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Development and Performance Evaluation of Static Angle of Repose Measuring System for Some Biological Materials

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ABSTRACT: Angle of repose (AOR) is a vital physical property used for characterization of the bulk seeds, grains, flours, and fruits needed for the design of processing, storage, and conveying systems. In this work, static AOR measuring device capable of measuring wide varieties of bio-materials was designed and constructed. The major components of the machine include removable circular sample base, adjustable pointer, calibrated rule system, adjustable leg and the fixed sample base. Performance evaluation of the system on three seeds was carried out. Height, diameter and AOR for maize were 4.87 cm, 16.62 cm and 30.51^o respectively. Melon seeds had a height, diameter and AOR values of 5.15 cm, 16.82 cm and 31.55^o respectively while the values for beans were 3.2 cm, 10.78 cm and 30.21^o respectively. The findings were consistent with similar reports in literature.

Keyword: Design, construction, melon seeds, angle of repose, performance evaluation

I INTRODUCTION

One of the most outstanding properties used to characterizing bio-materials in the design, development of automated or manual discharge, processing and transport systems, is the angle of repose (AOR) (Wójcik et al., 2017). When particles are poured onto a flat surface, a conical pile is formed. Material with a low AOR forms flatter piles than material with a high AOR. The angle between the slant height and the base of a cone is known as the AOR (Wójcik et al., 2019; Al-Hashemi and Al-Amoudi, 2018). The value of the AOR affects the behavior of a given granular material during processing, transport and discharge, owing to which it is perceived as a decisive factor in the design of conveyors and silos. Its values depend on friction between moving particles, which – to a large extent – is dependent on moisture content, density, gravity, granulometric composition, shape, size, and surface texture of the particles (Wójcik et al., 2017) as well as nature of material and differences in the state of stress (Khanal et al., 2017)

The angle of repose could be categorized into static and dynamic. For the static AOR, the material on the slope face is on the verge of sliding, usually between 0^o-90^o. For the dynamic AOR, sediment grains move continuously from the upper to lower end of the slope, yielding a surface shear layer of grains that flow down the plane inclined at a fixed angle. AOR has very wide and varied applications such as agricultural engineering, enthomology, geothechnical engineering, hydrodynamic and sendimentology, particle technology and material science. Infact, knowledge of AOR is of crucial importance for engineering and industrial practices (Chen et al. 2019). The flowability or transport of granular materials is highly dependent on a number of factors, one of which is the AOR (Wójcik et al., 2019; Al-Hashemi and Al-Amoudi, 2018). The definition of AOR is based on the particular application and the corresponding behavior. Physically, the AOR can be defined as the angle that differentiates the transitions between phases of the granular material. One of the most commonly used definitions of the AOR is the steepest slope of the unconfined material, measured from the horizontal plane on which the material can be heaped without collapsing (Tan et al., 2020; Chukwu and Sunmonu, 2010). The basic methods used for AOR measurement include the emptying, piling, submerging or pouring methods. There are also the rotating and aerating methods ((Wójcik et al., 2017).

Ranking of AOR for granular materials had been well reported (Carr, 1970). Bio-materials with the AOR less than 30^o are ranked as very free flowing. Values between 30 -38^o are classified as free flowing. AOR values between 38 – 45^o are described as fair to passable flow. Values of 45 –

55° are ranked as cohesive, while those of AOR greater than 55° are classified as very cohesive, showing non flowability (Table 1).

Table 1. Classification of flowability of bio-materials based on AOR

Description	Repose Angle
Very free-flowing	<30°
Free flowing	30–38°
Fair to passable flow	38–45°
Cohesive	45–55°
Very cohesive (non-flowing)	>55°

Source: Al-Hashemi and Al-Amoudi, 2018

Typically, the processing of agricultural bio-materials to industrial or residential materials include preprocessing (leaning and cleaning), chemical pretreatment, size reduction, conveying storage etc. Due to the geometry/properties of the bio-materials, design of systems for efficient feeding and handling of raw biological materials still pose quite a significant substantial challenge. To address engineering problems in bio-material utilization and develop well-designed facility for any step mentioned above, particularly for some indegenous crops, research on the AOR of indigenous crops are expedient.

Numerous works have dealt on the determination of AOR for granular materials (Tan et al., 2020; Chen et al., 2019; Wojcik et al., 2019; Al-Hashemi and Al-Amoudi, 2018; Wojcik et al., 2017 and Khamal et al., 2017), determination of physical properties of bio-materials (Kanakabandi and Goswami, 2019; Kumar et al., 2018; Mansouri et al., 2017 and Chukwu and Sunmonu, 2010), as well as design and construction of devices for processing of bio-materials (Fadele and Aremu, 2016 and Ajav and Makinde, 2015). Bulk of these studies only focused on the physico-mechanical characterization of granular biological materials such as grains, seeds, biomasses etc. In this case, the AOR is usually one of many properties usually subjected to investigation. Currently, there is very little report on the development of AOR devices. The aim of this study is to design and construct an efficient AOR measuring device for indigenous biological materials, using readily available materials and conduct performance evaluation of some local crops varieties whose AOR values had not been known.

II MATERIALS AND METHODS

Material Sectioning

The materials used for the design of the measuring device of static AOR of granular materials were galvanized metal sheet, iron rod and flat bars. An iron rod of thickness ½ inch (12.74 mm) with dimension (50 x 50cm) was cut into four places (400mm x 400mm) using a hacksaw, try square, and measuring tape from which a box was constructed. A 50 cm-long rule was screwed to one side of the constructed box, which was used to measure the height of the cone of granular materials.

A round or flat plain sheet of diameter 30 cm was also used. A bottomless cylinder of height, 10cm and diameter, 7.5 were also used. A meter rule was calibrated in other to take the reading of the experiment

Methodology

The device bottomless cylinder was filled with granular solids whose static AOR is to be determined. The solid is allowed to escape from the box leaving a free standing cone of solid on the circular platform. With the aid of the meter rule in the box been adjusted to and fro, the indicated heights were measured and the angle of repose, θ was computed using the geometry of cone given by EFMH (1991) and Kumar et al. (2018) as shown in equation (1):

$$\theta = Tan^{-1}\left(\frac{2H}{D}\right) \quad (1)$$

where: H is height of cone from datum (cm) and D is diameter of circular platform (cm).

Digital vernier caliper was used to measure the major, minor and the intermediate diameters. Gravimetric method was used to determine the moisture contents before calculating the AOR of the granular materials.

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The AOR is therefore proportional to the height of cone formed at constant values of the platform diameter. The platform was adjusted at a constant value of 23.5 cm. The smooth nature of some nuts do not allow them to adhere together, hence, such nuts do not have high value of H and thus has a smaller AOR. Conversely, the rough nature of some seeds with surface coat make them adhere together and a higher value of H would be obtained.

Isometric view of the design

Figure 1 presents the engineering drawing of the designed static AOR device in third angle projection. The 3D (right and left views) as well as the autographic drawing of the angle of repose device is shown in Figure 2

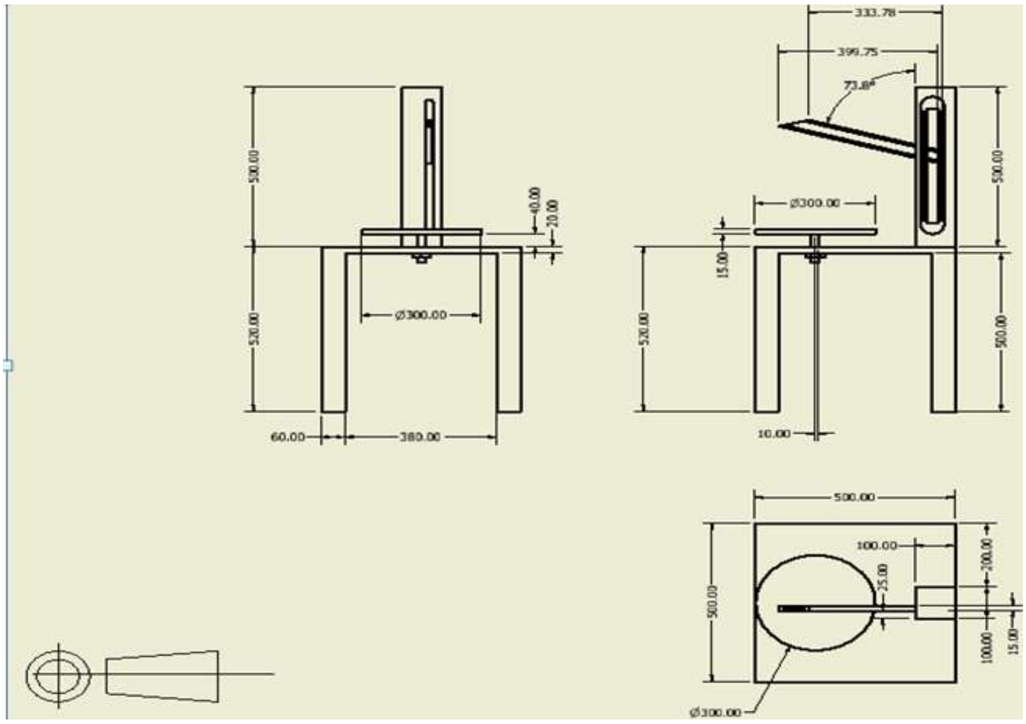

Figure 1. Engineering drawing of the designed static AOR device in third angle projection

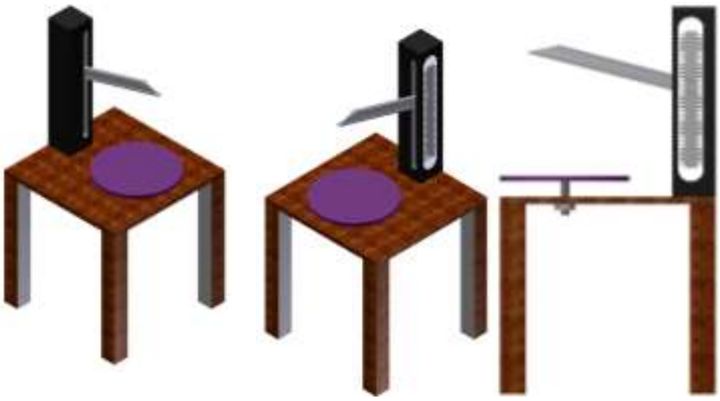

Figure 2. The 3D (right and left views) as well as the autographic drawing of the AOR device

2.4 Mode of operation.

The developed device is used to measure the static AOR of biomaterial. The working principles is by filling method, in this case the bottomless cylinder is filled with a particular biomaterial until it runs over and gradually removed in other to make a pile. After the pile one measures the height of the piled bio material and the diameter of the piled material to get the AOR

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III RESULTS AND DISCUSSION

Performance evaluation of the fabricated devices.

The fabricated device was evaluated and the height, diameter and static AOR measured using maize, melon and beans for 25 replications with results presented in Tables 2. The mean values for height, diameter and AOR for maize were 4.87 cm, 16.62 cm and 30.51° respectively (Table 2). Melon seeds had a height, diameter and AOR values of 5.15 cm, 16.82 cm and 31.55° respectively (Table 2) while the values for beans were 3.2 cm, 10.78 cm and 30.21° respectively (Table 2). The AOR values for maize, melon and beans could be classified as free flowing (Carr, 1965; Carr, 1970). The values of AOR for the agricultural materials were slightly below the values of 38.93° earlier documented for rough paddy (Kumar et al., 2018). These were different from the dynamic AOR value of 44.82° for pepper earlier reported.

Table 2. Measured H, D and AOR values for for dried maize, melon and beans seeds

Statistical function	Biological materials								
	Maize			Melon			Beans		
	Height, H (m)	Diameter, D (m)	Angle of repose, AOR (°)	Height, H (m)	Diameter, D (m)	Angle of repose, AOR (°)	Height, H (m)	Diameter, D (m)	Angle of repose, AOR (°)
Mean	4.1	16.62	30.51	5.15	16.82	31.55	3.2	10.78	30.21
Standard. Deviation	3.3	0.6	2.67	0.37	1.02	2.25	0.43	0.54	2.9
Maximum value	5.8	17.8	36.51	5.7	18.5	34.66	3.8	11.8	36.42
Minimum value	5.2	15.4	24.69	4.4	14.9	26.44	2.3	10.1	23.62

Figure 3 presents the comparison between the AOR of maize, melon and beans with their error bars in a simple bar chart. Melon seeds had the highest AOR (31.55±2.25°), followed by maize (30.51±2.67°) and beans (30.21±2.9°) (Figure 3). This could be attributed to the physical geometry of the biomaterials and their viscous nature. The AOR values for melon seeds were clearly in conformity with values of 27. 23° and 31.66° earlier reported by Mansouri et al. (2017) for seeds and kernel respectively. The height and the diameter of pile vary with the biological material (Figure 4). Melon seeds had the highest height of pile (5.15 ±0.37 cm), followed by maize (4.87±0.62 cm) and beans (3.2 ±0.42 cm). The diameter of pile for melon, maize and beans were 16.82±1.02 cm, 16.62±0.6 cm and 10.78 0.54 cm respectively (Figure 4)

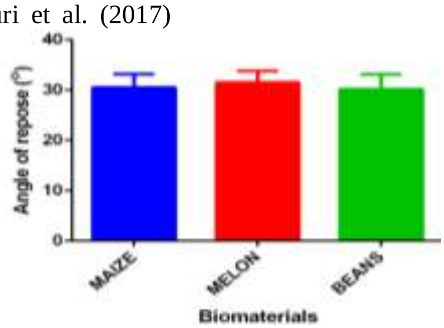

Figure 3. A simple bar chart of the mean values of AOR for maize, melon and beans with their standard errors

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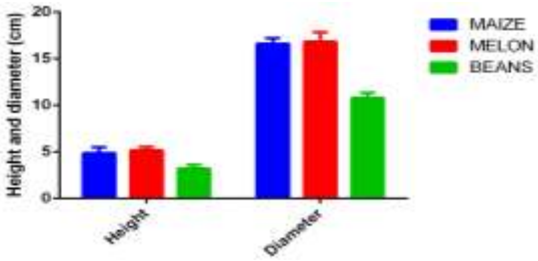

Figure 4. An interleaved bar chart showing the mean values of height and diameter for maize, melon and beans.

IV CONCLUSION

In conclusion, the AOR system vital for measuring wide varieties of biological, plant-based materials was designed and constructed. The major components of the machine include removable cylindrical sample base, adjustable pointer, calibrated measuring system and the fixed sample base. Performance evaluation of the system on three seeds was carried out. The height, diameter and AOR for maize were 4.87 cm, 16.62 cm and 30.51^o respectively. Melon seeds had a height, diameter and angle of repose values of 5.15 cm, 16.82 cm and 31.55^o respectively while the values for beans were 3.2 cm, 10.78 cm and 30.21^o respectively. The findings were consistent with similar reports in literature.

SOME OF THE ADVANTAGES FROM THE ABOVE RESULTS

a) Angle of repose (AOR) measuring devices was designed and constructed
b) Knowledge of AOR is vital in the design, and construction of processing, transport, discharge and handling systems.
c) Melon, maize and beans had AOR of 31.55^o, 30.51^o and 30.21^o respectively
d) Bulk bean seeds with lowest AOR values will form flatter piles than maize and melon seeds
e) The AOR values for maize, melon and beans could be classified as free flowing

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