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Determination of voidage of palm nuts in a vessel

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Abstract

Inaccurate estimation of nuts volume in a hopper may likely influence the design of some components of palm nut processing system such as shaft, rotor, electric motor power, hopper supporting rods, etc. In an effort to address this challenge the voids/ spaces were considered as inherent in palm nuts when stored in a vessel. In this study, 5 kg of dried and ready to crack mixed varieties of palm nuts were grouped based on their minor diameter (d_1) as small size: $d_1 <$ 13.00 mm; medium size: 13.00 $\leq d_1 <$ 17.00 mm and large size: $d_1 \geq$ 17.00 mm for each size range, nuts were randomly selected and each range placed into different 100 ml beaker. Toluene was poured into each of the beaker until the nuts at the top were tipped covered. The volume of toluene ($V_{toluene}$) used in filling to the tip of the top nuts was quantified as void / space unoccupied by the nuts. The experiment was repeated using 150, 200, 250 and 300 ml beaker respectively. Each experiment was carried out in duplicate and their mean and standard deviation computed. Result showed that voidage of palm nut in a processing vessel was 45 ± 4%. This designates that the actual volume of palm nuts occupied in a processing vessel such as hopper would likely be 55% of its container's volume. Hence, could be used in the design of storage facilities such as silo, bin, etc.

Keywords: Voidage; Palm nuts; Beaker; Toluene; Size range

1. Introduction

Voidage (Ɛ) is referred to as the portion of the total volume that is free space available for fluid flow, and thus the fractional volume of the vessel occupied by solid material equal 1 – Ɛ. Based on porous material, the voidage could range from near zero to almost one (i.e., 0 < Ɛ < 1) (Chhabra and Richardson, 1999; Kramer *et al.,* 2021; Amin and Saman, 2022). When food and agricultural products are stored or stacked in a vessel (hopper, silo, bin, etc.), voids / spaces are created. The amount of voidage formed depends on the geometric shape of the material stored. The more irregular the material is, the more spaces created among the material (Huaqing *et al.,* 2017; Ravindra *et al.,* 2018). Palm nuts create voids / spaces when loaded in a processing vessel. In a typical palm nut processing system, vessel such as hopper is fitted to receive the feed (nuts) and channel them to the cracking chamber. Its capacity is designed based on the volume of product to be processed (Childs, 2021). Already, several works have been carried out in an attempt to provide models for predicting individual palm nut dimension and volume (Antia and Assian, 2018a and b).

$d_2^2 = d_1 d_3$ (Antia *et al.,* 2015)……..(1)

Where, d_2 = intermediate diameter, d_3 = major diameter and d_2 = minor diameter of palm nut.

GMD = $(d_1 d_2 d_3)^{1/3}$ (Gbadam *et al.,* 2009; Antia and Assian, 2018a)……… (2)

Where GMD = geometric mean diameter

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$$Y = ae^{bx} \text{ (Antia and Assian, 2018b)……..(3)}$$

Where, Y= volume of palm nut, a = 76.548, b = 0.196 and x = geometric mean diameter (GMD)

Basically, the actual volume occupied by the nuts is less than the volume of its container. Thus, the weight of the nuts in a container is essentially a function of the volume occupied in the container (Rao *et al.,* 2005). In addition, the weight of the nuts in a hopper may influence the design of palm nut processing system components such as shaft diameter with its attachment (rotor), electric motor power, hopper supporting rods, etc. During the system component design stage, exact weight or volume of palm nuts in the hopper must be considered or else, improper design and selection of components may likely hamper system efficiency. So, it is pertinent to have quantitative idea of palm nut voidage. Thus, in this study palm nut voidage determination in a processing vessel (hopper) was carried out. The value of voidage could be employed in the computation of weight of feed hopper and its content, design of shaft, silo, bins, etc.

1.1. Theory

Let the volume of space/ void in the beaker containing the nut equal *Y*. The total volume of the beaker (*X*) is the volume of the nuts and volume of space between the nuts. Then, the percentage of space between the nuts (void) [Ɛ] is given as:

$$\mathcal{E} = \frac{Y}{X} \text{ …………..(4)}$$

$$Y = \mathcal{E}\, X \text{ ………… (5)}$$

Hence, a plot of *Y* against *X* will give slope as Ɛ.

2. Material and methods

2.1. Materials

Materials and equipment used in this work included dried and ready to crack palm nuts, digital weighing balance, digital vernier calipers, containers / beakers, hot air oven, toluene, etc.

2.2. Methods

About 5 kg of dried and ready to crack palm nuts of mixed varieties was weighed out using digital weighing balance. The nuts were grouped based on their minor diameter (d_1) using digital vernier calipers into three size ranges namely, small size: d_1 < 13.00 mm; medium size: 13.00 ≤ d_1 < 17.00 mm and large size: d_1 ≥ 17.00 mm. Containers used were graduated beakers; were cleaned and dried in the hot air oven at 105 °C. The small size range of the samples (nuts) was hand-picked randomly into a beaker. The beaker was gently tapped until the nuts levelled at 100 ml mark. The beaker with its content was filled with toluene until the nuts were covered up to the tip of the top nuts at the 100 ml mark. The liquid was gently poured out into a measuring cylinder and its volume read as $V_{toluene}$. The $V_{toluene}$ is regarded as volume of void / space occupied by toluene. The experiment was repeated for the medium and large size ranges of the nuts. Each experiment was carried out in duplicate. These experiments were repeated using 150, 200, 250 and 300 ml beaker. The mean and standard deviation of $V_{toluene}$ were computed for the three size ranges using the five different beaker volumes (100, 150, 200, 250 and 300 ml). Plots for each size range based on Equation 4 were carried out and slopes of the plots obtained for small, medium and large size ranges were denoted as $\mathcal{E}_{n.small}$, $\mathcal{E}_{n.medium}$, $\mathcal{E}_{n.large}$, respectively. The % $\mathcal{E}_{n.mean}$ for the bulk samples was calculated as (Frank and Althoen, 1995):

$$\% \mathcal{E}_n = \frac{\% \mathcal{E}_{n.small} + \% \mathcal{E}_{n.medium} + \% \mathcal{E}_{n.large}}{3} \text{ ………..(6)}$$

The standard deviation was computed as (Spiengel and Stephens, 1999):

$$\text{SD}= \sqrt{\frac{\sum d^2}{n-1}} \text{ ………….. (7)}$$

Where, d = deviation = voidage – mean voidage (bulk sample).

3. Results and discussion

The results of the plot of void/ space occupied by toluene against volume of beaker / container are presented in Figure 1 based on experimental data computed and presented in Appendix.

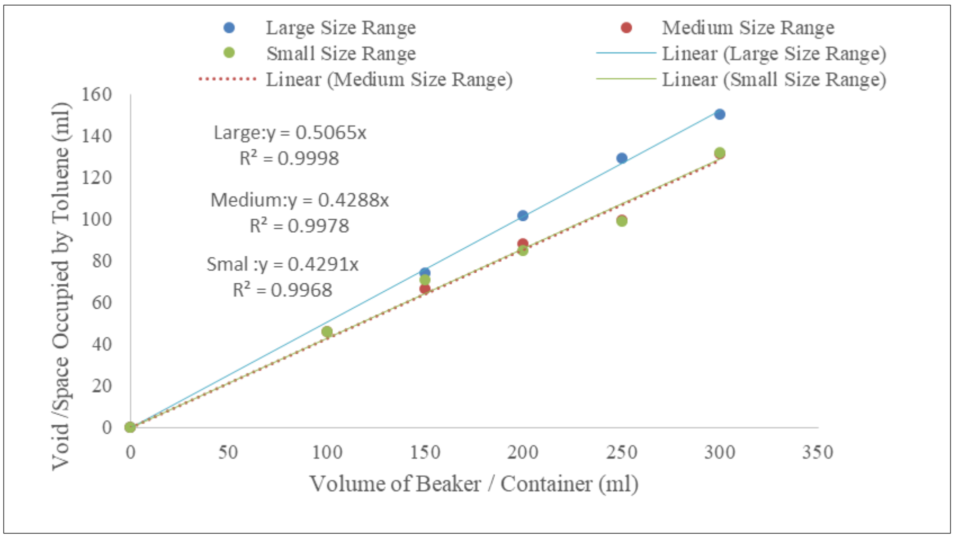

Figure 1 Void/ space occupied by toluene against volume of beaker / container

From Figure 1, the slopes for small, medium and large size ranges were 0.4291, 0.4288 and 0.5065, respectively. These values were the voidage in decimal obtained for small, medium and large size ranges.

The voidage of the bulk sample or mean voidage of palm nuts (% $\varepsilon_{n.mean}$) with standard deviation was 45 ± 4%, and is presented in Table 1.

Table 1 Bulk or mean voidage of the palm nuts

Mean (decimal)	SD	% Voidage	Volume Occupied by Palm Nut in any Vessel
0.45	0.04	45%	100% - 45 % = 55%

This implies that the actual volume of palm nuts occupied in a certain vessel, for instance, silo would be 55% of hopper volume.

4. Conclusion

In this study, voidage of palm nut in a vessel was conducted using toluene and found to be 45 ± 4%. This indicates that the actual volume of palm nut occupied in a vessel such as hopper would be 55% of its container's volume. The finding may also be used in the design of other storage facilities such as silo, bin, hopper, etc.

Compliance with ethical standards

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Disclosure of conflict of interest

Authors have declared that no competing interests exist.

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