Moisture-Dependent Physical Properties of Popcorn

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***Abstract*—Physical properties of agricultural products are essential in design of postharvest equipment, they are moisture-dependent as behave in certain ways with a shift in the moisture content. The main objective of this study is to determine the effect of moisture on some physical properties of popcorn. Materials used for this study include regular popcorn variety, inclined plane, measuring cylinder, oven, polythene bags, refrigerator, distilled water, angle of repose box and measuring tape while the physical properties determined include bulk density, particle density, angle of repose, porosity and coefficient of friction. The moisture content was varied between 20-60 %wb across the properties studied. It was obtained that within this moisture range, the bulk density decreased from 0.929 to 0.664g/cm^3, particle density decreased from 0.623 to 0.346g/cm^3, porosity increased from 33 to 47.9% and angle of repose increased from 60.75 to 80.22º. The coefficient of friction determined on five structural surfaces (plywood, mild steel, stainless steel, plastic and glass) showed that friction coefficient increased linearly with moisture content for all the contact surfaces. The maximum friction was recorded for plywood and mild steel plate while the stainless steel plate, plastic plate, glass plate offered minimum friction. Increase in friction with moisture may be attributable to water present in the popcorn seeds. Values obtained in this research will aid design of equipment for storage, production, utilization and generally postharvest handling of popcorn seeds**

Keywords— popcorn seed, bulk and particle density, porosity, angle of repose and coefficient of friction

I. INTRODUCTION (*Heading 1*)

Popcorn (*Zea mays everta*) is one of the world's favorite snack food. Depending on how it is prepared and cooked, some consider popcorn to be a health food, while others caution against it for a variety of reasons. Popcorn can also have non-food application, ranging from holiday decorations to packaging materials. Demand for popcorn has remained steady throughout years with a peak in the 1990s. The majority of popcorn is grown by farmers with over 100 acres, so most popcorn is mechanically harvested however, the number of farms and acres dropped by over one-third from 2002 to 2007 while the production increased by 9 percent over the same time period [1]. Popcorn comes in many different varieties, including sweet corn, field corn, regular popcorn, rainbow blend popcorn, medium white hulless popcorn, baby white popcorn, midnight blue hulless popcorn as described by [2]. Nutritionally, it is one of the best all-around snack foods, providing 67% as much protein, 110% as much iron and as much calcium as an equal amount of beef [3]

Due to difficulties in operation, processing, production, utilization and drying of agricultural produce, there is need for some physical properties to serve as database for design of equipment and facilities for handling, processing, storing, cleaning, sorting, grading and all related postharvest operations for agricultural produce. Physical properties of agricultural product is the first consideration for engineers in designing such equipment [4]. Moisture is a natural constituent of all agricultural products and for the purposes of processing, storage and utilization, it is often necessary to reduce the level of moisture in an agricultural produce. However, some of these physical properties are moisture-dependent as they tend to behave in certain ways with a shift in the moisture content of agricultural products. The main objective of this study is to determine the effect of moisture content on some physical properties of popcorn

II. MATERIALS AND METHODS

A. Materials

The major materials used for this study include: regular popcorn variety, inclined plane (with 3 tops: mild steel plate, plastic plate, glass plate, plywood and stainless steel plate), measuring cylinder, micrometer screw gauge, Vernier caliper, electric oven, refrigerator, envelopes, polythene bags, distilled water, angle of repose box with measuring tape.

B. Seed Preparation and Conditioning

Regular popcorn seed varieties were obtained from Bodija International Market (BIM), Ibadan, Oyo State, Nigeria. The seeds were manually cleaned to remove all foreign materials and broken seeds were discarded. To determine the moisture content, the seeds were dried in electric oven at 130 ± 2°C for 24 hours in accordance with ASAE standard method. However, to achieve desired moisture content levels of 20, 30, 40, 50 and 60% wb, the seeds were conditioned by adding desired quality of distilled water and sealed in different polythene bag after thorough mixing and they were otherwise stored in refrigerator at 5^0C for 24hrs. The popcorn samples were allowed to equilibrate at room temperature for 2hrs to determine the actual moisture content present in the popcorn prior to experiments for determination of its properties. Equations 9 and 8 were used to determine the quantity of water added and removed from the seed samples as described by [5].

$$B = \frac{A\,(100-a)}{(100-b)} \qquad ...1$$

$$Q = \frac{A\,(b-a)}{(100-b)} \qquad ...2$$

Where: A is the initial mass of the seed (g), B is the final mass of the seeds after drying (g), a is the initial moisture content of sample (%wb), b is the desired/final moisture content of seeds (%wb) and Q is the mass of water to be added (g).

C. Bulk Density (ρb)

This is the ratio of the mass of sample of the grain to its total volume. It was determined by using a $120cm^3$ beaker filled with distilled water. The beaker was first weighed empty, the seed was then put poured and fill the beaker to the brim. A ruler was used to strike off any grain above the beaker's top level; the beaker with its content was weighed. The difference in weight, in the mass of the seed (popcorn) and since the volume of beaker is known, the bulk density was obtained by dividing the weight of the seed by the volume of beaker (Equation 3) as described by [6].

$$\text{Bulk density } (\rho b) = \frac{Ms}{Va}\ (g/cm^3) \qquad ...3$$

Where: Ms is the bulk mass of the seeds (g) and Vs is the bulk volume of the seeds (cm^3).

D. Particle (True) Density

This is the ratio of given mass of sample to its true volume. The volume and density of each seed was determined by the water displacement method as described [7]. This was achieved by filling a measuring cylinder to a certain level and submerging a bunch of popcorn seeds of known weight into the cylinder resulting in a rise in the level of water. Thus, the difference between the two levels of water gives the volume of the popcorn seed as described by [8]. Equation 4 was used to determine the particle density of the seeds.

$$\text{Particle density } (\rho p) = \frac{Ms}{Va}\ (g/cm^3) \qquad ...4$$

Where Ms is the mass of the bunch (g) and Vs is the volume of the seeds (cm^3)

E. Porosity

This is the fraction of the space in the bulk grain which is not occupied by the grain. It is a property of the grain, which depends on its bulk and particle density. It was calculated from the percentage average values of bulk and true densities. The porosity of the popcorn seeds was determined using Equation 5 [8].

$$\text{Porosity} = 1 - \frac{\rho p}{\rho b} \times 100 \qquad ...5$$

Where:

ρb is the bulk density of the sample and ρp is the particle density

F. Angle of Repose

This was determined using a specially constructed repose box with a removable front panel. The box was filled with grain, and the front panel was quickly removed which allows the grains to flow to its natural slope. The inclination angle was obtained and angle of repose of the seeds was calculated using Equation 6 [9].

$$\text{Angle of repose } (\theta st) = \text{Sin } \theta = \frac{\text{opposite side}}{\text{hypothenous side}} \qquad ...6$$

G. Coefficient of Static Friction

This was determined with respect to each of five structural materials which are mild steel plate, plastic plate, glass plate, plywood and stainless steel plate. A topless and bottomless tin was filled with grain and placed on an adjustable tilting plate, faced with the test surface. The cylinder tin was raised so as not to touch the surface. The structural surface with box resting on it was inclined gradually with a screw device until the box just started to slide down and the angle of tilt was read from a graduated scale which is calculated by taking the tangent of the inclination angle. Equation 7 was used to determine the coefficient of static friction of the seeds

$$\mu = \text{Tan } \alpha \qquad ...7$$

where: μ is the coefficient of static friction and α is the angle of tilt in degrees

III. RESULTS AND DISCUSSIONS

The effect of moisture content on the physical properties of popcorn seeds was studied. The results obtained were based on the mean (average) and standard deviation for each parameter on the popcorn seed. The result obtained are highlighted below:

Bulk Density: The bulk density decreased from 0.929 to 0.664 g/cm^3 as the moisture content increases from 20 to 60% wb respectively (Table 4.1), this can be attributed to an increase in seed volume with an addition of moisture which will otherwise results to decrease in the bulk density. [4] reported that this is typical of biological materials however, similar trend was reported for chickpea seeds by [10], *lablab* seeds by [11], arecanut kernels by [12] and round red lentil grains by [13]. Bulk density has been reported to have practical applications in the calculation of thermal properties in heat transfer problems, in determining Reynolds number in pneumatic and hydraulic handling of materials and in predicting physical structure and chemical composition [14]

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Table 4.1: Effect of moisture content on Bulk density (g/cm^3)

No of observation	Moisture content (%wb)				
	20	30	40	50	60
1	0.931	0.846	0.776	0.716	0.665
2	0.940	0.854	0.782	0.721	0.670
3	0.921	0.838	0.769	0.710	0.660
4	0.931	0.846	0.776	0.716	0.665
5	0.921	0.838	0.769	0.710	0.660
Mean	**0.929**	**0.884**	**0.774**	**0.715**	**0.664**
Standard deviation	176×10^{-4}	1.40×10^{-4}	5.22×10^{-4}	3.60×10^{-4}	2.44×10^{-4}

Particle Density: The particle density decreased from 0.623 to 0.346g/cm^3 for the moisture range of 20 to 60% wb (Table 4.2). In analysis of variance, significant difference was observed in the means when there is decrease in bulk density which is due to increase in volume of material, the particle density decreased

Table 4.2: Effect of moisture content on Particle density (g/cm^3)

No of observation	Moisture content (%wb)				
	20	30	40	50	60
1	0.620	0.517	0.443	0.388	0.346
2	0.633	0.526	0.450	0.393	0.349
3	0.608	0.508	0.437	0.383	0.341
4	0.620	0.517	0.443	0.388	0.345
5	0.633	0.526	0.450	0.393	0.349
Mean	**0.623**	**0.519**	**0.445**	**0.389**	**0.346**
Standard deviation	8.86×10^{-4}	4.54×10^{-4}	2.44×10^{-4}	1.40×10^{-4}	9.00×10^{-4}

Porosity: The porosity increased from 33 to 47.9% for the moisture range of 20 to 60% wb (Table 4.3). A comparison of porosity of popcorn seed with those of other grains revealed that it increased with moisture content similar to that for other grains [15]. In analysis of variance, it has significant difference means when there is increase in moisture content and decrease in bulk density and particle density, it results to increase in porosity of popcorn seed.

Table 4.3: Effect of moisture content on Porosity

No of observation	Moisture content (%wb)				
	20	30	40	50	60
1	33.4	38.9	42.9	45.8	48.0
2	32.7	38.4	42.5	45.5	47.9
3	34.0	39.4	43.2	46.1	48.4
4	33.4	38.9	42.9	45.8	48.1
5	31.3	37.2	41.5	44.6	47.1
Mean	**33.0**	**38.6**	**42.6**	**45.6**	**47.9**
Standard deviation	6.8×10^{-3}	5.64×10^{-3}	3.52×10^{-3}	2.68×10^{-3}	1.88×10^{-3}

Angle of Repose: There is a significant difference between the angle of repose and moisture content of the seeds. The angle of repose increased from 60.75 to 80.22º within moisture range of 20 to 60 %wb respectively. All biological materials appear to exhibit an increase in angle of repose with moisture content [16]. Table 4.4 shows the angle of repose of popcorn seeds at varying moisture content.

Table 4.4: Effect of moisture content on Angle of Repose

Trials	Moisture content (%wb)				
	20	30	40	50	60
1	60.75	60.96	70.18	70.93	80.23
2	60.74	60.95	70.19	70.94	80.21
3	60.76	60.94	70.18	70.92	80.20
4	60.75	60.97	70.17	70.95	80.22
5	60.75	60.96	70.18	70.94	80.23
Mean	**60.75**	**60.96**	**70.18**	**70.94**	**80.22**
Standard deviation	6.00×10^{-4}	1.20×10^{-4}	4.00×10^{-4}	1.20×10^{-4}	1.40×10^{-4}

Coefficient of Static friction: The effect of moisture content on each coefficient of static friction of popcorn seed such as plywood plate, mild steel plate, stainless steel plate, plastic plate, glass plate at different moisture content in which parameter were replicated five times are summarized in table 4.5. The friction coefficient increased linearly with moisture content for all contact surfaces. For the plywood plate, it increased from 0.34 to 0.48 for the moisture range of 20% to 60% wb. For the mild steel plate, it increased from 0.39 to 0.48 for the moisture range of 20% to 60% wb. For the stainless steel plate, it increased from 0.34 to 0.44 for the moisture range of 20% to 60% wb. For the plastic plate, it increased from 0.36 to 0.44 for the moisture range of 20% to 60% wb. For the glass plate, it increased from 0.38 to 0.44 for the moisture range of 20% to 60% wb. The maximum friction was offered by plywood plate and mild steel plate while the stainless steel plate, plastic plate, glass plate offered minimum at friction. In analysis of variance, it has significant difference means there is higher moisture content may be owing to the water present in the popcorn seed, it will results to increase in friction coefficient. Fig. 4.1 represented the graph presentation of coefficient of static friction with moisture content for each structural material.

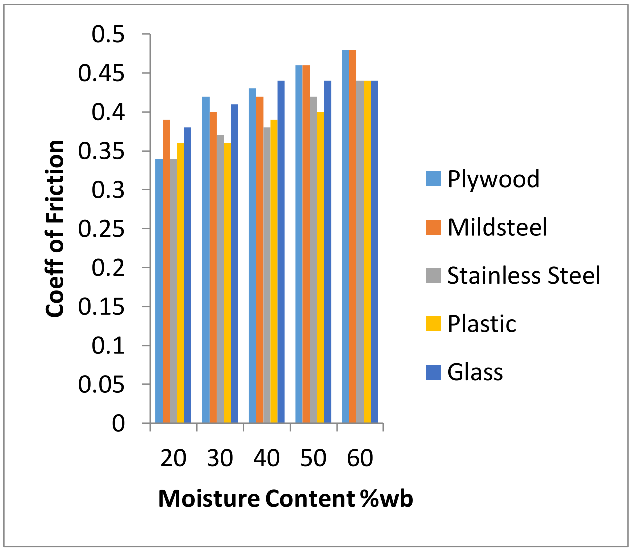

Figure 4.1: Coefficient of Friction of Popcorn seeds

IV. CONCLUSIONS

All the physical properties of the popcorn seed studied in this project work varied with moisture content.

i. At any moisture content between 20% to 60% wb., the terminal velocity increased from 6.88m/s to 7.82m/s, as a result if there is increase in moisture content across the air path and due to friction on the edges of popcorn seed in motion it tends to increase in terminal velocity.

ii. The bulk density decreased from 0.929g/cm³ to 0.664g/cm³ for the moisture range of 20% to 60% wb., as a result if there is increase in moisture content , the particle volume increase which tends to decrease in bulk density.

iii. The particle density decreased from 0.623g/cm³ to 0.346g/cm³ with increase in moisture content from 20% to 60% wb., as a result if there is decrease in bulk density is due to increase in volume of the material which tends to the decrease in particle density.

iv. The porosity increased from 33% to 47.9% for the moisture range of 20% to 60% wb., as a results if there is increase in moisture content of popcorn seed, which tends to increase in porosity of popcorn seed.

v. The angle of repose increased from 60.75º to 80.22º for the moisture range of 20% to 60% wb., as a results if there is higher of angle of repose to the rough surface or shape factor of popcorn seed which tends to increase in angle of repose

vi. The coefficient of static friction such as plywood plate (0.34 to 0.48), mild steel plate (0.39 to 0.48), stainless steel plate (0.34 to 0.44), plastic plate (0.36 to 0.44), and glass plate (0.38 to 0.44) which all increased for the moisture range of 20% to 60% wb., as a results if there is higher moisture content which may be owning to the water present in the popcorn seed, it tends to increase in friction

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