index is used to evaluate the shape of the coffee berries and calculated according to the following equation Mohsenin (1970):

$$\text{Shape Index} = \frac{\text{L}}{\sqrt{\text{W} * \text{T}}} \qquad (7)$$

The coffee berry is considered an oval if the shape index > 1.5 on the other hand it is considered spherical if the shape index ≤ 1.5.

Contact surface:

The coefficient of contact surface is very important parameter to evaluate the contact surface between the berry and the other surfaces such as milling machine's surface. This coefficient can be calculated using the following equation Mohsenin (1970):

$$\text{Coefficient of contact surface} = \frac{A_f - A_t}{A_f} * 100 \qquad (8)$$

Where:

A_f is the frontal surface area $= \pi/4 \times L \times W$, mm^2

A_t is the transverse surface area $= \pi/4 \times T \times W$, mm^2

Bulk density of the coffee bean seeds:

The bulk density of the coffee bean seeds was measured by filling a circular container of one lit. volume and weighing the contents. It was calculated from the mass and volume.

Angle of repose

The repose angle of the three categories of the coffee bean varieties was determined by allowing the parchment to flow on a plate to form a pile and the angle of repose is measured by fixing a protractor on the side of the plate.

Coefficient of friction:

The need for knowledge of the coefficient of friction of the agricultural materials on various surfaces has long coffee bean seeds recognized by engineers concerned with rational design of seed bins, silos and other storage and handling structures. Coefficient of friction is the ratio of the force required to slide seeds over a surface. Coefficients of friction were determined for seed on four surfaces: galvanized steel, plywood, tin plate and glass. The material surface was fastened to a tilting table. A frame made with square wooden bars was placed on the surface. The frame was filled with coffee bean seeds. The table was tilted slowly manually until movement of the whole seeds mass and frame was detected by the operator. The coefficient of friction was the tangent of the slope angle of the table measured with a protractor (Oje and Ugbor, 1991).

RESULTS AND DISCUSSION

Engineering properties:

Length, width and thickness:

The data were collected and recorded. Figs. (1 through 3) show the frequency distribution of the coffee bean seeds length, width and thickness. It can be noticed that the highest frequency distribution were 30, 34 and 44 % at 10 mm length and 7 mm width and thickness respectively. From the obtained results, the width and thickness are the same. This means that the shape of coffee bean seeds tented to roller easily on the surfaces. From the basic dimensions of the coffee bean seeds the designed of the clearance in the machines must be not higher than the maximum dimension frequencies of both length and width.

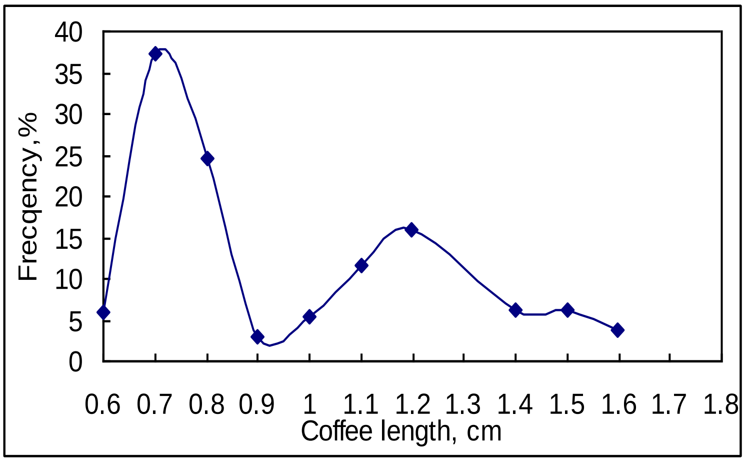


Fig. 1. Frequency distribution curve for coffee length.

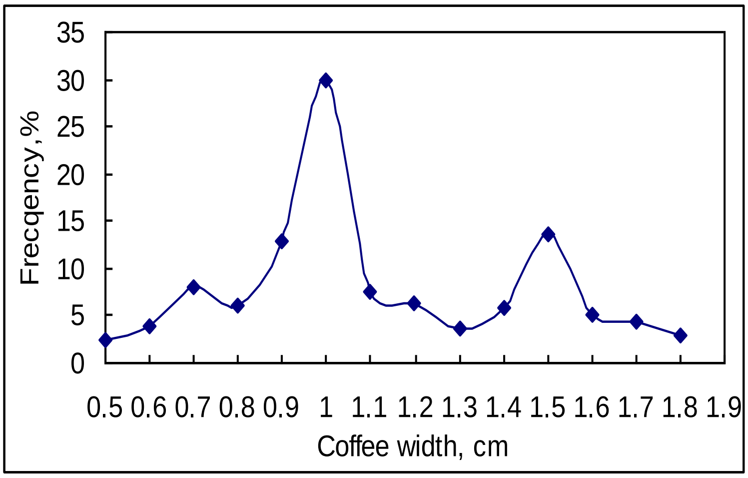


Fig. 2. Frequency distribution curve for coffee width.

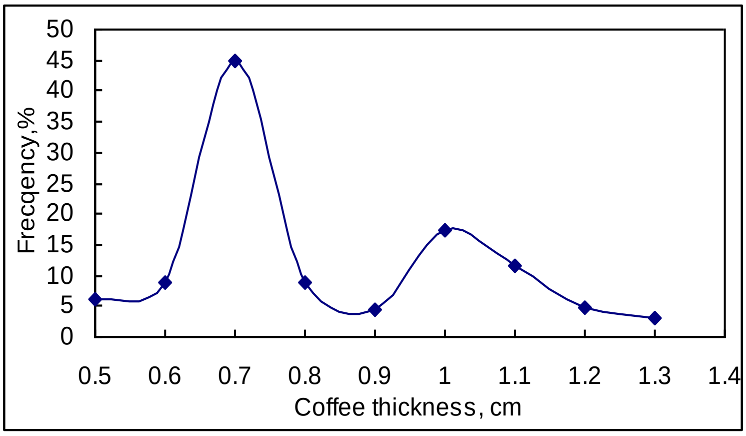


Fig. 3. Frequency distribution curve for coffee thickness

Shape index and coefficient of contact surface:

The average and standard deviation of the shape index and coefficient of contact surface were estimated from coffee berries categories. Three different varieties and the data are shown in table (1).

Table 1. Shape index and coefficient of contact surface.

Variety	Shape index			Coefficient of contact surface, %		
	< 7 mm	7–10 mm	> 10 mm	< 7 mm	7–10 mm	> 10 mm
Himy	1.200	1.125	1.091	28.6	27.8	28.0
Esmaely	1.167	1.111	1.167	16.7	33	28.6
Ma'arepy	1.143	1.100	1.154	25	30	28.6
Mean	1.170	1.112	1.137	23.43	30.27	28.40
SD	0.029	0.013	0.041	6.10	2.61	0.35

SD is the standard deviation

It indicates also that all the coffee bean seeds are spherical in shape according to Abd Alla (1993). From the results it can be seen that the sieves of a grading machine can be designed with a circular holes ranging from 6 to 10 mm.

Volume, geometric and arithmetic diameters, frontal and cross sectional areas and spherical percentage:

Table (2) shows the mean and standard deviation of volume, geometric and arithmetic diameters, and frontal and cross sectional areas and spherical percentage of coffee bean seeds categories for three different varieties. The overall mean volume, geometric diameter, arithmetic diameter, frontal surface, cross-sectional of surface area, spheroid were 139 mm^3, 6.32 mm, 6.33 mm, 33.5 mm^2, 96.0 mm^2, and 0.901 %, respectively for < 7 mm at all varieties. Therefore, the corresponding values for coffee bean seeds categorize 7–10 mm were 434 mm^3, 9.32 mm, 9.33 mm, 71.2 mm^2, 206.7 mm^2, and 0.932 %, respectively for 7–10 mm respectively at all coffee bean seeds varieties. Meanwhile, there were 1047 mm^3, 12.53 mm, 12.56 mm, 129.5 mm^2, 373.4 mm^2, and 0.918 %, respectively for > 10 mm at three coffee bean seeds varieties under study.

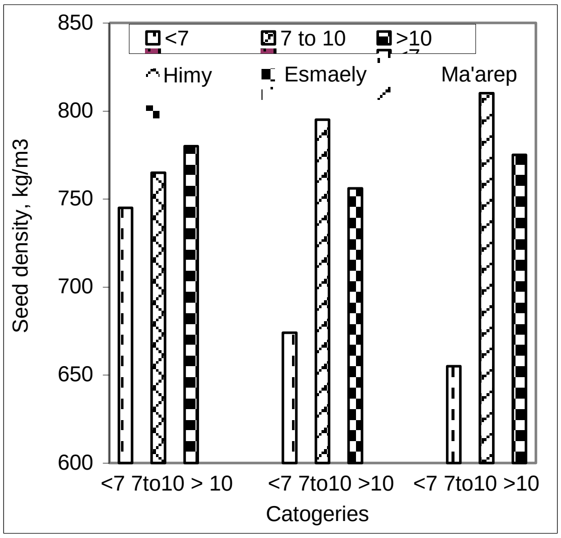
Table 2. Volume (V), geometric mean diameter (GMD), arithmetic mean diameters (AMD), frontal surface area (A_f), cross-sectional area (A_{cs}) and spheroid percentage of coffee berries.

Variety	V (mm^3)	GMD (mm)	AMD (mm)	A_f , (mm^2)	A_{cs} (mm^2)	Sphericity (%)
Category < 7 mm						
Himy	79	5.32	5.33	23.6	67.0	0.886
Esmaely	132	6.32	6.33	33.0	94.5	0.903
Ma'arepy	205	7.32	7.33	44.0	126.6	0.915
Mean	139	6.32	6.33	33.5	96.0	0.901
SD	63.264	1.002	1.000	10.215	29.861	0.015
Category from 7 – 10 mm						
Himy	301	8.32	8.33	56.5	163.5	0.925
Esmaely	424	9.32	9.33	70.7	205.1	0.932
Ma'arepy	576	10.32	10.33	86.4	251.5	0.938
Mean	434	9.32	9.33	71.2	206.7	0.932
SD	137.374	1.000	1.000	14.922	43.981	0.007
Category > 10 mm						
Himy	760	11.32	113.3	103.6	302.5	0.944
Esmaely	1055	12.63	126.7	131.9	377.8	0.902
Ma'arepy	1327	13.63	136.7	153.1	439.9	0.909
Mean	1047	12.53	12.56	129.5	373.4	0.918
SD	283.467	1.158	1.171	24.811	68.795	0.022

Bulk density and angle of repose:

Sample shows the mass of 1000 seeds, bulk density and angle of repose for three categories of coffee bean. It shows that the mass increased with the increase of coffee diameter for all varieties. Fig. (4) showed that the bulk density of the coffee bean seeds was 745, 765 and 780 kg/m^3, respectively at coffee bean seeds categories (< 7 mm, from 7-10 mm and > 10 mm), for Himy variety. The bulk density was higher at the medium size than both small and large sizes coffee bean seeds for varieties (Esmaely and Ma'arepy). However, the porosity of the medium size was lower than those of both small and large sizes. This may be due to the smaller size for many seeds which were not fully ripened which make them lighter than they would. The angle of repose increased with the decrease of coffee bean seeds size. It ranged from 10 to 14 degree on the glass surface, as illustrated in Fig.(4).

Meanwhile, the bulk density and the angle of repose can indicate the hopper main dimensions and its slope angles.



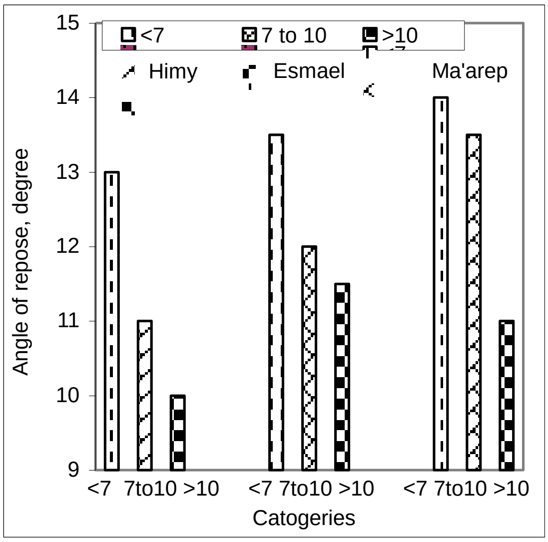


Fig. 4. Angle of repose and Density for average three size categories of coffee.
Coefficient of Static Friction.

Fig. (5) shows the coefficient of friction of three sizes of coffee on four different surfaces; plywood, galvanized steel, tin plate and glass for the different varieties under study. The results showed that the coefficient of friction decreased with the increase of coffee grain categories at all surfaces. The highest value was 0.3 for the small size and the lowest value was 0.19 for the large size. The maximum coefficient of friction was offered by plywood surface followed by galvanized steel, tin plate, and glass for all categories of the coffee grains, these results agreed with those obtained by Helmy (1995).

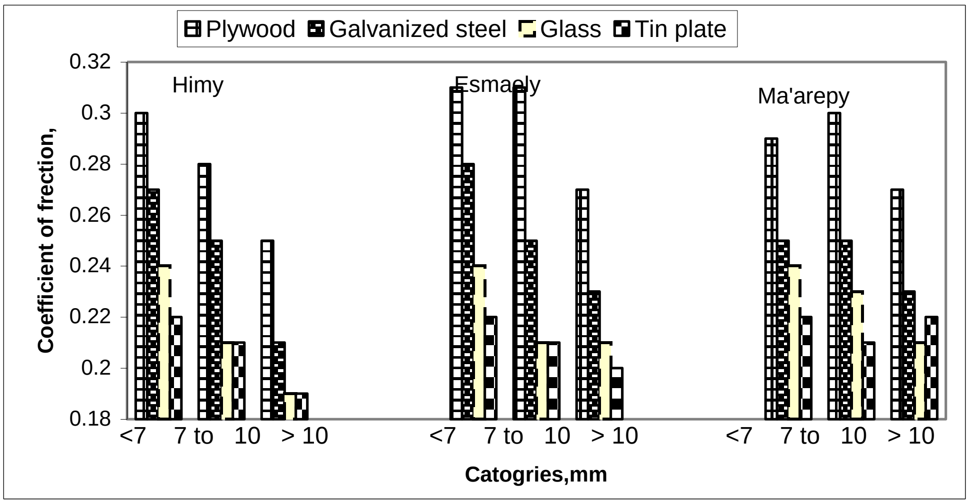


Fig.5. Coefficient of friction of coffee with four different surface Conclusions

- The highest frequency length, width and thickness of the coffee grains were 10.0, 7.0 and 7.0 mm.
- Shape index and coefficient of contact surface revealed that the coffee grains are spherical in shape.
- The medium size (from 7-10 mm) was denser than both small and large size of coffee as the porosity of that size was lower than those of both small and large sizes.
- The angle of repose increased with the decrease of coffee size. It ranged from 8.75 to 14.3 degrees on the glass surface.
- The coefficient of friction decreased with the increase of coffee size at all surfaces.
- The maximum coefficient of friction was offered by plywood surface followed by galvanized steel, tin plate, and glass for all categories of the coffee grains.

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الخصائص الهندسية لبعض أصناف حبوب البن العربية

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معهد بحوث الهندسة الزراعية - مركز البحوث الزراعية – الدقى – الجيزة

يهدف البحث إلي دراسة بعض الخصائص الهندسية لأصناف مختلفة من البن العربي لتحليل سلوك المنتج لتصميم آلة لتقشير وتدريج حبوب البن. استخدمت ثلاثة أصناف من حبوب البن (Himy, Esmaely, Ma'arepy) لقياس الأبعاد الرئيسية (الطول، العرض، السمك)، والكتلة والكثافة وزاوية التكدس ومعامل الإحتكاك كما تم تحديد الحجم المتوسط والقطر الهندسي، والقطر الحسابى، ومساحه مقطع الحبه والشكل الكروى للحبة.

تم رسم منحنى التوزيع التكرارى للأبعاد الخطية وكان متوسط أكبر طول ، وعرض وسمك لحبوب البن هي 1.0 و 0.7 و0.7 سم. والحجم المتوسط (7–10 مم). تتزايد زاوية التكدس لحبوب البن بتناقص الحجم، و تراوحت بين 8.75 إلى 14.30 درجة على سطح الزجاج.

إانخفض معامل الاحتكاك بزيادة حجم حبوب البن على جميع الأسطح. أقصى قيمة لمعامل الإحتكاك على السطح الخشبي ثم الصلب المجلفن ثم القصدير ثم الزجاج وذلك لجميع اصناف حبوب البن.