Moisture-Dependent Physical Properties of Ethiopian BH540 and BH661 Maize Variety Concerning with Planter Design

YABEBAL CHEKOLE MIHRET
Faculty of Mechanical and Industrial Engineering
Bahir Dar Institute of Technology, Bahir Dar University
Bahir Dar, ETHIOPIA

SOLOMON TEKESTE
Faculty of Mechanical and Industrial Engineering
Bahir Dar Institute of Technology, Bahir Dar University
Bahir Dar, ETHIOPIA

Abstract: Maize is one of the most widely produced and consumed cereal crops and knowledge of the engineering properties of these agricultural materials is an important tool for designing agricultural machines and equipment for planting, harvesting, processing, packaging, and storage. From these engineering properties, physical properties are the main ones and include size, geometric mean diameter, surface area, volume, 1000grain mass, bulk density, true density, porosity, sphericity, and angle of repose. And considering these physical properties mostly geometric mean diameter, sphericity, surface area and angle of repose are important during planter design, especially for hopper, seed metering cup, seed plate, and delivery tube design. So the moisture-dependent physical properties of two hybrid maize varieties BH540 and BH661 are determined. For BH540 maize, an increase of moisture content from 7.19% to 39.54% increases geometric mean diameter from 8.7140 to 9.4792mm, surface area from 240.95 to 285.04mm^2, sphericity from 0.8629 to 0.8639, porosity from 5.06 to 14.82%. For the BH661 maize variety, as moisture content increase from 8.83% to 35.40% geometric mean diameter increases from 7.504 to 8.1749mm, surface area from 177.77 to 210.94mm^2, sphericity from 0.0.6417 to 0.6488, porosity from 5.08% to 20.93%. At a moisture content of 10.31% and 11.3% the seed has a minimum angle of repose 22.2^0 and 29.3^0 for BH540 and BH661 maize varieties respectively.

Keywords: Maize, Physical properties, Moisture, BH540, BH661

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1. Introduction

Maize is the most produced and consumed cereal crop worldwide. It is one of the most important cereal crops in the world which is ranked second to wheat production, first in Africa and Latin America but third after rice and wheat in Asia. In Africa, maize production is increasing every year and Ethiopia contributes more. According to the central statistical agency (CSA) of Ethiopia, maize production is increasing every year. It is necessary to look at the increase in the production of maize for the last four years. During the 2015/2016 main cropping season, cereal crops accounted for 79.88% of the total area under crops, of which maize ranked second to teff. Moreover, cereals accounted for 86.68% of total production, of which maize ranked first (CSA, 2018). According to CSA, the maize production in quintals per hectare increased each year for the production year 2017 maize yield is 36.75Qt/ha, for the 2018 production year 39.44Qt/ha, for 2019 39.92Qt/ha, and production year of 2020 maize yield is 42.37Qt/ ha (CSA, 2020, 2018, 2019, 2021). To get such increased maize yield application of chemicals for pests and weeds, the application of fertilizers, the use of modified hybrid seeds, and mechanization of the farming operation are important. From these things, hybrid seeds are already done for more than 4 decades in Ethiopia. While the application of chemicals, and fertilizers is recent history. To apply chemicals and fertilizers for the maize farm mechanization of the farm as well as consideration of agronomic requirements is important to use effectively the land, resources, labor, and increased product. The first activities in maize farm mechanization are land preparation and the next one is planting operation. So, to mechanize the planting operation of the maize knowing and studying the engineering properties of maize is critical. However, studying agricultural materials engineering properties is recent history and began after the second world war. The study of agricultural products and the determination of material laws, and their application, gained ever-increasing importance at the annual conferences of the ASAE in the United States (Sitkey, 1986)-(Kovács & Kerényi, 2019). Engineering properties of biological materials are useful and necessary in the design as well as the selection of appropriate equipment employed in the field of planting, harvesting, handling, food processing, and storage. Among these properties, thermal, electrical and dielectric, mechanical, physical, aero-dynamic, textural, rheological, chemical, acoustic, optical, and nutritional are considered. Physical characteristics take precedence over these other factors since they will help in the design and selection of suitable handling, processing, and storage equipment that will guarantee nutriment standards and welfare and minimize environmental effects (Ofori et al., 2019). And also scientific data on the physical properties of any biological material concerning its moisture content is of prime importance as a basis to aid in designing or selecting appropriate equipment which will be used for processing (drying, winnowing, separation, grading, aeration) as well as equipment for planting, harvesting, and storage (Chakraverty et al., 2003; Ofori et al., 2019). Physical properties include size (Length, width, height), geometric mean diameter, surface area, volume, 1000grain mass, bulk density, true density, porosity, sphericity, and angle of repose. The physical properties of maize such as size, shape, axial dimensions, roundness, and sphericity help to determine the maximum size of the cup in the seed plate and chute diameter or seed tube dimension, the weight help in the material selection for the frame of the planter and hopper, the bulk density and moisture content helps to know the reaction of the seed with the planters hopper material at its highest heat setting (Kaliniewicz et al., 2015). These properties help in specifying the design considerations of planting equipment especially metering unit or device cell size, hopper size and inclination, and chute tube or seed tube diameter, length, and clearance between the furrow. Because it will be a waste of time, assets, energy, and cash if the machine doesn't live up to expectations after fabrication. Therefore, to avoid design and construction failure and economic loss study of the planted seed (in this case hybrid BH540 and BH661 maize varieties) is crucial.

2. Literature Review

Different researchers and scholars are tried to study the physical properties of agricultural products. (Sharma et al., 2017) studies the physical and psychological properties of eight inbred lines of maize like waxy maize, double recessive, quality protein maize (QPM), popcorn, dent (indurate Sturt), flint (indurate Sturt), sweetcorn, Sugary, and Shrunken (Brar et al., 2017) examine three varieties of maize seed PMH-1, PMH-10 and PIONEER-3396 to know their engineering properties. (Barnwal et al., 2012) studies the influence of moisture content on the physical properties of maize and reports that the increase of wet basis moisture content from 12.8-29%. (Tarighi et al., 2011) studies the moisture-dependent physical and mechanical properties of corn seed by increasing dry basis moisture content from 5.5-22%. (Karababa & Coşkuner, 2007) reports the physical and frictional properties of maize as the moisture content varies from 9.12 to 17.06%. (Bhise et al., 2014) evaluated the physical properties of PMH-1 maize as a function of moisture content by increasing the moisture from 10–18% wet basis (wb). (Seifi & Alimardani, 2010) carried out a study to determine the effect of moisture content on some physical properties and mechanical behavior of corn grains under compression load of two varieties of corn (Sc704 and Dc370) which are the most cultivated varieties by Iranian farmers and by four levels of moisture content ranging from 4.73-22% (wb) and 5.15-22% (wb) for Sc704 and Dc370, respectively. (Sangamithra et al., 2016) investigate the moisture-dependent physical properties of maize kernels and report that as the moisture content rose from 8.7 to 21.7% db, the average length, width, thickness, geometric mean diameter, and arithmetic diameter of the maize kernels, respectively, increased from 10.59 to 11.87 mm, 8.11 to 8.75 mm, 4.81 to 5.52 mm, 7.42 to 8.30 mm, and 7.84 to 8.61 mm. (Ofori et al., 2019) This study specifically seeks to find out the changes in moisture content (MC) on two maize varieties (Opeaburoo and Abontem) concerning designated physical attributes during drying. To report the variation four designated MC within a range of 22.3 to 12.8% wb for Opeaburoo and 21.5 to 12.3% wb for Abontem were used. (Ashwin et al., 2017) determine the physical characteristics of the grain samples at the specified moisture content levels of 12, 14, 16, 18, and 20 (%wb) and research the impact of moisture content on the physical characteristics of maize grain seeds.. (Yenge et al., 2018) determine the physical and mechanical properties of maize grains as a function of moisture content in the range of 10-30 %wb using standard techniques. (Soyoye et al., 2018) studies some physical and mechanical properties of soybeans and maize concerning planter design and report the mean values measured and recorded for the length, width, thickness, geometric mean diameter, surface area, bulk volume, bulk density, true density, porosity, sphericity, mean angle of repose and coefficient of friction over stainless steel, galvanized steel, mild steel and plywood, fracture load on the major, middle, and minor axis. They conclude that, when designing the delivery tube of a planter, the average minimum diameter to use for maize and soybean should be 0.716 and 0.600 cm respectively, while designing seed plate, the average surface area to use for maize and soybean should be 1.621 cm^2 and 1.135 cm^2 respectively. Based on the literature the physical properties of maize and other agricultural materials are different depend on the varieties and growing zone. Those literatures showed that physical properties of agricultural materials are mostly dependent of moisture content. As the moisture content increases the main dimension or size of maize length, width, thickness, arithmetic mean diameter, geometric mean diameter, surface area, volume, mass and sphericity increased and some other properties decrease with the increase of moisture content linearly or exponentially. Most researchers report that physical properties of maize have linear relationship with the moisture content for different varieties. So, verifying this conclusion is important and necessary by taking BH540 and BH661 hybrid maize varieties available in our country Ethiopia by varying the seed moisture content.

3. Materials and Methods

3.1 Sample preparation

The sample used in this study is found from the Ethiopian Agricultural Business corporation (EABC). The samples taken are hybrid maize BH540 and BH661 varieties. The sample is randomly taken and it is dry since the store place is clean and free from any moisture formation things. After taking the sample from the store the initial moisture content of the seed is measured from their lab by using a moisture meter by taking a random sample from the total sample taken 10 times and the initial moisture content is determined for the next physical properties measurement. After determining the initial moisture content of the seed, 100 seeds are selected randomly for further measurement and study from each variety.

Figure 1: Sample maize seed BH540 left and BH661 right respectively

3.2 Material

To study or determine the moisture-dependent physical properties of hybrid maize BH540 and BH661 the following materials and equipment are used. Moisture meter to determine the initial moisture content of the seed. An electronic digital micrometer of capacity 0-25mm with a calibration of 0.001mm is used to determine the length, width, and thickness of each maize seed for each moisture content. To measure the bulk mass and individual mass of each variety of maize seed at each moisture content electronic precision balance that can measure a maximum of 120 grams and readability of 0.0001gram sensitivity is used. Two measuring cylinders of 100ml and 15ml; 20℃ were used to measure the bulk volume and true volume of the sample seed at each moisture content. A plastic bottle serves as a container for water during the experiment. A drying oven and refrigerator are also used to reduce moisture content, increase moisture content, and preserve the maize seed during the experiment. To measure the angle of the repose table and ruler were used and finally, Microsoft office 2016 excel and JASP is used to analyze the data and to generate comparisons and results in graphs.

3.3 Methods

The methods used in this study are those whose simplicity and practicability get wide acceptability and have a high degree of accuracy except for the angle of repose measuring methods.

Size determination

To determine the size (length, width, and thickness) of the seed for each variety electronic digital micrometer is used.

Min: minimum length, width, and thickness from the total sample seed for each variety.

Max: maximum length, width, and thickness from the total sample seed for each variety.

Average/mean size: the average value of the total sample seed for each variety.

- Average length, $L_a = \frac{\sum L}{n}$ where, $\sum =$ summation, L=length (mm) and n=No of sample
- Average width, $W_a = \frac{\sum W}{n}$ where W=width (mm)
- Average thickness, $t_a = \frac{\sum t}{n}$ where t=thickness (mm)

Arithmetic mean diameter

The arithmetic means the diameter of a seed is determined as follows using the equation below.

$$\mathrm{Da} = \frac{L+W+t}{3} \tag{1}$$

Where, D_a is the arithmetic mean diameter, mm; L is the length or maximum dimension, mm; W is the width or intermediate dimension, mm; t is the thickness or minimum dimension, mm.

Geometric mean diameter

The geometric mean diameter of agricultural materials is determined by using equation 2.

$$\mathrm{Dg} = (L * W * t)^{1/3} \tag{2}$$

Where, D_g is geometric mean diameter, mm; L is length, mm; W is width, mm; t is thickness, mm.

Surface area and volume

The surface area and volume of agricultural materials are determined by using the geometric mean diameter (Ofori et al., 2019) as follows using equations 3 and 4.

$$S_A = \pi \mathrm{Dg}^2 \quad (3)$$

$$\mathrm{V} = \frac{\pi}{6}\mathrm{Dg}^3 \quad (4)$$

Where, S_A is surface area, mm^2; D_g is geometric mean diameter, mm; V is volume, mm^3. The volume found by this method is an approximation and is used for a single seed when there is no other method of volume measurement. For this study, volume is measured directly by the displacement method discussed in the next section.

Sphericity factors

The shape of every type of seed is described by determining the following sphericity factors from equations 5 to 11 (Kaliniewicz et al., 2015).

$$\mathrm{K1} = \frac{t}{L} \quad (5)$$

$$\mathrm{K2} = \frac{W}{L} \quad (6)$$

$$\mathrm{K3} = \frac{t+W}{2L} \quad (7)$$

$$\mathrm{K4} = \frac{t*W}{L^2} \quad (8)$$

$$\mathrm{K5} = \frac{\mathrm{Dg}}{L} \quad (9)$$

$$\mathrm{e} = \frac{\mathrm{L}}{W} \; OR \; \frac{1}{K2} \quad (10)$$

$$\mathrm{f} = \frac{\mathrm{L+W}}{2t} \quad (11)$$

Where, K1, K2, K3, K4, and K5 are sphericity factors and dimensionless; t is thickness, mm; L is length, mm; W is width, mm; D_g is geometric mean diameter, mm. The last sphericity factor or equation 9 is sphericity (Curray, 1951) by itself and K2 or equation 6 is called aspect ratio by many scholars and equations 10 and 11 eccentricity index and flatness index respectively.

Bulk mass and individual mass

The bulk mass and individual mass of the sample maize seed are measured by using an electronic precision balance with a maximum of 120 grams and minimum 0.0001-gram reading capability. The mass of individual seeds is recorded once by placing one seed at a time but for bulk mass, the measurement is repeated 10 times for each variety to become confident about the result and to take the average value.

Bulk volume

The bulk volume of each maize variety is determined by the liquid displacement method by using the water displacement method and a 100ml measuring cylinder. First, the measuring cylinder was filled with water to a known ml and the initial volume was recorded. Then the seed was added into the measuring cylinder that has water and the final volume was recorded. Finally, the bulk volume of the seed is determined by subtracting the initial volume recorded from the final volume recorded. The procedure is repeated 10 times for each variety to take the average volume. So, the volume found by subtraction is the bulk volume of the seed.

Bulk density

The bulk density of agricultural materials is determined by mathematical calculation from the bulk mass and bulk volume of the material. In this study, the bulk density is determined by using the mean bulk mass and mean bulk volume found by measurement. The mathematical expression of the bulk density of the material is as follows and it is expressed by kg/m^3.

$$Bulk\ density = \frac{bulk\ mass}{bulk\ volume} \quad (12)$$

True density

The true density of the sample is measured by measuring the mass and volume of 10 random seeds from the total sample at a time. Since there are 100 seeds in the total sample and 10 seeds measured at a time total of 10 trials are needed to measure all seeds. The mass of 10 seeds is measured first by using an electronic precision balance and the volume is then measured by a 15ml measuring cylinder by liquid displacement method by using easily available water. After finishing the 10 trials the average is taken and considered as the true density of the maize seed for each variety and expressed in kg/m^3. Mathematically true/solid density is expressed as follows using equation 13.

$$True\ density = \frac{average\ mass\ of\ single\ seed}{average\ volume\ of\ single\ seed} \quad (13)$$

Porosity

It is the void volume or pore volume (space) relative to the total volume and is determined by using bulk density and true density (R. A. Thompson and G. W. Isaacs, 1967) and (Chang, 1988). Mathematically porosity is determined or expressed as follows using equation 14.

$$porosity = 1 - \frac{bulk\ density}{true\ density}$$
(14)

Angle of repose

The angle of repose is the angle compared to the horizontal at which the material will stand when piled. Normally it is measured by sliding box, but since there is no such setup in our area there is another simple and approximating way to measure the angle of repose of seeds by using a flat surface and ruler. In this study wood table and ruler are used. First, the sample seeds are piled on the table until they form the final heap. When there is no seed left in hand first measure the height of the heap and second measure the diameter of the heap formed at the base by using a ruler. The diameter is the average diameter of the minimum and maximum diameters measured in each trial. A total of 10 trials was performed for each variety and the minimum, maximum, and mean angle of repose is determined for each variety.

Thousand-grain mass

The thousand-grain mass is calculated by multiplying the 100 seeds' mass by 10 (Ofori et al., 2019) or directly measured by taking 1000 grains as a sample and measuring the mass by using a precision electronic balance.

Thousand grain mass=100grain seed mass*10
(15)

Moisture calculation

Moisture content is measured in two ways. The initial moisture content of the seed is measured directly by using a moisture meter. But during the experiment when the seeds are placed in the refrigerator and drying oven the moisture content is measured or calculated by weight difference or it is the ratio of change in weight to the initial weight as follows:

$$\text{moisture content} = \frac{\text{weight before} - \text{weight after}}{\text{weight before}} * 100$$
(16)

Where weight before is the weight before drying and weight after is the weight after drying. That means the weight of the seed sample before being inserted into the frig or drying oven is measured and recorded and the weight after drying loss of weight or refrigeration gain of weight is measured and the moisture content is then calculated by using the formula on a dry basis or wet basis. The above-listed materials and methods are used again and again for each moisture content that the test experiment performed.

4. Result and Discussion

The project was conducted to determine the common physical properties of BH540 and BH661 maize varieties at seedling moisture content and compare them with the Limu variety studied by (Mulusew et al., 2019) and to study the effect of moisture on those common physical properties concerning planter design.

While comparing the three maize varieties at the seedling moisture content in most cases BH540 maize variety shows dominance and has the greatest maximum, intermediate and minimum dimensions. Whereas the other two varieties show dominance interchangeably one in one case and the other in another case. At the initial moisture content, BH540 maize has the largest geometric mean diameter 8.8988mm, Limu maize second 7.733mm, and BH661 at least 7.553mm. In addition, BH540 has a sphericity approach to 1 which is 0.8639 and this shows the resemblance of the variety to sphere and Limu next which has a sphericity of 0.6889, and BH661 least which has a sphericity of 0.6352 in resemblance to a sphere. While designing the seed metering cup at this seedling moisture content the designer should take the average geometric mean diameter as a cup size to avoid two or more seed pickup and emptiness of the seed metering cup and based on this the seed metering cup size is 7.733mm for Limu, 8.8988mm for BH540 and 7.553mm for BH661 maize at 10.9%, 10.31% and 11.3% seedling moisture content respectively. At this moisture content for a smooth flow of seeds from the top of the hopper to the bottom different types of hoppers, designs are used. But the most important thing is the seed's angle of repose. So, the minimum angle at which seeds start moving or rolling freely is 22.2^{o} for BH540 maize and 29.3^{o} for BH661 maize at seedling moisture content or 10.31% and 11.3% respectively.

Main seed dimensions length, width, thickness, arithmetic mean diameter, and geometric mean diameters are affected mostly by moisture content and they have a linear relationship with moisture content. As moisture content increases from 7.19 to 39.54% length, width, thickness, arithmetic mean diameter, and geometric mean diameter increase from 10.1427 to 11.0133, 9.1317 to 10.0363, 7.2549 to 7.8043, 8.8431 to 9.6179 and 8.7140 to 9.4792mm respectively for BH540 and 11.745 to 12.6512, 8.950 to 9.7442, 4.049 to 4.4635, 8.248 to 8.9530 and 7.504 to 8.1749mm respectively for an increase of moisture content from 8.83 to 35.40% for BH661 maize variety.

Again, surface area, volume, 1000grain mass, and true density show a linear relationship with moisture content and as moisture content increases, they increase and as moisture content decreases, they also decrease. As moisture content increases from 7.19 to 39.54% surface area, volume, 1000grain mass, and true density increases from 240.95 to 285.09mm^2, 356.94 to 459.23mm^3, 407.743 to 568.85kg and 1087.31 to 1236.85kg/m^3 respectively for BH540 maize and 177.77 to 210.94mm^2, 224.54 to 290.12mm^3, 322.169 to 436.22kg and 1150.6 to 1283.0kg/m^3 respectively for BH661 maize as moisture content increases from 8.83 to 35.40%. Bulk density shows an increase and decreases as the moisture content increases for both BH540 and BH661 maize varieties.

Other dimensionless shape factors like aspect ratio, sphericity, eccentricity index, flatness index, and roundness are moisture dependent but the relationship with moisture content is mostly not linear and is not consistent. As moisture content increases these physical property parameters increase one time and show a decrease at another time. But for both maize varieties, sphericity shows an increase, and as moisture content increase from 7.19 to 39.54% sphericity increases from 0.8629 to 0.8631 for the BH540 variety and from 0.6417 to 0.6488 as moisture content increases from 8.83 to 35.40% for BH661 variety.

Finally, while designing maize planters' consideration of the moisture-dependent physical properties of maize is important. Larger moisture content gives the largest sphericity for rolling faster in the hopper but due to its moisture abrasion creates and resists high moisture seeds to roll and move at the required time and speed and also not recommended to plant seeds with high moisture content since it is preventing germination. Due to this, the properties at the high moisture content of 39.54% for BH540 and 35.40% for BH661 maize is not considered for design purpose.

5. Conclusion

To design the seed metering cup and seed delivery tube of the planter the average minimum diameter used is 8.714mm, 8.8988mm, and 9.1069mm at 7.19%, 10.31%, and 12.08% wb moisture content respectively for BH540 maize and 7.504mm, 7.553mm and 7.9066mm at 8.83%, 11.3% and 12.21% wb moisture content respectively for BH661 maize variety.

When designing for the seed plate the average surface area used for BH540 maize be 240.95mm^2, 253.88mm^2 and 262.98mm^2 at 7.19%, 10.31%, and 12.08% wb moisture content and for BH661 maize be 177.77mm^2, 180.10mm^2 and 197.30mm^2 at 8.83%, 11.3% and 12.21% wb moisture content respectively. In addition, keeping the distance between the seed tube and the soil small would protect the seed from wind erosion and wind effect during planting since the individual mass of the seed is very small.

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