SOME ENGINEERING PROPERTIES OF SHEA KERNEL IN GHANA

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ABSTRACT

Data on engineering properties of agricultural produce are essential for designing of equipment for harvesting, processing, transportation, cleaning, sorting, separation, packaging and storage. In this research, some geometric, gravimetric and frictional properties of the shea kernel were investigated. The geometric properties investigated are the axial dimensions (Length, L, Width, W and Thickness, T), geometric mean diameter, arithmetic diameter, aspect ratio, sphericity, surface area and volume. While the gravimetric properties investigated included 1000-kernel mass, true density, bulk density and porosity. The frictional properties investigated were angle of repose and static co-efficient of friction; determined: on five structural surfaces, namely: glass plywood, Mild steel, Galvanized steel and Stainless steel. Moisture content was determined on dry basis. The results obtained indicated that the mean values for the length, Width, Thickness ,Geometric mean diameter, Arithmetic diameter, Aspect ratio, Sphericity, Surface area and Volume were 2.543±0.196cm, 1.803±0.142 cm, 1.576±0.107cm, 1.928±0.101cm, 1.974±0.098cm, 71.279±4.750%, 76.104±7.249%, 11.716±1.196cm^2, 3.793±0.581cm^3, and ranged between (2.137-2.973cm), (1.295-2.222cm), (1.145-665.966cm), (1.610-2.194cm), (1.651-2.272cm), (46.614-90.285%, 62.530-87.968%, (8.145-15.119cm^2), 2.190-5.542cm^3) respectively. Also1000-kernel mass, true density, bulk density, Porosity were 4117.833g, 1.093g/cm^3, 0.682±0.013g/cm^3, 38.347±0.612%, and ranged between (2600.000-6020.000g), (0.867-2.008g/cm^3), (37.300-38.929g/cm^3), (37.300-38.929%), respectively. Angle of repose and Coefficient of static friction on Glass, Plywood, Mild steel, Galvanised steel, Stainless steel were 34.818±3.932^0 and 0.168±0.020, 0.461±0.013, 0.385±0.016, 0.238±0.016, 0.292±0.027and ranged between (27.245-40.325^o) and (0.151-0.184), (0.436-0.483), (0.361-0.394), (0.220-0.256), (0.262-0.301) respectively. Plywood had the highest static co-efficient of friction while glass had the least co-efficient of friction. This is due to the degree of roughness or smoothness. Data was analysed using descriptive statistics (minimum and maximum values, mean and standard deviation). All experiments were conducted at a moisture content of 6.763± 0.440 % (d.b).

Key words: Aspect ratio, Axial dimensions, Engineering properties, Static co-efficient of friction, Shea belt, shea kernel, sphericity.

INTRODUCTION

Shea nut (*Vitellaria paradoxa*) is a cash crop grown wild in the north of Ghana. Shea butter, a vegetable fat is obtained from this nut. The tree is resistant to harsh conditions such as drought and fire. It grows well in the guinea and Sudan savannas.

There has been a steady increase in international demand for shea nuts and butter for use in food, chocolates, pharmaceuticals and cosmetics, which has also triggered increases supply though the supply is not commensurate with the demand (Bup *et al.,* 2013). This has resulted in the export of raw shea nut for processing in Europe, Japan and America which poses a threat to the industry since importers have the tendency of dictating prices of the commodity as done in the cocoa industry. Nuts and butter from Ghana is highly valued and as such it is the leading exporter of raw shea nuts in the world (Lovett and Haq, 2000). FAO, (2008) estimated that Ghana exported 42,424mt of shea worth 14.8 million dollars. However this quantity of raw nuts could have yielded 21,212mt of shea butter at a premium value of 21.2 million dollars, a percentage increase in value of 42.9% if it was locally processed. The cosmetics industry offers a market to producers from African countries due to the growing demand for natural and organic beauty products (Akosah-Sarpong, 2003). The production of natural unrefined shea butter is however concentrated on small scale local processors who are mainly women and children. The processing operations are predominantly done manually. This is not only time consuming, but also arduous.

Despite the importance of sheanuts to the economy of Ghana, little is known about its engineering properties which are essential for designing appropriate production machines and equipment for various unit operations in its processing, to reduce drudgery and to improve the sanitation in the processing chain. Presently, the equipment used in processing sheanut have been locally design without taken into consideration the physical properties of sheanuts which include the size, mass, bulk density, true density, sphericity, porosity, coefficient of static friction and angle of repose and resultant systems leads to reduction in working efficiency and increase in product losses (Manuwa and Afuye, 2004; Razari *et al*., 2007). It is important to have an accurate estimate of shape, size, volume, density, surface area and other physical and mechanical properties that may be considered as engineering parameters for that product, when biomaterials are studied either in bulk or individually.

Also, mechanical damage to seeds which occurs in harvesting, threshing, and handling can seriously affect viability and germination power, growth vigour, insect and fungi attack and also the quality of the final products (Mohsenin, 1970).

Various researchers have done some work on different agricultural materials. Notably among them are (Bart-plange and Baryeh, 2003)-on cocoa beans, (Baryeh and Mangope 2003)- on pigeon pea, (Adejumo et al., 2007)- for bambara groundnut, (Manuwa and Afuye, 2004)-for soya beans, (R.M. Davies, 2009)-on groundnut grains, (Davies R.M, Zibokere D S 2011)-on three varieties of cowpea, (Davies, R.M. 2012)-on Palm kernel and nut, (Seth Idowu Manuwa and H. A. Muhammad, 2011)- for shea kernel, (BUP *et al,.* 2014)-on shea kernel, (Aviaraet *al,.* 2005)-on sheanuts, (sayed et al., 2011), on peanuts, (Razari *et al.,* 2007) on pistachio nut and its kernel, (Tabatabaeefar, 2003) on wheat, (Bart-Plange *et al.,* 2012)-on cashew, (Prashant N. Ghadge and K. Prasad, 2012)-on rice.

Although few works have been done on shea kernel in other countries, there is no single work done to determine the engineering properties of the shea kernel in Ghana which is the third producer and the leading exporter of the commodity in the world. This gap is what necessitated the study. Results obtained will then reveal differences in engineering properties of the shea kernel if any. The objective of the study therefore is to determine the geometric, gravimetric, frictional properties of the shea kernel. These will be useful parameters in designing of handling and processing equipment. Plates 1 and 2 are shea nuts and kernel respectively.

Plate 1: Shea nuts

Plate 2: Shea kernels

MATERIALS AND METHOD

Sample Selection and preparation

Fresh ripen shea fruits which have fallen off the tree were collected from different trees. The sheanuts were parboiled and dried. After five days sun-drying, the nuts were cracked to release the kernel. All impurities and broken kernel were removed.100 kernels were randomly selected for the study.

Determination of Moisture Content

The standard method of moisture determination was used to determine the moisture content of the kernel. In this method, samples were kept in an oven (DIN EN 60529-IP 20 Shchutzar, Germany) at 105 °C for 72 hrs. Weight loss on drying to a final constant weight was recorded as moisture content by AOAC (1984) recommended method and using equation (1):

$$MCdb = \left(\frac{Ww - Wd}{Wd} \right) \times 100 \qquad\qquad 1$$

Where: MCdb = Moisture content (dry basis); Ww = Weight of materials before oven drying; Wd = Weight of material after oven drying.

DETERMINATION OF GEOMETRIC PROPERTIES

In the determination of axial dimensions, 100 shea kernels were randomly selected and length (L), width (W) and thickness (T) were measured using a digital caliper with a resolution of 0.01mm. The diameter was calculated by using the geometric mean diameter (DgM) and arithmetic means diameter (Da) of the three axial dimensions. The arithmetic mean diameter, (Da), and geometric mean diameter, (DgM) of the shea kernel were calculated by using equation 2 and 3 respectively used by (Galedar *et al.,* 2008; Mohsenin, 1980).

$$Da = \left(\frac{L + W + T}{3} \right) \qquad\qquad 2$$

$$DgM = (LXWXT)^{\frac{1}{3}} \qquad\qquad 3$$

Where: Da – arithmetic mean diameter (mm), DgM – geometric mean diameter (cm), L – length (cm), W– width (cm), T –thickness (cm).

The criteria used to describe the shape of the seed are the sphericity and aspect ratio. Thus, the sphericity ($\emptyset$) was accordingly computed by using Equation 4 (Koocheki *et al.,* 2007; Milani et al., 2007).

$$\emptyset = \frac{(LXWXT)^{\frac{1}{3}}}{L} \qquad \qquad 4$$

The aspect ratio, Ra in (%) was calculated using equation 5, given by (Maduako and Faborode, 1990):

$$Ra = \left(\frac{W}{L}\right)X100 \qquad \qquad 5$$

The surface area (Sa) in cm^2 of the shea kernel was found by analogy with a sphere of the same geometric mean diameter. In obtaining the surface area, equation 6 given by McCabe *et al.* (1986, Arthur (2009) was used:

$$Sa = \pi(DgM)^2 \qquad \qquad 6$$

Unit volume of shea kernel

Since the shea kernel is a prolate ellipsoid, its volume was theoretically determined using the kernel's axial dimensions by equation 7 by Stroshine (1998).

$$V = \pi\left(\frac{LXWXT}{6}\right) \qquad \qquad 7$$

DETERMINATION OF GRAVIMETRIC PROPERTIES

1000- Kernel mass

The 1000 kernel mass was determined using precision electronic balance (Model: JH 600G10, India) to an accuracy of 0.01g. 10 randomly selected kernels were weighed individually and the average weight was multiplied by 1000 to obtain the mass of 1000 kernel. This procedure was observed 10 times and the mean value taken.

True density

The true density (ρt), was determined using the ratio of the unit values of unit mass and the theoretical unit volume of individual kernel and calculated using equation 8. This procedure was replicated five times and the average value recorded.

$$\rho t = \left(\frac{Mi}{Vi} \right) \qquad 8$$

Where: ρt – true density (g/cm^3), M_i – mass of individual kernel (g), V_i- volume (cm^3) of individual kernel.

Bulk density

The bulk density is the ratio of mass of a sample of the kernel to its total volume. It was determined by filling an empty 1000 mm^3 graduated cylinder with kernel from a height of 15 cm and then weighing the contents. The weight of the kernels was obtained by subtracting the weight of the cylinder from the weight of the cylinder with kernels. To achieve the uniformity in bulk density the graduated cylinder was tapped for the kernel to consolidate. The volume occupied was then noted. The process is replicated five times and the average bulk density for each replication was calculated from the following equation:

$$\rho b = \left(\frac{Mb}{Vb} \right) \qquad 9$$

Where ρb is the Bulk density in g/m^3, Mb is the Weight of the sample in g, Vb is the Volume occupied by the sample in cm^3

Porosity

Porosity (ε), in % shows the amount of pore spaces in the bulk material. It was calculated from the particle and bulk densities using the relationship given by Mohsenin (1986).

$$\varepsilon = \left(1 - \frac{\rho b}{\rho t} \right) X 100 \qquad 10$$

Where ε is the porosity in %, ρ_b is the bulk density in g/cm^3 and ρt is the true density in g/cm^3.

DETERMINATION OF FRICTIONAL PROPERTIES

Angle of repose

The filling angle of repose θf, was determined. This is the angle the side of the heap makes with the horizontal at which the material will stand when piled.

This was determined using a topless and bottomless cylinder of 12 cm diameter and 20 cm height. The cylinder was placed at the centre of a raised circular plate having a diameter of 20 cm and was filled with shea kernels. The cylinder was raised slowly until the kernel formed a conical heap on the circular plate. The height of the heap was measured and the filling angle of repose (θf) was calculated by the following relationship by (Karababa, 2006; Kaleemullah and Gunasekar, 2002).

$$\theta f = Tan^{-1}\left(\frac{2H}{D}\right) \qquad 11$$

Where: H is the height of the heap and D is the known diameter of the circular plate.

Static coefficient of friction

The static coefficient of friction for the shea kernel was determined on five structural surfaces (Glass, Plywood, with grains along the motion, Mild steel, Galvanized steel and Stainless steel). A topless and bottomless wooden box of 20 cm length, 10cm width and 5 cm height was filled with the sample and placed on an adjustable tilting plate, faced with test surface. The surface was raised gradually with a screw device (plate 3) until the box just started to slide down and the angle of inclination (θ) was read from a protractor attached to the tilting device.
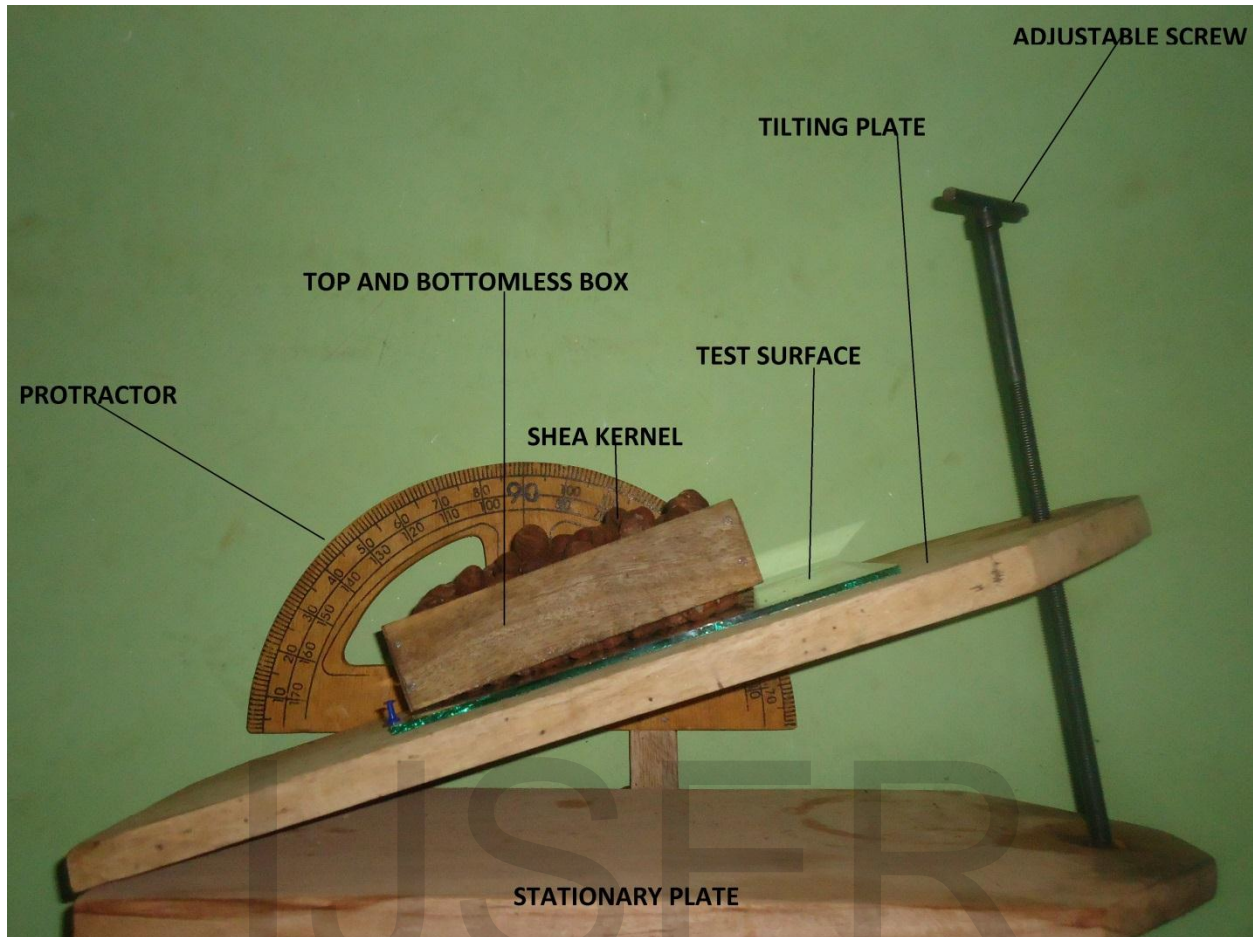
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Plate 3: A Tilting plate apparatus for determining static co-efficient of friction

For each replicate, the sample in the container was emptied and re-filled with a new sample. There were five replicates. The static coefficient of friction (µs) was calculated based on an equation used by Altuntas and Yildiz (2007).

$$\mu s = tan\theta \qquad\qquad 12$$

Statistical analysis

In the study, the results are expressed as means and standard deviations (S.D.) using Microsoft spread sheet.

RESULTS AND DISCUSSION

Table 1 gives the summary of the results for all the parameters determined. The determined dimensional axes in mm were converted into cm.The moisture content of the kernels at the time of experiment was 6.76% (d.b). The moisture content found can help to suggest the stability in storage of shea kernel.

Table 1. Physical, gravimetric and frictional properties of the shea kernel

S/N	Property	No. of Observations	Minimum Value	Maximum Value	Mean Value	Standard deviation
	A. Geometric Properties					
1.	Length, (cm)	100	2.137	2.973	2.543	0.196
2.	Width, (cm)	100	1.295	2.222	1.803	0.142
3.	Thickness, (cm)	100	1.145	2.000	1.576	0.107
4.	Arith. Mean Dia,(cm)	100	1.651	2.272	1.974	0.101
5.	Geo. Mean Dia, (cm)	100	1.610	2.194	1.928	0.098
6.	Sphericity, (%)	100	62.530	87.968	76.104	4.750
7.	Aspect ratio, (%)	100	46.614	90.285	71.279	7.249
8.	Surface area, (cm^2)	100	8.145	15.119	11.716	1.196
9.	Volume, (cm^3)	100	2.190	5.542	3.793	0.581
	B. Gravimetric properties					
10.	1000-kernel mass, (g)	10	2600.000	6020.000	4117.833	617.775
11.	True density (g/cm^3)	5	0.867	2.008	1.093	0.120
12.	Bulk density (g/cm^3)	5	0.668	0.704	0.682	0.013
13.	Porosity (%)	5	37.300	38.929	38.347	0.612
	C. Frictional properties					
14.	Filling angle of repose ($^{\circ}$)	5	27.245	40.325	34.818	3.932
15.	Co-efficient of friction on:					
i.	Glass	5	0.151	0.184	0.168	0.020
ii.	Plywood	5	0.436	0.483	0.461	0.013
iii.	Mild steel	5	0.361	0.394	0.385	0.016
iv.	Galvanized steel	5	0.220	0.256	0.238	0.016
v.	Stainless steel	5	0.262	0.301	0.292	0.027
D.	Moisture content (d.b.) %	3	6.480	7.270	6.763	0.440

Geometric Properties
The length ranged from 2.137cm-2.973cm with a mean value of 2.543±0.196cm and the width from 1.295cm-2.222cm with mean value of 1.803±0.142cm. While the thickness ranged between 1.145cm-2.000cm with a mean value of 1.576±0.107cm. The range and mean values for the arithmetic mean diameter and geometric mean diameter were 1.651-2.272cm, 1.974±0.101cm and 1.610-2.194cm, 1.928±0.098cm respectively. Similar results were obtained by Manuwa and Muhammad (2011).The importance of these dimensions in determining sieve holes and other parameters in machine design were discussed by (Mohsenin, 1986).The size and shape are important in the electrostatic separation of agricultural products from undesirable materials and in the development of sizing and grading machinery.

The shape of the kernel is close to a sphere (>70%). Values of sphericity ranged between 62.53%-87.97% and mean value of 76.104±4.750% while aspect ratio ranged between 46.614%-90.285% and a mean value of 71.279±7.249%. This shows that the material will always tend to roll when it is on a particular orientation (Afonso et al., 2007). These properties are always considered when designing hopper and de-hulling equipment for seeds.
The surface area of kernel ranged between 8.145cm^2-15.119cm^2 with a mean value of 11.716±1.196cm^2 while volume ranged between 2.190cm^3-5.542cm^3 and a mean value of 3.793±0.581cm^3. It predicts how grains will behave on oscillating surfaces during processing and also affects the velocity of air stream that can be used in other to separate the seed from unwanted material in pneumatic separator or to convey seed in pneumatic conveying (Alonge, 1999). Volume of food materials and agricultural products play an important role in the design of silos and storage bins (Waziri and Mittal, 1997).

Gravimetric Properties

The mean mass of the 1000 kernel is 4117.833±617.775g when weighed with a sensitive weighing balance (Model: JH 600G10, India). Weight is an important parameter used in the design of cleaning grains using aerodynamic forces. The mean values of kernel's true density, bulk density and porosity were 1.093±0.120g/cm^3, 0.682±0.013g/cm^3, 38.347±0.612g/cm^3 and ranged between 0.867-2.008g/cm^3, 0.668-0.704g/cm^3, 37.300-38.929% respectively. The kernel true density is greater than that of water (1.000g/cm^3). This means that the seeds will sink in water. It is therefore possible to separate the kernel from materials that are less dense than water (Sirisomboon et al., 2007). This is an important property in grains processing. During wet cleaning, the kernel does not float on water. This property is also required in air and heat flow treatment in agricultural material. It shows how easily or difficult a stream of heated air for drying will pass through a pack of material and thus affect the rate of drying of the material. The results indicate that the kernel has large pores and aeration of the crop is easier, quicker and may not require bigger fans. Natural aeration is possible. High power fans and motors may not be required for effective aeration.

Frictional Properties

The filling angle of repose of the shea kernel was found to be 34.818^o±3.932. Using the filling method, this property determines the minimum slope of flow in a bin or hopper. The angle of repose determines the maximum angle of a pile of grain in the horizontal plane, and is important in the filling of a flat storage facility when grain is not piled at a uniform bed depth but is peaked (Mohsenin, 1986). Also the design of grain hoppers for processing machinery requires data on bulk density and angle of repose.

Static co-efficient of friction was determined on five different structural surfaces, namely: Glass, Plywood, Mild steel, Galvanized steel and Stainless steel. These materials are used mainly in construction of Agricultural handling and processing equipment. Of the five surfaces tested, plywood (with grains along direction of motion) had the highest coefficient of static friction (0.461±0.013) due to the rough surface, followed by Mild steel (0.385±0.016), Stainless steel (0.385±0.027) and Galvanised steel (0.238±0.016). Glass had the least static co-efficient of friction (0.168±0.020). This is due to its smooth surface. It was observed that the rougher the surface, the higher the static co-efficient of friction and the smoother the surface, the lower the static co-efficient of friction for the kernel. This value is needed in the design of agricultural machine hoppers and other conveying equipment. It determines how a pack of grain or seed will flow in these systems. The angle of internal friction indicates the angle at which chutes must be positioned in order to achieve consistent flow of material through it (Olajide and Igbeka, 2003).

Moisture content

The standard method of moisture determination was used to determine the moisture content of the kernel. In this method, samples were kept in an oven (DIN EN 60529-IP 20 Shchutzart) at 105°C for 72 hrs. Weight loss on drying to a final constant weight was recorded as moisture content by AOAC (1984) recommended method. The moisture content was 6.763± 0.440% (d.b.).

Conclusions

The following conclusions are made after the study:

1. The average axial dimensions of length, width and thickness of the shea kernel are 2.543±0.196cm, 1.803±0.142cm and 1.576±0.107cm respectively. The average values for the arithmetic mean diameter, geometric mean diameter, surface area and volume of the shea kernel are 1.974±0.101cm, 1.928±0.098cm, 11.716±1.196cm^2 and 3.793±0.581cm^3 respectively.

The shea kernel can best be described as triaxial ellipsoid. Value of sphericity is 76.104±4.750% while aspect ratio is 71.279±7.249%.

2. The shape of the kernel is close to a sphere (>70%). This shows that the material will always tend to roll when it is on a particular orientation.

3. Thousand kernel mass was 4118g when weighed with a sensitive weighing balance with accuracy of 0.001g, true density, bulk density and porosity are 1.093±0.120 g/cm^3 , 0.682±0.0132 g/cm^3 and 38.347±0.612% respectively. The kernel density is greater than that of water (1.000g/cm^3). This means that the seeds will sink in water during cleaning with water. The large porosity value means that, the shea kernel has large air spaces when held in bulk. The larger the particle-size of a grain, the larger the porosity and vice versa.

4. The filling (Øf) angle of repose of the shea kernel was found to be 34.82 ±3.932^o. The static co-efficient of friction (μs) on Glass, Plywood, Mild steel, Galvanized steel and Stainless steel are 0.168, 0.461, 0.385, 0.238 and 0.292 respectively. Plywood (with grains along direction of motion) had the highest coefficient of static friction (0.461) due to the rough surface while Glass had the least static co-efficient of friction (0.292).This is due to its smooth surface. It was observed that the rougher the surface, the higher the static co-efficient of friction and the smoother the surface, the lower the static co-efficient of friction for grains.

5. The moisture content of the kernel was 6.763±0.440 % (dry basis).

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