MODIFICATION OF ANGRAU HAND OPERATED MAIZE SHELLER FOR ENHANCED CAPACITY

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B.Tech (Agril. Engg.)

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(PROCESSING AND FOOD ENGINEERING)

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BY

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2013

CERTIFICATE

Mr**. B. ASHWIN KUMAR** has satisfactorily prosecuted the course of research and that thesis entitled "**MODIFICATION OF ANGRAU HAND OPERATED MAIZE SHELLER FOR ENHANCED CAPACITY**" submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that neither the thesis nor its part thereof has been previously submitted by her for a degree of any university.

Date: **Chairperson**

CERTIFICATE

This is to certify that the thesis entitled **"MODIFICATION OF ANGRAU HAND OPERATED MAIZE SHELLER FOR ENHANCED CAPACITY"** submitted in partial fulfillment of the requirements for the degree of "**MASTER OF TECHNOLOGY IN AGRICULTURAL ENGINEERING"** in the major field of **"PROCESSING AND FOOD ENGINEERING"** of the Acharya N.G. Ranga Agricultural University, Hyderabad is a record of the bonafide research work carried out by **Mr. B.ASHWIN KUMAR** under my guidance and supervision.

No part of the thesis has been submitted by the student for any degree or diploma. The published part and all the assistance received during the course of the investigations have been duly acknowledged by the author of the thesis.

Thesis is approved by Student Advisory Committee

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I, **B. ASHWIN KUMAR** hereby declare that the thesis entitled **"MODIFICATION OF ANGRAU HAND OPERATED MAIZE SHELLER FOR ENHANCED CAPACITY"** submitted to the **Acharya N.G. Ranga Agricultural University** for the degree of **MASTER OF TECHNOLOGY IN AGRICULTURAL ENGINEERING** is the result of original research work done by me. I also declare that the thesis or any part has not been published earlier in any manner.

Place : Bapatla (**B.ASHWIN KUMAR**)

Date : **I.D.NO. BEM-11-001**

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ABSTRACT

Name of the Author	:	**B. ASHWIN KUMAR**
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Physical properties of ten varieties of maize (both conventional and hybrid) were determined at different moisture content levels varying from 12 to 20% w.b. It was observed that three axial dimensions, sphericity, surface area, volume, thousand grain weight, true density and porosity were increased with increase in moisture content from 12 to 20 % w.b., whereas, the bulk density of all the ten varieties were decreased with increase in moisture content. It was also observed that angle of repose and coefficient of static friction increased on all surfaces (mild steel, plywood and glass) with increase in moisture content. The modifications were carried out to the ANGRAU hand operated maize sheller i.e., the diameter of the cylinder was increased from 13 cm to 21 cm, the adjustable peg tooths were made in peg tooth cylinder, provision was made to change the clearance between cylinder and concave and power transmission system is provided with belt and pulley instead of gears for easy cranking. The existing and modified ANGRAU hand operated maize sheller were tested with variety (NANIYA) at six levels of moisture contents ranging from 10 to 12% w.b. at feed rate of 65 kg/h. It was found that, the shelling efficiency (99.31%, 80.06%) of modified ANGRAU hand operated maize sheller found higher at moisture content of 10 % w.b. as compared to the existing ANGRAU maize sheller, unshelled (0.69%, 19.94%) and visible damage

(1.21%, 2.05%) percentage of modified ANGRAU maize sheller are found to be significantly lower at moisture content of 12% w.b, as compared to existing ANGRAU maize sheller respectively. The modified ANGRAU hand operated maize sheller was tested with variety (RUDHIRA 145) at six levels moisture contents ranging from 12 to 20% w.b and feed rates of 120, 130 and 140 kg/h. These three feed rates corresponded to 300, 330 and 350 rpm of the cylinder speed, respectively. It was observed that the shelling efficiency (99.96%) was higher as compared to other combination treatments, whereas the unshelled grain percentage (0.04%) and visible damage percentage (0.77%) was lower when at moisture content of 12 % w.b and at feed rate of 130 kg/h. The popular tubular hand maize sheller was modified to suit different diameters of maize cobs and tested for its performance. The capacity of modified tubular maize sheller was found to be 22-24 kg/h and visible grain damage of percentage of 1.2%.

Keywords: Physical properties, Maize, Moisture content, Maize sheller, Shelling efficiency.

LIST OF SYMBOLS AND ABBREVIATIONS

cm	:	Centimeter
et al	:	And others
etc.,	:	*Etcetera*
Eq.	:	Equation
fig.	:	Figure
d.b	:	Dry basis
m.c.	:	Moisture content
°C	:	Degree Celsius
w.b	:	Wet basis
G	:	Gram
H	:	Hour
viz.	:	That is
l	:	Litre
m	:	Meter
mm	:	Millimeter
min.	:	Minutes
mg	:	Milligram
%	:	Per cent
±	:	Plus or minus
kg	:	Kilogram
rpm	:	Revolutions per minute
rps	:	Revolutions per second
kW	:	Kilo watt
kWh	:	Kilo watt hour
t	:	Tonnes

Chapter I

INTRODUCTION

Maize (*Zea mays* L) is also known as corn, is the world's third most important cereal crop after wheat and rice. It has very high yield potential and is commonly known as "Queen of cereals". World produces about 856 million tons of maize, whereas India produces about 21.76 million tons (2011-12), (www.indiastat.com). The important maize grown districts are Karimnagar, Medak, Nizamabad, Warangal and Adilabad, contribute about 80% of maize production in Andhra Pradesh. It is grown over an area of 8.33 lakh hectares in Andhra Pradesh with total production of 36.58 lakh tones (www.indiastat.com). Maize contains about 10% proteins, 4% oil, 70% carbohydrates, 2.3% crude fiber, 10.4% albuminoides and 1.4% ash. Maize has significant quantities of vitamin A, nicotinic acid, riboflavin and vitamin E. Over 85% of maize produced in the country is consumed as human food like chapattis prepared out of maize flour and grain, roasted ears and pop corn. Maize crop furnishes huge quantities of green fodder for cattle. Maize starch is used as chemical for production of plastics, fabrics and adhesives. Several industries like starch, milling etc., are based on maize products and by-products. In addition to big industries, several cottage industries are also flourishing on the by-products of maize.

The major steps involved in the processing of maize are harvesting, shelling and milling. Mostly harvesting of maize crop is being done manually with traditional sickle at a moisture content of about 33% and the crop is dried in sunshine to reduce the moisture content to 15-21% d.b. Shelling is one of the important post harvest technology operation where the kernels are to be separated from the cobs to use as seed, fodder, oil extraction and to prepare the value added products and also to maintain the quality of end product (Singh and Singh, 2010). The traditional method of separating the kernels from cobs is by pressing with fingers or with sickle are time consuming and tedious. The maize shellers which are manually or power operated, are used to remove the corn pearls from the cobs. There are hand-held devices of various designs and outputs i.e., small rotary hand sheller, free standing hand shellers, small/large hand operated shellers with cleaning and grading facilities. Tubular hand maize sheller is a simple metal pipe of diameter 65 mm and length 70 mm with four tapering blades or vanes welded on the inner surface of the pipe equally spaced at an interval of 90°. The cob is pressed at the input end of the tube and sheller is rotated and simultaneously pushed forward. After shelling on same length, the shelled cob is pulled out from the output end with rotation. The capacity of the sheller ranges from 20 to 22 kg per hour. The main draw back of this tubular maize sheller is when the cobs are more than 40 mm the cob will get choked during operation and cobs less than 30 mm diameter will come without getting shelled. Also, the handmade sheller shells only one cob at a time and has limitations with respect to the maize cob size. Various types of manually and power operated maize shellers have thus been developed and evaluated (Ali *et. al.,* 1986). Hand operated rotary maize shellers have been found suitable for small and marginal farmers for shelling maize, especially for seed purposes, as damage grains are lower in comparison to power operated maize shellers. The large power operated shellers are provided with loading, cleaning, grading and bagging facilities, but they are not affordable by small and medium farmers.

An attempt was made at Farm Implements and Machinery (FIM) scheme, Acharya N.G. Ranga Agricultural University, Rajendranagar, Hyderabad for development of hand operated maize sheller but it could not reach to the farmers due to low feed rate (65 kg/h) and more grain broken percentage (around 10%). (Anonymous, 2006). The factors affecting maize shelling efficiency are level of moisture content in the crop, size and quality of cobs, rate of supply of cobs and the extent of the dehusking of the machine. In view of this, it is highly essential to develop a continuous hand maize sheller for enhanced capacity with low grain broken percentage and a modified tubular hand maize sheller for the benefit of small and marginal farmers, especially for seed purposes. Keeping in view a study is undertaken with the following objectives:

The objectives of the investigation are:

1. To determine the physical properties of maize cobs of conventional and hybrid varieties grown in Andhra Pradesh, in relation of moisture content of grain.
2. Modification to ANGRAU hand operated maize sheller for enhanced capacity.
3. Testing and evaluation of modified ANGRAU hand maize sheller by varying the moisture content of grain and feed rate.
4. Design and development of a modified tubular hand maize sheller to suit different diameters of maize cobs.

Chapter II

REVIEW OF LITERATURE

This chapter deals with effect of moisture content on physical properties of grains, and performance evaluation of maize shellers varying in moisture contents and feed rates. Determination of physical properties is necessary to design equipment for grading, handling, processing and storage *etc.* The geometric mean diameter and sphericity are necessary to design machines for cleaning, grading, sorting and packing *etc*., where as the surface area and porosity are required to evaluate the rate of heat transfer for heating and drying and thus to design heat exchangers and driers *etc*. Bulk density, true density and porosity are required for the design of aeration, storage, transport and separation systems. True and bulk density data have also been used to determine the dielectric properties of cereal grains. Angle of repose and coefficient of frictions on various structural surfaces are required for designing bins, silos and other storage structures.

2.1 ANGRAU HAND OPERATED MAIZE SHELLER

An attempt was made at Farm Implements and Machinery (FIM) scheme, Acharya N.G. Ranga Agricultural University, Rajendranagar, Hyderabad for development of ANGRAU hand operated maize sheller (Plate 2.1) but it could not reach to the farmers due to low feed rate (65 kg/h) and more grain broken percentage (around 10%), (Anonymous, 2006).

Plate 2.1. ANGRAU hand operated maize sheller.

The various findings by different researchers in these areas of work have been reviewed and presented.

Sobukola *et al.* (2013) evaluated physical properties of high quality protein maize (SWAM 1) seeds as a function of moisture content varying from 9.38 to 32.7 % d.b. The length, width, thickness and the geometric diameter increased linearly from 9.80 to 10.55, 8.60 to 9.06, 4.00 to 4.75 and 6.85 to 7.69 mm, respectively. The sphericity index, seed volume, seed surface area and thousand seed mass also increased linearly from 69.89 to 72.85, 99.36 to 138.56 mm^3, 124.55 to 157.76 mm^2 and 240.36 to 303.71 g, respectively. Bulk density, true density and porosity decreased linearly from 1.109 to 1.057 g/m^3 1.365 to 1.176 g/m^3 and 18.75 to 10.12%, respectively. Static coefficient of friction was found to increase on plywood, galvanized iron, aluminium and stainless steel surfaces and it increased logarithmically from 0.55 to 0.91; 0.52 to 0.81, 0.49 to 0.70, and 0.46 to 0.68, respectively. Angle of repose increased linearly on plywood, galvanized iron, aluminium and stainless steel surfaces from 18.91 to 29.05, 17.00 to 26.96, 15.93 to 23.98 and 15.55 to 22.19°, respectively.

Barnwal *et al.* (2012) evaluated the physical properties of maize kernels as a function of moisture content 12.8 to 29.0 % w.b. It was reported that the maize kernel length, width, thickness, geometric mean diameter, surface area, sphericity and kernel volume increased linearly with increase in moisture content. The bulk density and true density decreased while porosity and thousand grains mass increased with increasing moisture content. The static coefficient of friction increased for mild steel sheet, galvanized iron sheet and aluminium sheet surfaces while rupture or cutting force and energy absorbed decreased with increasing moisture content.

Darvishi (2012) studied the effect of moisture content on the physical and mechanical properties of white sesame seed. The average length, width and thickness, geometric mean diameter, volume of the seed and 100 seed mass ranged from 3.019 to 3.074 mm, 1.844 to 1.935 mm and 0.724 to 0.771 mm, 1.589 to 1.659 mm, 1.315 to 1.508 mm^3 and 1.165 to 1.20 g as the moisture content increased from 4.5 to 15 % w.b. , respectively. As the moisture content increased, the bulk density, true density and porosity were found to decrease from 607.3 to 542.1 kg/m^3, 1140 to 943.5 kg/m^3 and 46.73 to 42.54%, respectively, whereas the angle of repose increased from 20.16 to 28.67°. When moisture content increased, the aspect ratio and surface area increased from 52.75 to 54.04%, from 24.06 to 25.12% and from 6.785 to 7.367 mm^2, respectively. The static coefficient of friction on various surfaces, namely, steel sheet, aluminium, galvanized metal also increased linearly with increase in moisture content. The highest static coefficient of friction was found on the steel sheet surface. The rupture force decreased with increasing moisture from 9.90 to 10.62 N.

Firouzi *et al.* (2012) carried out the experiment to determine the effect of moisture content on some physical properties of bean seed. Five levels of moisture content ranging from 12.1 to 32.1% d.b. were considered and reported that the average length, width, thickness, geometric mean diameter, unit mass, unit volume and surface area of seed were 16.59 mm, 7.51 mm, 5.81 mm, 8.97 mm, 0.50 g, 0.381 mm^3 and 252.88 mm^2, respectively, at a moisture content of 12.1% d.b. As the moisture content increased from 12.1 to 32.1 % d.b., the bean seed sphericity increased from 0.541 to 0.557, the bulk and true densities decreased from 672.77 to 640.15 kg/m^3 and from 1312.55 to 1122.93 kg/m^3, respectively. The porosity decreased from 48.74% to 42.95% and the angle of repose increased from 37.7° to 51.4°.

Naveenkumar and Rajashekarappa (2012) conducted research on development and evaluation of power operated maize sheller. The maize sheller consists of a cylinder and concave. The cylinder of 6.5 cm diameter was made up of high carbon steel. The cylinder length was 15 cm, having beaters which rotates along the cylinder and separates grains from the cobs. While the concave was fabricated using 6 mm size mild steel rods. The length of concave was 60 cm with slotted opening size of 7 cm and 1 cm. They reported that the developed power operated sheller had the shelling efficiency, total recovery, breakage and shelling capacity of 98.51, 66.62, 1.60% and 402.01 kg/h, respectively at a cylinder speed of 350 rpm.

Plange *et al.* (2012) determined the physical and mechanical properties of cashew nut and kernel in the moisture content range of 5.0 to 9.0 % w.b. It was observed that the average length, thickness, width, equivalent diameter, sphericity and volume for cashew nuts were 41.15 mm, 23.92 mm, 32.76 mm, 31.89 mm, 77.37% and 312.54 mm^3, respectively and that for the kernels were 33.16 mm, 15.87 mm, 17.91 mm, 21.23 mm, 64.02% and 101.47 mm^3, respectively. The bulk density of cashew nut and kernel decreased linearly from 625.62 to 592.68 kg/m^3 and 559.60 to 505.06 kg/m^3, respectively. However, true density, surface area, and porosity increased linearly from 1100.16 to 1209 kg/m^3, 2754.68 to 2918.18 mm^2, and 43.19 to 51.02%, respectively for the nuts while for the kernels the properties increased from 946.23 to 991.29 kg/m^3, 1189.98 to 1309.02 mm^2 and 40.86 to 49.05%, respectively.

Jouki and Khazaei (2012) had evaluated the physical and mechanical properties of rice for design of equipment to handle, transport, process and store the crop. The grain was tested for bulk density, true density, sphericity, porosity, angle of internal friction and coefficient of friction with various materials at 12 % d.b. moisture content. He concluded that the average length, width, thickness and the average thousand grain weight of the rice grains were, 7.43, 2.75, 2.53 mm and 26.91 g. The static coefficient of friction 0.4835, 0.4061 and 0.3670 for wood, galvanized iron and glass surfaces, respectively. The higher friction coefficient values were observed on wood surface and the lowest on steel surface.

Nwakaire *et al.* (2011) were carried out work to design, construct, and evaluate a low cost maize sheller for rural farmers in Nigeria and compared the human performance index for shelling and the machine performance index. The human mechanical efficiency, through-put capacity and grain handing capacity are 45%, 26.67

kg/h and 21.1 kg/h at a biomaterial test weight of 20 kg with actual shelled weight of 15.8 kg at a shelling time 45 minutes. For machine indices, through-put capacity and the grain handing capacity of the sheller are 86%, 119.76 kg/h and 109.99 kg/h respectively.

Sezer *et al.* (2011) evaluated the physical properties of seeds of Simon and Goldeclat dent corn (*Zea mays* var. *indentətə* sturt) cultivars as a function of moisture content. Three levels of moisture ranging from 12.76 to 17.0 % d.b, and 11.09 to 16.48 % d.b were used for Simon and Goldeclat cv., respectively. The averaged length, width, thickness, arithmetic and geometric mean diameter of seeds ranged from 10.54, 7.26, 4.57, 116.46 and 7.04 mm for Simon cv.; 10.80, 6.89, 4.81, 119.42 and 7.09 mm for Goldeclat cv., respectively. The sphericity, volume and surface area increased linearly from 0.668 to 0.684, 125.94 to 162.51 mm^3, 131.13 to 154.37 mm^2 for Simon cv.; 0.657 to 0.670, 128.19 to 155.63 mm^3, 133.18 to 150.89 mm^2 for Goldeclat cv., respectively. The bulk densities decreased from 762.60 to 675.51 kg/m^3 and from 783.37 to 714.48 kg/m^3 and true densities decreased from 1425.07 to 1367.35 kg/m^3 and from 1455.0 to 1396.36 kg/m^3 for Simon and Goldeclat cv., respectively, whereas, the angle of repose increased from 23.50 to 26.65° band from 21.86 to 25.27°. The highest static coefficient of friction was found on the wood and the lowest on the glass sheet among the materials tested.

Tarighi *et al.* (2011) studied the physical and mechanical properties of corn seeds as a function of moisture content in the range of 5.15 to 22 % d.b. They observed that the average length, width, thickness and arithmetic diameter were increased by 6, 2.2, 1.66, and 3.3%, with increasing moisture content, respectively. In the moisture range from 5.15 to 22 % d.b., the results showed that, the thousand seed mass increased from 267.7 to 305.8 g, the porosity from 31.41 to 45.98%, the static angle of repose from 42 to 57 and the coefficient of friction on compressed plastic, plywood and galvanized iron sheet surfaces were increased from 0.36 to 0.67, 0.36 to 0.6 and 0.38 to 0.57, respectively. The bulk density decreased from 679.1 to 632 kg/m^3 and true density increased from 999.33 to 1170.49 kg/m^3.

Zareiforoush *et al.* (2011) determined the effect of moisture content on some physical properties of paddy grains. Six levels of moisture content ranging from 8 to 24 % d.b. were used. They reported that the average length, width, thickness, equivalent diameter, surface area, sphericity, thousand grain mass, angle of repose and aspect ratio increased from 10.20 to 10.28 mm, 2.31 to 2.42 mm, 1.85 to 1.94 mm, 3.53 to 3.66 mm, 36.87 to 39.16 mm^2, 34.53 to 35.46 %, 24.43 to 28.27 g, 38.27° to 46.13° and 0.226 to 0.236, respectively, as the moisture content increased from 8 to 24 % d.b. As the moisture content of paddy grains increased from 8 to 24 % d.b., the bulk density and true density were found to increase from 381.77 to 428.5 kg/m^3, and 1328.65 to 1372.41 kg/m^3 respectively, while the porosity was found to decrease from 71.27 to 68.78%. The static coefficient of friction of paddy increased linearly against various surfaces, namely, glass (0.3577 to 0.4973), galvanized iron sheet (0.4629 to 0.5295), and plywood (0.4856 to 0.5830) as the moisture content increased from 8 to 24 % d.b.

Abba and Atiku (2010) studied the effect of moisture content on maize shelling speed using a manually operated hand sheller (cone type). Twenty (20) unthreshed maize cob samples (A to J) were used for the study. The results obtained indicated that sample J, after sixty nine hours (69^{th}) oven drying recorded the lowest moisture content 15.10 % w.b. and the fastest shelling speed (0.75 rps) compared to sample A (24 h drying time) which had the highest moisture content 28.99% w.b., and lowest shelling speed (0.96 rps). It was observed that sample J with the shortest shelling duration had the smallest grain weight (84.2 g), while sample 'A' recorded larger grain weight (162.9 g) due to differing moisture content of the maize grains. By considering results obtained, it is recommended that maize cobs be dried properly to enable easier and faster shelling operation with less fatigue and minimum grain damage.

Kiber *et al.* (2010) investigated the effect of moisture content on physical and mechanical properties of rice design for handling and storage facilities. They reported that length, width, thickness, arithmetic and geometric mean diameter ranged from 8.27 to 9.01 mm, 3.10 to 3.48 mm, 2.05 to 2.26 mm, 4.47 to 4.92 mm, 3.75 to 4.13 mm, respectively as the moisture content increased; sphericity, grain volume, surface area, true density and porosity increased from 43 to 45%, 130.97 to 160.32 mm^3, 38.68 to 46.91 mm^2, 939.0 to 962.1 kg/m^3, and 36.61 to 41.97%; bulk density decreased from 595.5 to 560.5 kg/m^3; the angle of internal friction increased linearly from 29.70° to 32.53° with the increase of moisture content; the static coefficient of friction increased from 0.764 to 0.972, 0.524 to 0.702 and 0.576 to 0.764 for concrete, galvanized steel and wood surfaces, respectively; the poisson ratio and pressure ratio decreased linearly with the increase of moisture content.

Ojediran *et al.* (2010) studied the physical properties for two varieties of Pearl millet seeds (cv Ex-Borno and SOSAT C88) as a function of moisture contents ranging from 10 to 20 % w.b. The two varieties (SOSAT C88 and Ex-Borno) seeds increased their width by 15.7% and 15.6%; similarly, their length increased by 15.3% and 19.8%, and their thickness increased by 22.4% and 7.8%, respectively. Seeds from Ex-Borno were the smallest. Sphericity changed with the increase in moisture content with SOSAT C88 coming closer to a spherical form. The solid and bulk densities of the seeds for different moisture levels decreased with the increase in moisture content. The porosity started at 17% and 15.2 % and increased to 26.6% and 32.6% for SOSAT C88 and Ex-Borno varieties respectively. The thousand seed mass and angle of repose also increased with increasing moisture levels for both varieties. Both varieties showed a comparable behaviour in relation with the static coefficient of friction, this variable increased with moisture content on two structural surfaces namely concrete and plastic, but decreased with increasing moisture levels on glass, steel and aluminium.

Seifi and Alimardani (2010a) determined the effect of moisture content on physical properties and mechanical behavior of corn grains under compression load of two varieties of corn (Sc704 and Dc370) at four levels of moisture content ranging from 4.73 to 22 % w.b. and 5.15 to 22 % w.b. The thousand grain weight increased linearly from 271.0 to 321.4 g for Sc704 and from 267.7 to 305.8 g for Dc370. As the moisture content increased, bulk density was found to decrease from 710 to 649 kg/m^3 and 679 to 632 kg/m^3 for Sc704 and Dc370, respectively whereas true density and porosity were found to increase from 1250 to 1325 kg/m^3 and 43.2% to 51.02% for Sc704 and 997 to 1170 kg/m^3 and 31.90% to 45.98% for Dc370. The static coefficients of friction on various surfaces, namely, galvanized iron, plywood and plastic also increased linearly with an increase in moisture content. The linearity of coefficients of friction data of galvanized iron and plastic for Sc704 was higher with moisture content than Dc370.

Seifi and Alimardani (2010b) determined the physical and mechanical properties of corn grains as a function of moisture content in the range of 4.73 to 22 % w.b. using standard techniques. The average length, width, thickness, geometric mean diameter, equivalent diameter, arithmetic diameter, sphericity, grain volume, surface area and aspect ratio ranged from 11.62 to 12.60 mm, 7.27 to 7.98 mm, 4.47 to 4.71 mm, 7.20 to 7.77 mm and 7.63 to 7.96 mm, 7.77 to 8.43 mm, 62.31% to 62.00%, 209.66 to 265.00 mm^3, 137.69 to 160.09 mm^2 and 63.05% to 63.77% as the moisture content changed from 4.73 to 22% w.b. With increase in moisture content, the bulk density was found to decrease from 710 to 649 kg/m^3, whereas true density and porosity increased from 1250 to 1325 kg/m^3 and 43.2% to 51.02%. In the moisture range from 4.73% to 22% w.b., studies on rewetted corn grains showed that the thousand grain weight (TGW) increased linearly from 271.0 to 321.4 g. The static coefficient of friction of corn grains increased linearly against surfaces of three materials, namely, plastic (0.32 to 0.51), plywood (0.48 to 0.60) and galvanized iron (0.38 to 0.65) and the static angle of repose increased from 49º to 58º when the moisture content increased from 4.73% to 22 % w.b. Rupture energy of corn grains generally increased in magnitude with an increase in moisture content, while rupture force decreased for compression.

Singh *et al.* (2010) studied the moisture dependent properties of barnyard millet grain and kernel. They observed that the geometric mean diameter, sphericity, grain surface area, thousand grain mass, true density (toluene displacement method), terminal velocity, dynamic angle of repose, coefficient of internal friction, coefficient of static friction at different surfaces (sunmica, canvas and mild steel surfaces), specific deformation and rupture energy of the grain were found to increase 12.21%, 4.79%, 30.47%, 30.75%, 6.74%, 32.99%, 127.05%, 60%, 18.57%, 34 to 67%, 69.2% and 88.87%, respectively at increase of moisture content from 0.065 to 0.265 kg/kg dry matter. However, true density (proximate composition method), bulk density, interstices and rupture force of grain was found to be decrease 8.64%, 20.1%, 86.49% and 21.17% respectively at increase of moisture content. Similar trend was observed for barnyard kernel also. True density (toluene displacement method) was found lower as compared to true density (proximate composition method) at all experimental moisture range indicated that the presence of void space inside the grain and kernel.

Tiwari *et al.* (2010) studied the effect of operating speed and cob size on performance of a rotary maize sheller and its operating speed was optimized. The shelling capacity and shelling efficiency of maize sheller for all categories of maize cobs increased curvilinearly with increase in operating speed up to about 70 rpm. The shelling capacity at a particular operating speed decreased with increase in the maximum diameter of cobs. On the other hand, the torque decreased with decrease in maximum diameter of maize cobs at a given operating speed. It was concluded that the operating speed of maize sheller should be 70 to 80 rpm for higher shelling capacity, shelling efficiency and lower operating torque.

Yaranal *et al.,* (2010) studied the development and performance evaluation of pedal operated maize sheller. The performance data revealed that the shelling capacity of developed sheller was 72 to 78 kg/h which was 9 to 12 times more than hand shelling and 4 to 4.6 times more than hand maize sheller. There was no visible damage in shelled grains between 7 to 9% moisture content. The shelling efficiency of pedal operated maize sheller was 94 to 96% and operating cost was in between Rs. 50 and Rs. 52/-.

Karimi *et al.* (2009) studied effect of moisture content ranging from 8, 12 and 18 % w.b. on physical properties of wheat. The average length, width and thickness were 6.75, 3.26 and 2.77 mm at a moisture content of 8% w.b., respectively. Studies on rewetted wheat seeds showed that the thousand-kernel weight increased from 18.38 to 22.43 g. The geometric and equivalent mean diameter, surface area, sphericity and aspect ratio at a moisture content of 8% w.b. were 3.93, 3.94 mm, 48.68 mm^2, 0.58, 0.48, respectively. The porosity increased from 0.43 to 0.45 %. Whereas the bulk density decreased from 0.72 to 0.66 kg/m^3 and the true density from 1.25 to 1.19 kg/m^3, with an increasing in the moisture content range of 8 to 18% w.b. The static and dynamic angle of repose varied from 37.28 to 47.33 and 29.89 to 36.5^o. The mean of static friction coefficient of three wheat varieties increased the linearly against surfaces of three structural materials, namely, compressed plastic (0.43 to 0.53), galvanized iron (0.33 to 0.53) and plywood (0.35 to 0.41) as the moisture content increased from 8 to 18 % w.b..

Tavakoli *et al.* (2009a) evaluated the effect of moisture content ranging from 6.92 to 21.19% d.b. on some physical properties and mechanical behaviour under compression load of soybean grains (*Glycine max* L.). The average length, width, thickness, arithmetic and geometric mean diameter, surface area, thousand grains mass and angle of repose increased as the moisture content increased from 6.92 to 21.19 % d.b.. As the moisture content increased from 6.92 to 21.19 % d.b., the bulk density and true density were found to decrease from 650.95 to 625.36 kg/m^3 and from 1147.86 to 1126.43 kg/m^3 respectively, while the porosity was found to increase from 43.29 to 44.48 %. The static coefficient of friction of soybean increased linearly against various surfaces as the moisture content increased from 6.92 to 21.19 % d.b.

Tavakoli *et al.* (2009b) carried out the experiment to evaluate the effect of moisture content ranging from 7.34% to 21.58 % d.b. on physical properties of barley grains. The average length, width, thickness, arithmetic mean diameter, geometric mean diameter, thousand grain mass, sphericity, surface area and repose angle increased from 8.91 to 9.64 mm, 3.30 to 3.74 mm, 2.58 to 2.98 mm, 4.93 to 5.45 mm, 4.23 to 4.75 mm, 44.48 to 51.30 g, 47.55% to 49.35%, 56.66 to 71.09 mm^2 and 31.16° to 36.90°, respectively, as moisture content increased from 7.34% to 21.58 % d.b. The bulk density, true density and porosity were found to decrease with increasing moisture content. The static friction coefficient of the grains increased linearly against various surfaces (plywood, glass and galvanized iron sheet) as the moisture content increased. At all moisture content, the maximum friction was offered by plywood, followed by galvanized iron sheet and glass surface.

Khateeb *et al.* (2008) studied the operating factors affecting using two different threshing machines for threshing sunflower heads. They observed that the maximum threshing efficiencies values of 99.33 and 98.67% for corn sheller and El-Shams thresher respectively was obtained at feeding rate of 2.5 kg/min under different sunflower heads moisture content. The maximum cleaning efficiency of 97.28 and 87.99 % for El-Shams thresher and corn sheller, respectively, at feeding rate of 2.5 kg/min under different heads moisture content. The maximum seed damage percentage of about 6.79 and 1.22 % for El-Shams thresher and corn sheller, respectively, at feeding rate of 2.5 kg/min. under different head moisture contents. Increasing drum speed from 300 to 600 rpm increased the power consumption from 9.22 to 13.8 kW and from 4.58 to 6.74 kW and energy requirement from 21.45 to 24.19 and from 17.62 to 19.25 kWh/fed for El-Shams thresher and Corn Sheller, respectively at feed rate of 2.5 kg/min. and sunflower heads moisture content of 17.07%.

Kibar and Ozturk (2008) determined the physical and mechanical properties of soybean at 8 to 16% moisture content. They observed that the moisture range, grain length, width, thickness, arithmetic average diameter and geometric average diameter increased from 7.24 to 8.19, 6.79 to 7.12, 5.78 to 6.23, 6.60 to 7.18, 6.57 to 7.14 mm, respectively. The volume of grain and area of grain surface increased linearly from 130.97 to 160.32 mm and from 125.46 to 144.39 mm^2, respectively. The sphericity, bulk density, true density and porosity decreased linearly from 0.91 to 0.87, 766.12 to 719.00, 983.33 to 905.67 kg/m^3 and 22.58 to 20.61%, respectively. The angle of internal friction increased linearly from 27.37 to 31.81° with the increase of moisture content. The static coefficient of friction increased from 0.385 to 0.571, 0.304 to 0.441 and 0.164 to 0.286 for concrete, wood and galvanized steel surfaces, respectively.

Ozturk and Esen (2008) had evaluated the physical and mechanical properties of barley as a function of moisture content of grain varying from 10 to 14% d.b. They reported that the moisture range, as the bulk density decreased linearly from 647.34 to 623.00 kg/m^3, true density increased linearly from 984.00 to 1013.67 kg/m^3. The porosity and angle of internal friction increased with the increase in the grain moisture content up to 38.50% and 22.50%, respectively, at 14% moisture content. The static coefficient of friction increased from 0.877 to 0.993, 0.773 to 0.920, 0.560 to 0.713 for concrete (BS 30), galvanized steel and wood surfaces, respectively.

Isik (2007) studied some engineering properties of soybean grains as a function of moisture content in the range of 10.62 to 27.06 % d.b. The average length, width and thickness were 7.795, 7.123 and 4.189 mm, at a moisture content of 10.62% d.b., respectively. In the above moisture range, the arithmetic and geometric mean diameters increased from 6.369 to 8.048 mm and from 6.149 to 7.933 mm, respectively, while the sphericity increased from 0.788 to 0.835. In the moisture range from 10.62 to 27.06 % d.b., and the thousand grain mass increased from 200 to 255 g, the projected area from 37.69 to 53.39 mm^2, the true density from 1090 to 1200 kg/m^3, the porosity from 40.36 to 54.16% and the terminal velocity from 8.01 to 9.1 m/s. The bulk density decreased from 650 to 550 kg/m^3 with an increase in the moisture content range of 10.62 to 27.06% d.b.. The static coefficient of friction of soybean grains increased the linearly against surfaces of six structural materials, namely, rubber (0.3443-0.3919), aluminum (0.2867-0.3115), stainless steel (0.2905-0.3443), galvanized iron (0.2962-0.3482), glass (0.2309-0.2773) and MDF (medium density fiber board) as the moisture content increased from 10.62 to 27.06%.

Milani *et al.* (2007) studied the physical properties of three varieties of cucurbit seeds (Riz, Chiny and Gushty). The results showed that the mean values of all geometric properties increased with increasing moisture content. Among the varieties, Chiny had the highest values of gravimetric properties, in all moisture contents studied. The maximum and minimum values of bulk density were obtained for Riz (550.3 kg/m^3) and Chiny (308.3 kg/m^3). The filling and emptying angles of repose ranged between 24.29 to 43.94° and 13.01 to 44.98°, respectively. At all moisture contents, the coefficient of static friction was the greatest against rubber (0.52 to 1.05), followed by plywood (0.42 to 1), glass sheet (0.31 to 0.99), galvanized iron sheet (0.39 to 0.94), and the least for fiberglass sheet (0.38 to 0.98). Among cucurbit varieties, Riz and Gushty showed the least and the greatest static coefficients of friction in all moisture contents studied, respectively.

Nkakini *et al.* (2007) developed manually powered continuous flow maize-sheller and evaluated its performance efficiency. At a speed of 60 rpm, a shelling effectiveness of 67% was achieved, with a low kernel-breakage factor of 0.090 and a throughput of 6.82 kg/h. For the trial runs, the machine was designed to shell a batch of 100 maize cobs, which were introduced into the feed hopper in one batch, without stopping until all the cobs were stripped via the shelling unit. This design is preferred, because of its rapid operation, low human-energy expenditure, low breakage factor for the kernels as well as relatively little dust being emitted during shelling; hence leading to a relatively-healthier local atmosphere for the operator.

Varnamkhasti *et al.* (2007) studied some physical properties of raw paddy. At moisture content of 10 % w.b., the average grain length, width and thickness were 8.54, 2.47 and 1.83 mm, respectively while the equivalent mean diameter, surface area and volume were 3.4 mm, 32.58 mm^2 and 21.06 mm^3, respectively. The sphericity and aspect ratio were 39.88 and 0.29%, respectively. True density, bulk density and porosity were 1193.38 kg/m^3, 471.16 kg/m^3 and 60.37%, respectively while the static coefficient of friction varied from 0.2186 on glass sheet to 0.4279 on plywood. The angle of repose for emptying was 35.83°.

Tastra *et al.* (2006) were tested three types of local maize shellers (SLM, KWT and TMO) at three levels of grain moisture content (32.5%, 35.0% and 35.5%) and cylinder speed. The effective shelling capacity increased with increase of the cylinder speed but decreased with an increase of the moisture content. Mechanically damaged maize increased with increasing cylinder speed and with moisture content of maize. The total drying cost decreased with increase in moisture content. The minimum total costs of shelling and drying were Rs 3573/t, Rs 3176/t and Rs 3315/t while the optimum grain mechanical damage was 18.4%, 17.8% and 21.1%. It was concluded that each type of local maize sheller has different optimum grain moisture content. Among the three types of maize shellers tested, the best local maize sheller was the KWT type.

Coskun *et al.* (2005) determined the physical properties of sweet corn seed as a function of moisture content in the range of 11.54 to19.74% d.b. The average length, width and thickness were 10.56 mm, 7.91 mm and 3.45 mm, at a moisture content of 11.54% d.b. respectively. In the moisture range from 11.54% to 19.74 % d.b., studies on rewetted sweet corn seed showed that the thousand seed mass increased from 131.2 to 145.5 g, the projected area from 59.72 to 75.57 mm^2, the sphericity from 0.615 to 0.635, the true density from 1133.8 to 1225.5 kg/m^3, the porosity from 57.48% to 61.30% and the terminal velocity from 5.56 to 5.79 m/s. The bulk density decreased from 482.1 to 474.3 kg/m^3 with an increase in the moisture content range of 11.54 to 19.74 % d.b..

Candia *et al.* (2004) redesigned and fabricated the AEATI motorized maize sheller and compared its performance with the old design using Longe-5 maize variety. The new model had higher mean output (1,490 kg/h/l of fuel) and shelling efficiency (99.7%) than the old one ($p<0.5$). There was inadequate evidence to show that the percentage of broken grain caused by the two models were significantly different ($p>0.5$). However the mean value of broken grain from the new model was 1.8% while from the old sheller stood at 2%. The mean seed germination tests were 90.8% and 90.4% for the new and old shellers respectively.

Srivatsava *et al.* (2003), studied the performance evaluation of power operated maize sheller at three levels of cob moisture content (14.2, 17.66 and 19.37 % d.b. and feed rates (1107.69, 1227.27 and 1384.62 kg/h). The combination of 14.2 % d.b. cob moisture content (grain moisture content 15.7 % d.b. and 1384.62 kg/h feed rate yielded maximum machine capacity (483.58 kg/h), maximum shelling efficiency (99.88%) and minimum percent grain damage (8.25%). However, the maximum grain recovery (92.66%) was found at 14.2 % d.b. cob moisture content and 1227.27 kg/h feed rate. The machine capacity decreases with increasing moisture content, while it increases with increasing feed rate. There was not much variation in shelling efficiency with different moisture contents and feed rates. The per cent grain recovery decreases with increasing moisture content at all levels of feed rate.

Akubuo (2002) evaluated the performance of a locally fabricated maize sheller for cob breakup, shelling efficiency, kernel damage and separation loss with three varieties (Nsukka Super, Nsukka Local and Agbuda Special) of local maize (*Zea mays*) over three harvest dates. Harvest date was found to have significant effects on most of the variables studied because of the variations in moisture contents. The kernel damage and cob breakup decreased significantly with later harvest date. The shelling efficiency was not significantly affected by changes in the harvest date for ‘Nsukka Super’ and ‘Nsukka Local’ maize varieties but the effects on the ‘Agbuda Special’ maize variety were more variable. The shelling capacity was not significantly influenced by harvest date or maize variety.

Baryeh and Mangope (2002) evaluated the physical properties of pigeon pea as a function of grain moisture content varying from 5 to 25% w.b. It was reported that the seed moisture content range, the grain surface area, volume and sphericity decreased nonlinearly from 100.28 to 47.39 mm^2, 94 to 28 mm^3 and 0.91 to 0.82, respectively, while true density, bulk density and porosity increased nonlinearly from 0.75 to 1.22 g/mm^3, 0.70 to 0.87 g/mm^3 and 8% to 28% respectively. The 1000 seed mass, angle of repose and terminal velocity increased linearly from 96 to 140 g, 17° to 31° and 6.52 to 11.58 m/s, respectively. The coefficient of static friction increased nonlinearly from 0.28 to 0.51 for plywood, 0.23 to 0.38 for galvanised steel and 0.18 to 0.31 for aluminium.

Dauda and Aviara (2001) investigated the effect of five maize threshing methods, namely bare hand threshing, hand held manually operated tool sheller, stick beating, pounding in mortar and tractor, operated machine threshing on the threshing output, grain damage and seedling emergence of three varities of maize, namely Hybrid 8341-6, TZESR-Y and TZESR-W. Among the five threshing methods, bare hand threshing gave the lowest per cent grain damage (0.5% on hybrid, 0.3% on TZESR-Y and o.2% on TZESR-W), while the stick beating method gave the highest percentage (4.0%) on hybrid 8341-6 2.0% on TZESR-Y and 1.0% TZESR-W. Grain viability determined on the basis of percent seedling emergence of planted maize, was found to be high for products of the threshing methods expect that of stick beating.

Adewale *et al.* (2000) reported that rasp bars are easier to adjust and monitor and are relatively simple to operate and durable. The efficiency of shelling machines varies from one machine to the other as affected by some factors like the crop moisture content, feeding rate, shelling mechanism and the concave –cylinder clearance.

Alonge and Adegbulugbe (2000) evaluated the locally developed grain thresher to determine the effects of speed on the shelling output, cracking and grain losses at three moisture content levels. The results showed that the rate of shelling increased as the speed was increased. Grain losses decreased as the speed was increased while more breakages were recorded at high speed. It was further observed that the rate of shelling, grain losses and breakages decreased as the moisture content increased.

Singh and Goswami (1996) evaluated the physical properties of cumin seed as a function of moisture content, the average length, breadth and thickness were 5.61, 1.77 and 1.55 mm respectively. In the moisture range from 7 to 22% d.b., studies on dried or rewetted cumin seed showed that bulk density initially increased from 477 to 502 kg/m^3 then decreased from 502 to 410 kg/m^3, true density increased from 1047 to 1134 kg/m^3, and porosity increased from 54 to 64% . The 1000 seed weight and terminal velocity increased linearly from 4.13 to 4.80 g and 2.6 to 4.8 m/s respectively. The angle of repose increased linearly from 36.5 to 51.3^0 and the static coefficient of friction also increased linearly on four metal surfaces, namely, mild steel (0.54 to 0.70), galvanized iron (0.48 to 0.65), stainless steel (0.37 to 0.62) and aluminium (0.43 to 0.63) with the increase in moisture content from 7 to 22% d.b. seed weight, terminal velocity, angle of repose and static coefficient of friction. The range of the moisture content was selected from 7 to 22% d.b., as harvesting and most of the processing operations of crops are performed in this moisture range.

Kunjara *et al.* (1988) tested and evaluated two models of maize sheller namely, rasp bar (RB) and peg tooth (PT) to determine their operational performance. Using maize kernel of moisture content 14.5% w.b., shelling capacity of RB and PT type were 1.4 and 8.8 ton/h at shelling drum speed of 540 and 680 rpm respectively. Shelling and cleaning efficiencies of both shellers were 99%. Loss of shelling in term of unshelled, blown and mechanically broken grain, was less than 1.5%.

From the foregoing discussions it was revealed from the literature that sphericity, surface area, volume, true density, porosity, thousand grain weight, angle of repose and coefficient of static friction were increased with increase in grain moisture content, but bulk density has been decreased. Hand operated maize shellers are found suitable for small and marginal scale farmers for seed purposes as damaged seed percentage is low compared to power maize shellers. With the increase in moisture content, shelling and cleaning efficiency has been decreased and the following knowledge gaps have been identified:

1. No literature is available regarding physical properties of the maize varieties grown in Andhra Pradesh in relation to moisture content, which are required for design of maize shellers.

2. The existing hand maize shellers are of low output and high visible damage loss.

3. The existing tubular hand maize sheller is not useful to the farmers while the cob diameters are changing.

Considering the knowledge gaps and scope exist for further work, the present study has been undertaken with the following objectives

1. To determine the physical properties of maize cobs of conventional and hybrid varieties grown in Andhra Pradesh, in relation to moisture content of grain.

2. Modification to ANGRAU hand operated maize sheller for enhanced capacity.

3. Testing and evaluation of modified ANGRAU hand maize sheller by varying the moisture content of grain and feed rate.

4. Design and development of a modified tubular hand maize sheller to suit different diameters of maize cobs.

Chapter III

MATERIAL AND METHODS

This chapter deals with selection of raw materials, procedure for determination of various physical properties of maize at different moisture content levels, description of hand operated maize sheller and modified tubular hand maize sheller and procedure for performance evaluation of both hand operated modified ANGRAU maize sheller and tubular hand maize sheller. The experiments were conducted at the College of Agricultural Engineering, Bapatla.

3.1 RAW MATERIALS

Ten varieties of maize cobs namely, DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA, RUDHIRA 145 were selected and procured from different parts of Andhra Pradesh (Hyderabad, Warangal, Nizamabad, Karimnagar, Khammam, Bapatla and Chirala) for conducting the research work. The maize cobs were manually shelled and cleaned to remove all foreign matter such as surface dust, dirt, stones and chaff. The initial moisture content of the samples were determined for all the samples.

3.2 PREPARATION OF THE SAMPLE

Ten varieties of cleaned maize samples namely DHM 117, DHMM 115, AMBER CORN, MADHURI, 30 V 92, 900M GOLD, PIONEER B12, EDEN, NANIYA, RUDHIRA 145 were selected for conducting this experiment.

The maize samples of 100 grams were taken from each variety of maize and the desired moisture content of samples were achieved by adding "Q" amount of distilled water, as calculated from the following relationship

$$Q = \frac{W_t(M_f - M_i)}{(100 - M_f)} \qquad \textbf{... (3.1)}$$

Where Q = Weight of required water, g

W_t = Total weight of sample, g

M_f = Final moisture content, %

M_i = Initial moisture content, %

The samples were then transferred to separate polyethylene bags and the bags were sealed tightly. The samples were kept at 5^0C in a refrigerator for a week to enable the moisture to be distributed uniformly throughout each sample. Before starting a test, the required quantities of the samples were taken out of the refrigerator and allowed to warm up to the room temperature for about 2 h. This rewetting technique is to attain the desired moisture content in the grain samples. All the physical properties of the grain samples were determined at the desired moisture content (12, 14, 16, 18 and 20% w.b. (Tavakoli *et al.,* 2009.b)

3.3 PHYSICAL PARAMETERS OF MAIZE GRAINS

3.3.1 Determination of Moisture Content

The moisture content on wet basis of the dried grain were determined by hot air oven method for all the varieties, this was done by putting 10-15 g of grains at 130°C for 1h for each variety into two containers and then weighed using weight balance. The average moisture content of the two samples was calculated to obtain the moisture content of the samples using the relationship below (Chen, 2003).

$$\text{MC (w.b) \%} = \frac{W_W - W_d}{W_W} \times 100 \qquad \textbf{... (3.2)}$$

Where , W_W = weight of wet grains, g

W_d = weight of dried sample, g

3.3.2 Physical Parameters

Physical parameters like length, width, thickness, geometric mean diameter, spericity, surface area, volume, thousand kernel weight, bulk density, true density, and angle of repose of maize samples were estimated as per the following procedure.

3.3.2.1 Determination of axial dimensions, geometric mean diameter, sphericity, surface area and volume

Ten maize grains from each sample were randomly selected and their length, breadth and thickness were measured with a digital vernier calliper (Aerospace Model, 0-300mm, Plate No. 3.1). (Seifi *et al.,* 2010.b and Barnwal *et al.,* 2012). These values were used to calculate the derived geometric mean diameter, sphericity, surface area and volume using standard relationships.

Calculation

Geometric mean diameter, D_g = $(LWT)^{1/3}$ **... (3.3)**

Sphericity, S_p = $\dfrac{(LWT)^{1/3}}{L}$ **... (3.4)**

Surface area = ΠD_g^2 **... (3.5)**

Volume = $0.25[\frac{\pi}{6}L(W+T)^2]$ **... (3.6)**

Where, L - Length of the maize grain, mm

W - Width of the maize grain, mm

T - Thickness of the maize grain, mm

Plate 3.1. Digital vernier callipers.

3.3.2.2 Determination of thousand grain weight

Thousand grain weight was measured by weighing 250 grains in an electronic balance with an accuracy of 0.01 g and then multiplied by 4 to give weight of 1000 kernels (Barnwal *et al.,*2012).

3.3.2.3 Determination of bulk density

The average bulk density of the maize samples were determined by using the standard test weight procedure by filling a container of 1000 ml with samples of 100 ml by tapping twice for uniform packing and to minimise wall effect and then weighed the contents (Singh and Goswami, 1996).

$$\text{Bulk density, kg/m}^3 = \frac{\text{weight of the grain, kg}}{\text{volume, m}^3} \qquad \textbf{... (3.7)}$$

3.3.2.4 Determination of true density

The average true density was expressed as the ratio of weight of 10 grain samples to volume of toluene displaced, was determined by using the toluene displacement method. The volume of toluene (C_7H_8) displaced was found by immersing a weighed quantity of maize samples in the toluene (Barnwal *et al.*, 2012).

$$\text{True density, kg/m}^3 = \frac{\text{weight of 10 grains}}{\text{volume of toluene displaced in measuring flask}} \times 1000 \qquad \textbf{... (3.8)}$$

3.3.2.5 Determination of porosity

The porosity was calculated from bulk and true densities by the following equation (Mohsenin, 1970)

$$\text{Porosity} = (1 - \frac{\text{Bulk density}}{\text{True density}}) \times 100 \qquad \textbf{... (3.9)}$$

3.3.2.6 Determination of angle of repose

The angle of repose is the angle compared to the horizontal at which the material will stand when piled. This was determined by using the apparatus shown in Plate No. 3.2; consisting of a plywood box of 60 × 60 × 60 mm and two plates: fixed and adjustable. The box was filled with the sample, and then the adjustable plate was inclined gradually allowing the grains to follow and assume a natural slope, this was measured as emptying angle of repose (Tarighi *et al.,* 2011).

Plate 3.2. Apparatus used for measuring angle of repose.

3.3.2.7 Determination of static coefficient of friction

The static coefficient of friction of maize samples against three different surfaces, namely; plywood, glass and MS sheet were determined. The coefficient of friction was calculated from the following equation: (Tarighi *et al.,* 2011).

$$\mu = \tan \alpha \qquad \textbf{... (3.10)}$$

Where, μ = Static coefficient of friction.

α = Angle of repose, °.

3.4 MODIFIED ANGRAU HAND OPERATED MAIZE SHELLER

The hand operated maize sheller was fabricated at Vishwakarma Industries, Kattedan, Hyderabad (Plate No. 3.5).

3.4.1 Construction Features

3.4.1.1 Frame

The frame was made up of mild steel. The overall dimensions of frame were 92.5 cm length, 85 cm width and 136.5 cm height. The sheller unit was fixed to this framework. The frame has a bottom set, stand, flywheel.

3.4.1.2 Cylinder

It is made up of high carbon steel of 21 cm diameter. The length of cylinder was 86 cm having adjustable metal pegs/ spikes which are placed at a spacing of 9 cm in equally spaced in four rows which rotate along the cylinder (Plate No. 3.3) and separate grains from the cobs.

Plate 3.3. Cylinder in maize sheller.

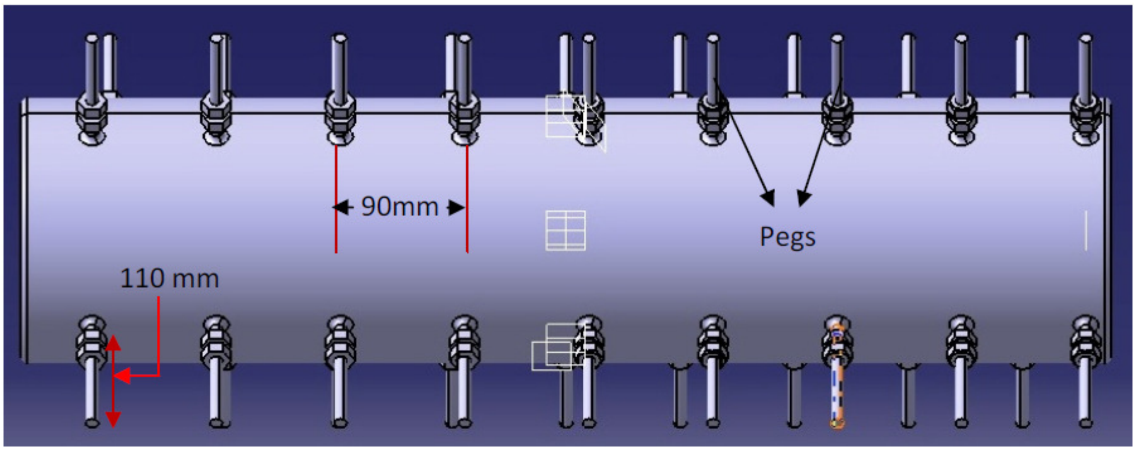


Figure 3.1 Schematic diagram of cylinder in maize sheller

3.4.1.3 Hopper

The hopper was fabricated in trapezoidal shape, using mild steel of 18 gauge thickness and dimensions of 28 cm length, 18 cm width and 39 cm height. It is placed on the outer casing for feeding the maize cobs.

3.4.1.4 Concave

The concave (Plate No. 3.4) was fabricated using 5 mm mild steel rods. The length of the concave was 91 cm with slotted opening size 30.3 x 2.5 cm. It was fabricated using two half round rings on which 5 mm mild steel rods were welded at spacing of 2.5 cm. The clearance between concave and cylinder was adjustable but normally it is around 2 to 3 cm.

Plate 3.4. Concave of maize sheller.

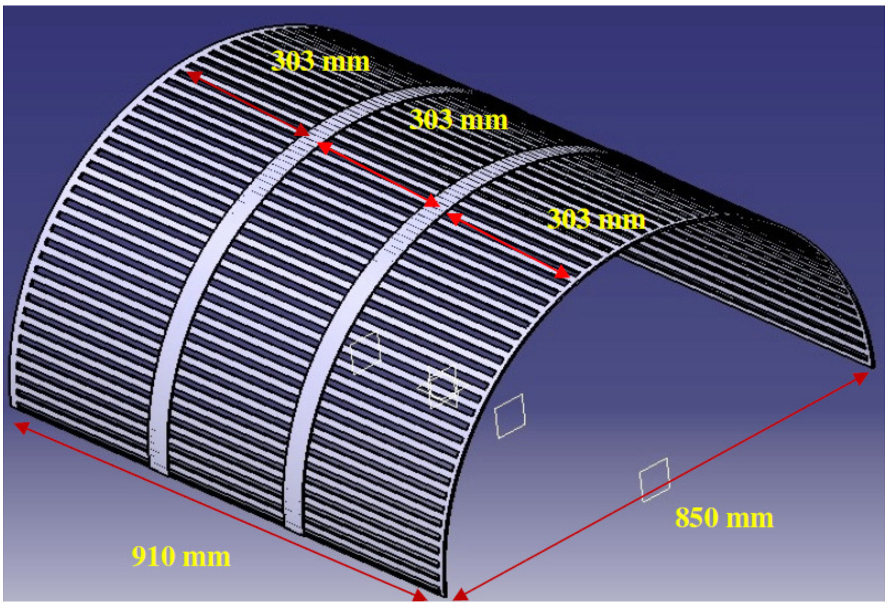


Figure 3.2 Schematic diagram of concave in maize sheller

3.4.1.5 Outer cover

It was made up of 16 gauge mild steel sheet and was bent to semicircular shape of diameter 43.3 cm and was rigidly fixed to give protection to the cylinder and to avoid grains spilling out. It has a provision for attaching to hopper. A flange was attached to it along the length to facilitate cleaning of inner cylinder.

3.4.1.6 Rotor shaft

It was the main key component of the machine on which flats of cylinder, bearing and fly wheel were mounted. A 10 cm bearing attached to the shaft was connected to the rotating pulley of 30 cm diameter using a ‘V’ belt. The power was transmitted from pulley to bearing through ‘V’ belt which will facilitate in rotation of fly wheel.

3.4.1.7 Outlet

The outlet is made up of metal sheet which is placed at the bottom of the shelling cylinder to collect the grains without shattering outside. The specifications of the modified ANGRAU hand operated maize sheller were compared with the existing ANGRAU hand maize sheller in table 3.1.

(a) Front view (b) Side view

Plate No. 3.5. Modified ANGRAU hand operated maize sheller

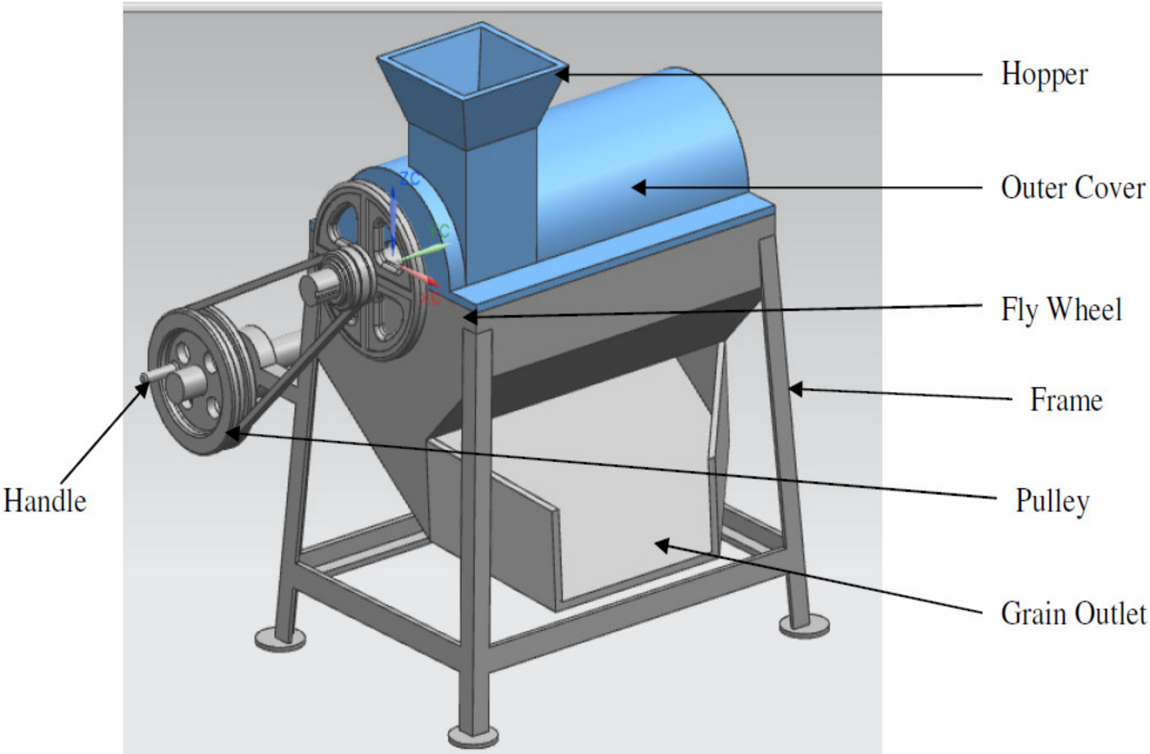
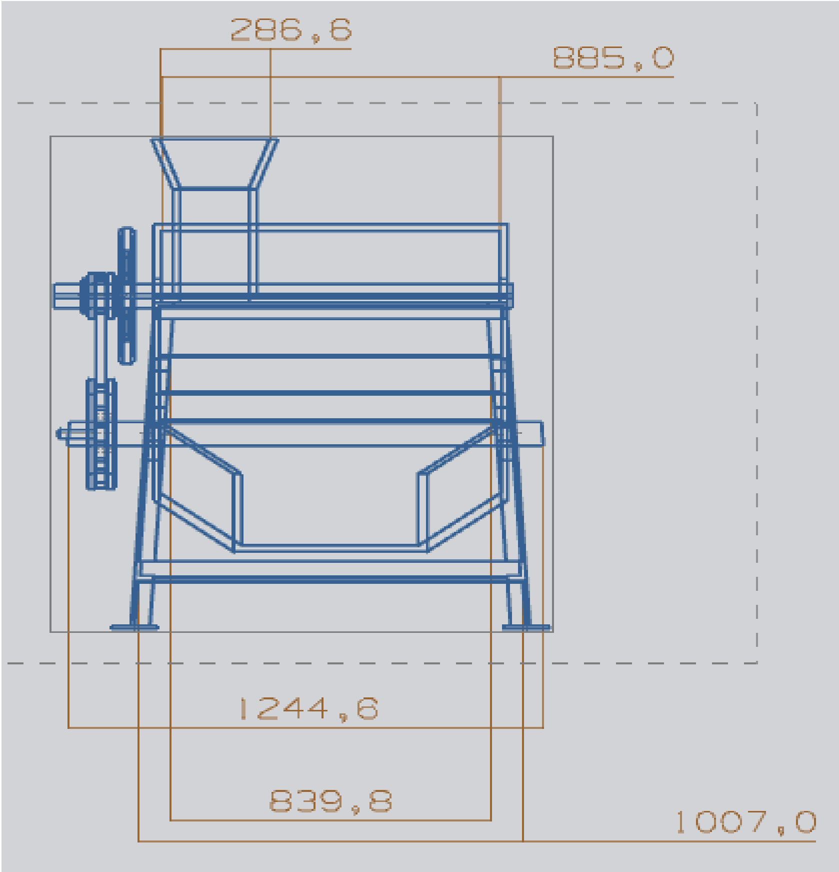


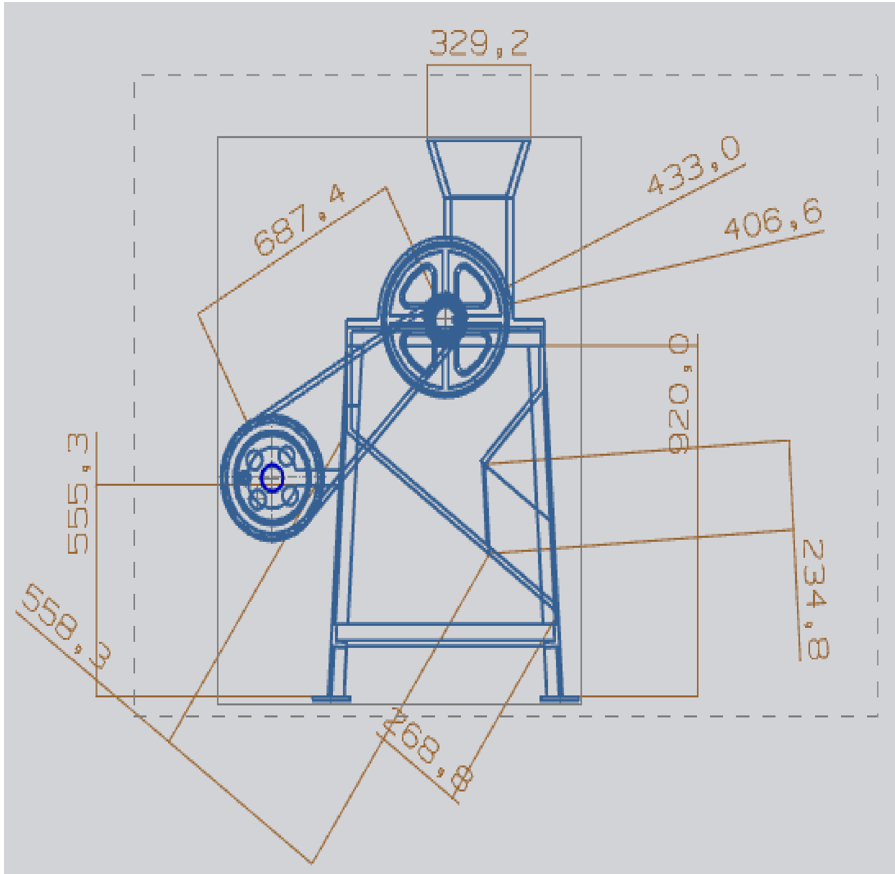
Figure 3.3. Overall view of modified ANGRAU hand operated maize sheller.

Table 3.1 Details of the construction features of existing and modified ANGRAU hand operated maize sheller

Particulars	Existing	Modified
Frame	74×78×159 cm	92.5×85×136.5 cm
Hopper	36×35×35 cm	28×18×39 cm
Outer cover	43.3 cm diameter	27.4 cm
Cylinder	13×59 cm	21×86 cm (Diameter×Length)
Concave	Concave with 61 cm length and 1cm diameter opening	Concave with 91 cm length and 2.5 cm slot opening
Cylinder concave clearance	Fixed (2 cm)	Adjustable (2 to 5 cm)
Transmission system	Gear	Belt and pulley
Fly wheel	No	16 inch diameter flywheel

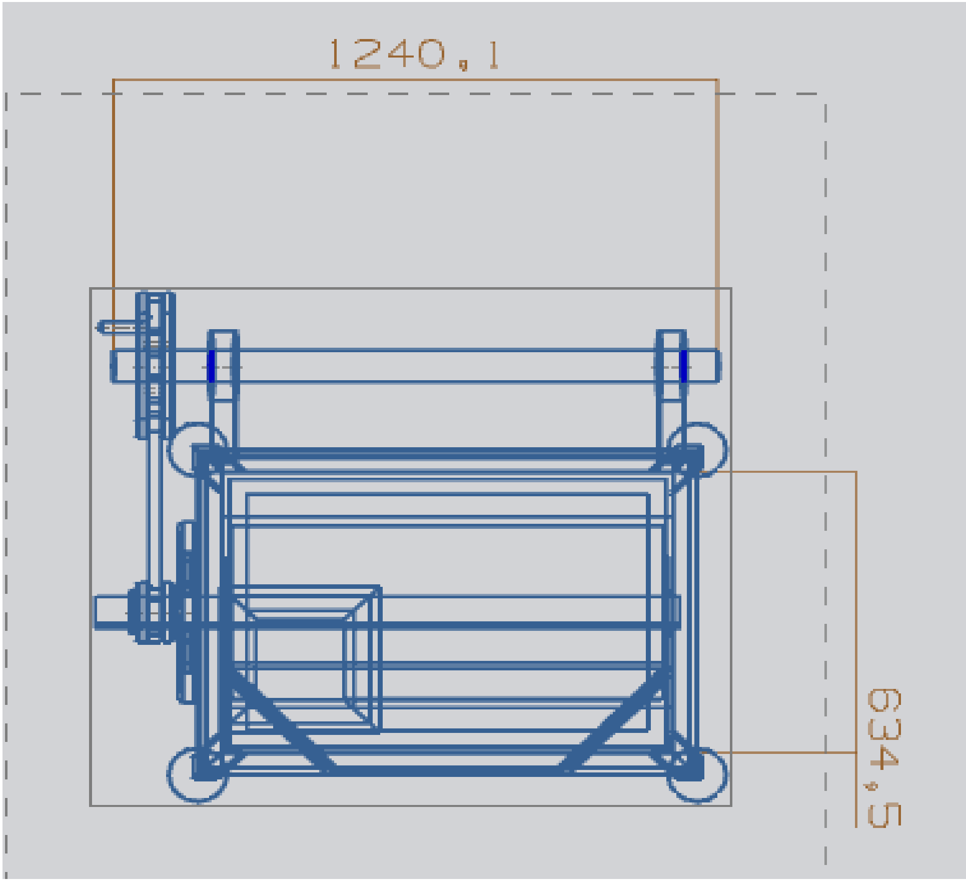


a) Front view



b) Side view

All dimensions are in mm



c) Top view

All dimensions are in mm

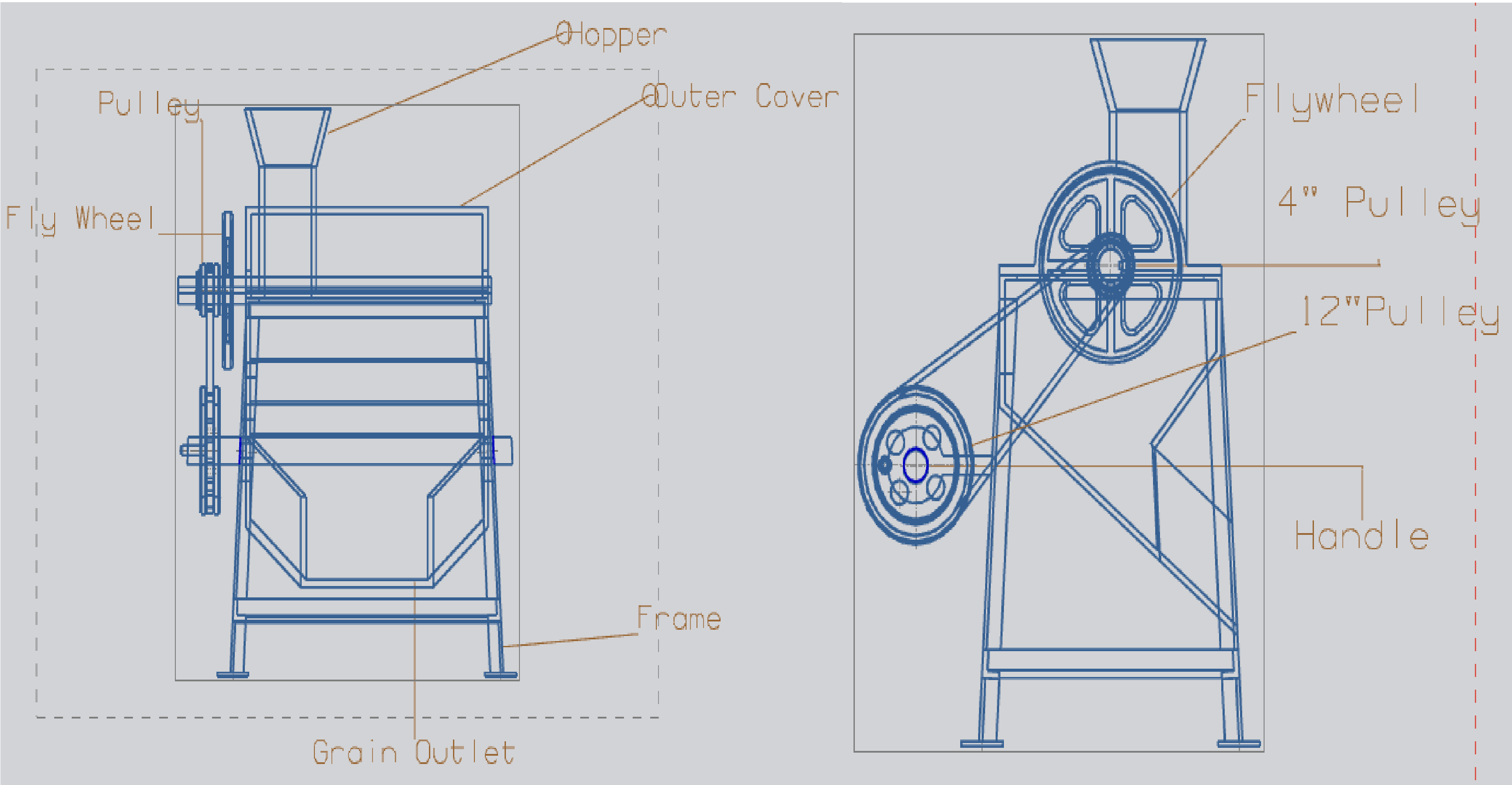


Figure 3.4. Schematic diagram of modified ANGRAU hand operated maize sheller

3.4.2 Working of the Sheller

The developed sheller was tested as per the standard procedures (Indian Standard test code for power maize sheller IS: 7052.1973) for combination of various moisture contents *i.e.,* 10, 12, 14, 16, 18 and 20 % w.b. and different feed rates *i.e.,* 120, 130 and 140 kg/h. These three feed rates corresponded to 300, 330 and 350 rpm of the cylinder, respectively. Before starting the actual testing, direction of rotation of pulleys was checked. The clearance between cylinder and concave was determined using vernier calipers. The cylinder speed was also recorded using a tachometer.

The maize cobs from each treatment combination samples were fed continuously through the hopper. The rotating beaters produced two kinds of forces namely impact and shearing which caused to remove grains from maize cobs and kernels were collected at the bottom end of the outlet. Two persons were engaged for these operations, one for feeding maize cobs at hopper and the other for rotating the pulley. The shelled grains were collected at the bottom of the outlet.

Weight of whole grains, broken grains and unshelled cobs from all outlets were recorded and time of operation to calculate feeding capacity, shelling efficiency and visible damage percentage, were also recorded.

3.4.3 Performance Evaluation of Existing and Modified ANGRAU Hand Operated Maize Sheller

The existing ANGRAU hand operated maize sheller was tested with maize variety (NANIYA) at six levels moisture contents ranging from 10 to 20 % w.b. at feed rate of 65 kg/h.(Both the machines were tested at feed rate of 65 kg/h as the maximum feed rate of existing ANGRAU hand operated maize sheller is 65 kg/h).

3.4.4 Performance Evaluation of Modified ANGRAU Hand Operated Maize Sheller

Even though, the physical properties of maize were determined at five levels of moisture content (12, 14, 16, 18, 20% w.b.), the performance evaluation of the machine was carried out at six levels of moisture content (10, 12, 14, 16, 18, 20% w.b.), to observe the performance evaluation of machine at lower moisture content i.e. 10% w.b. than the optimum moisture content i.e. 12% w.b. The modified ANGRAU hand operated maize sheller was tested with maize variety (RUDHIRA 145) at six levels moisture contents ranging from 10 to 20 % w.b. and feed rates of 120, 130 and 140 kg/h at 300, 330 and 350 rpm, respectively. The weight of whole grains, broken grains and unshelled cobs from all outlets were recorded at the time of operation and feeding capacity, shelling efficiency and broken percentage were determined as follows:

3.4.4.1 Efficiencies of sheller

3.4.4.1.1 Shelling efficiency

Percentage by weight of shelled grains from all outlets of the sheller with respect to total grain input and it is calculated by the following formulae. (IS: 7052.1973)

Shelling efficiency (%) = 100 – percentage of unshelled grains **… (3.11)**

3.4.4.2 Determination of total losses

3.4.4.2.1 Grain content

Ten samples (each sample not less than 1 kg) of the cobs were taken at random. The grain was separated manually and the ratio of weight of grain and shelled cob was taken as grain content. The average of the ten samples shall be taken as grain and shelled cob ratio (IS: 7052-1973).

3.4.4.2.2 Total grain input

Total grain input = Feed rate x Grain content, kg **… (3.12)**

3.4.4.2.3 Unshelled cobs

Unshelled grain from all outlets with respect to total grain input, expressed as percentage by weight (IS: 7052.1973).

Unshelled grain (%) =

$$\frac{100\ (\text{quantity of unshelled grain obtained from all outlets in kg})}{\text{total grain input in kg}} \quad \ldots \quad \textbf{(3.13)}$$

3.4.4.2.4 Visible damage

Visible damage grains from the specified grain outlet with respect to total grain received at outlet expressed as percentage by weight (IS:7052.1973).

$$\text{Visible Damage (\%)} = \frac{100 \times (\text{Broken grains from specified outlets in kg})}{\text{Total grain input in kg}} \quad \ldots \textbf{(3.14)}$$

3.5 MODIFIED TUBULAR HAND MAIZE SHELLER

Modified tubular hand maize sheller was a simple metal pipe of diameter 55 mm and length 75 mm with four tapering blades or vanes welded on the inner surface of the pipe equally spaced.

Shelling action of vanes was similar to the operation done by the fingers. The pipe was made of 18 guage thick mild steel sheet. The sheet was rolled over a cylindrical mandrel (to form the cylindrical shape) and was welded at the ends. The vanes were 75 mm in length and were tapered from a width of 15 to 10 mm. These vanes were bent in L shape and bottom portion of vane was welded to the inner surface of the cylinder. One leg of the vane was supported by the inner cylindrical face and the other was projected radially towards the centre and acted as the shelling element. These four vanes were placed at an equal interval of 90 degrees. It had two fins of 20 mm which extended outwards connected with two screws along with springs so that it was flexible for all the diameters of maize cobs.

The cob was pressed at the input end of the tube and sheller was rotated and simultaneously pushed forward. After shelling on same length, the shelled cob was pulled out from the output end with rotation. The corn should be at matured stage at the time of shelling. If immature cob was used, it resulted in heavy breakage of the pearls. When the size of the cobs varied widely, then a single tubular maize sheller did not work for all cobs. The sheller had a maximum working space at feeding end was 35 mm diameter and outlet end was 25 mm diameter.

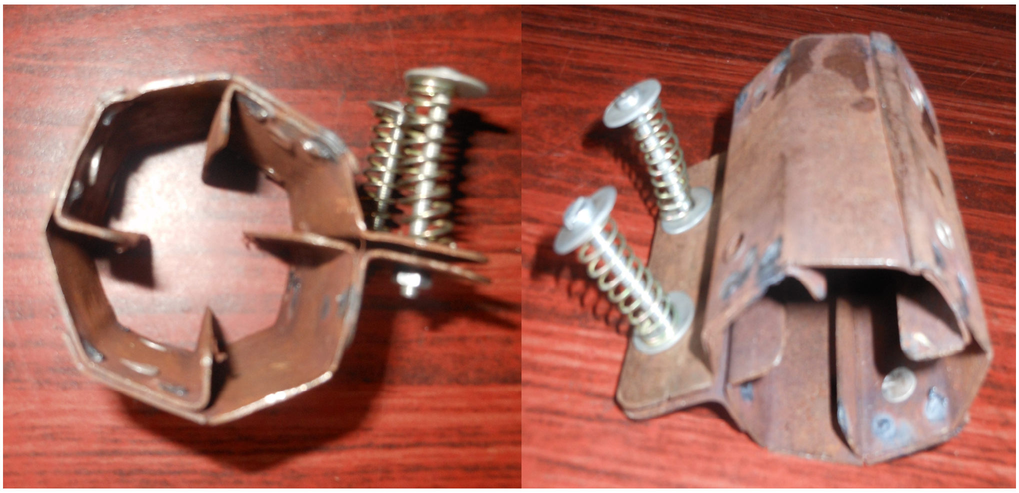


Plate No. 3.6. Modified tubular hand maize sheller.

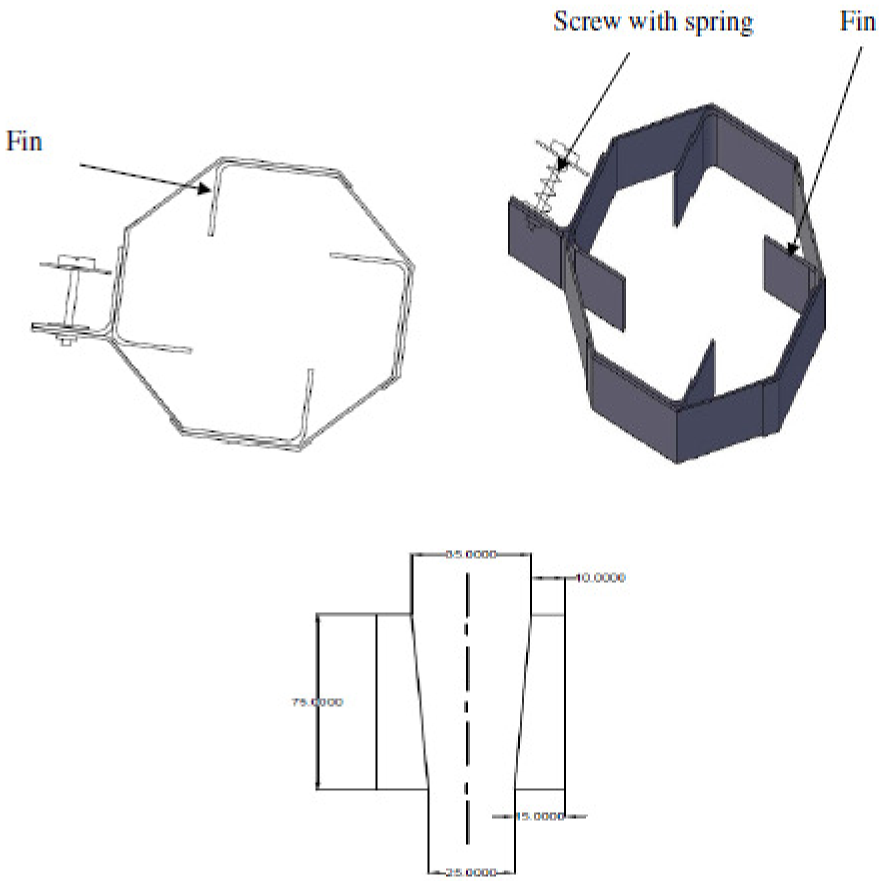


Figure 3.5. Schematic diagram of modified tubular maize sheller

Chapter IV

RESULTS AND DISCUSSION

Experiments leading to the "Modification of ANGRAU hand operated maize sheller for enhanced capacity" were conducted to fulfil the objectives of the project. The results pertaining to effect of moisture content on physical characteristics of maize and performance evaluation of existing and modified maize sheller at different moisture content levels are also presented and discussed in this chapter.

4.1 PHYSICAL CHARACTERISTICS OF MAIZE SAMPLES

4.1.1 Effect of Moisture Content on Principal Dimensions of Maize Samples

The length, breadth and thickness of ten varieties of maize samples viz., DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 were determined at each level of different moisture contents viz., 12, 14, 16, 18 and 20% w.b. The three axial dimensions for all the ten varieties were increased with increase in moisture content from 12 to 20% w.b. The increase in linear dimension may be due to the fact that as moisture content increases, these grains tend to swell due to moisture absorption (Sobukola *et al.,* 2013). Each principal dimension appeared to be linearly dependent on the moisture content are shown in Fig 4.1, 4.2 and 4.3.

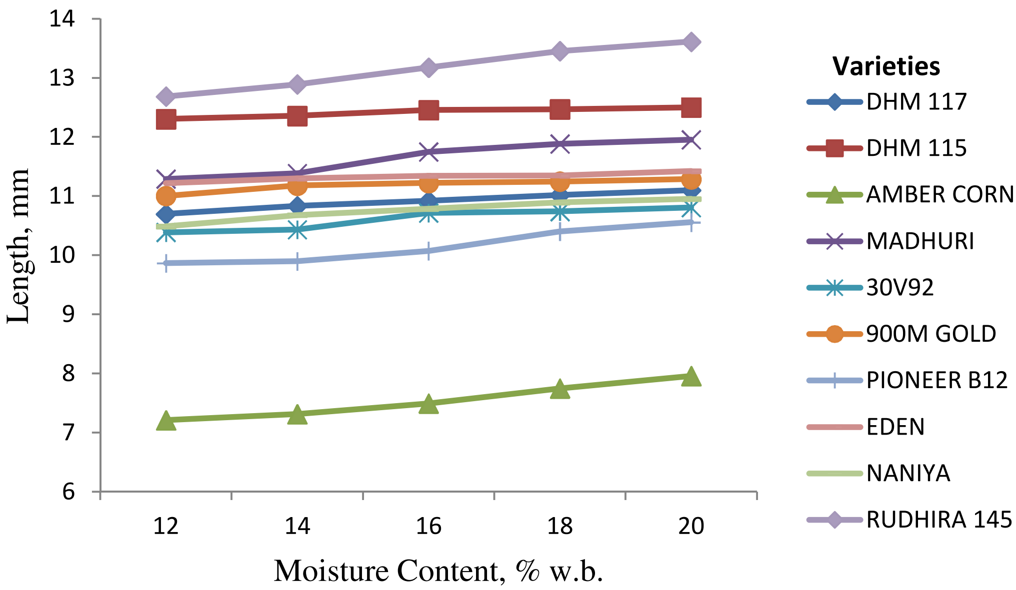


Figure 4.1. Effect of moisture content on length for different varieties of maize.

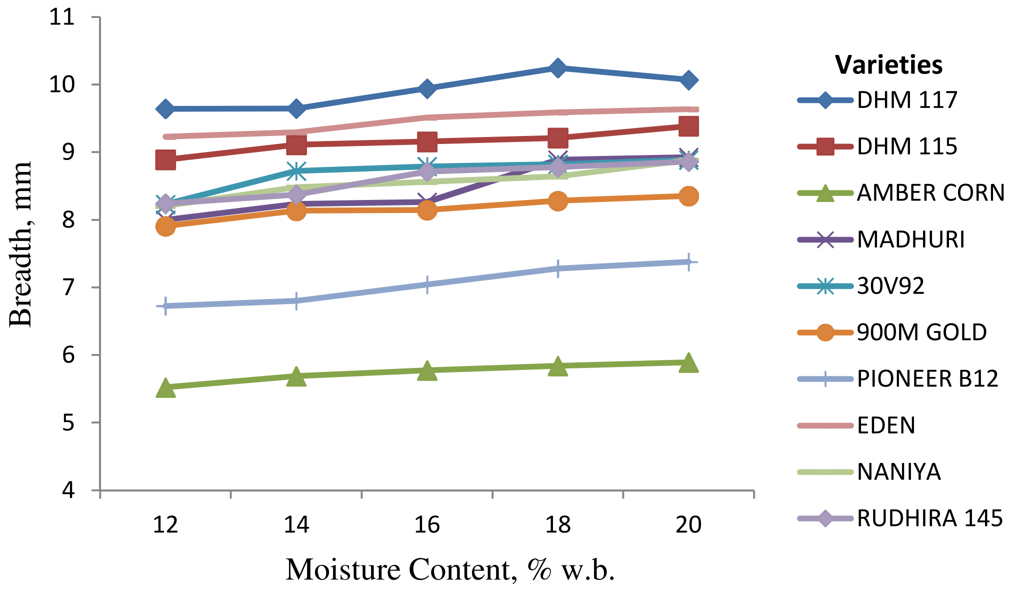


Figure 4.2. Effect of moisture content on breadth for different varieties of maize.

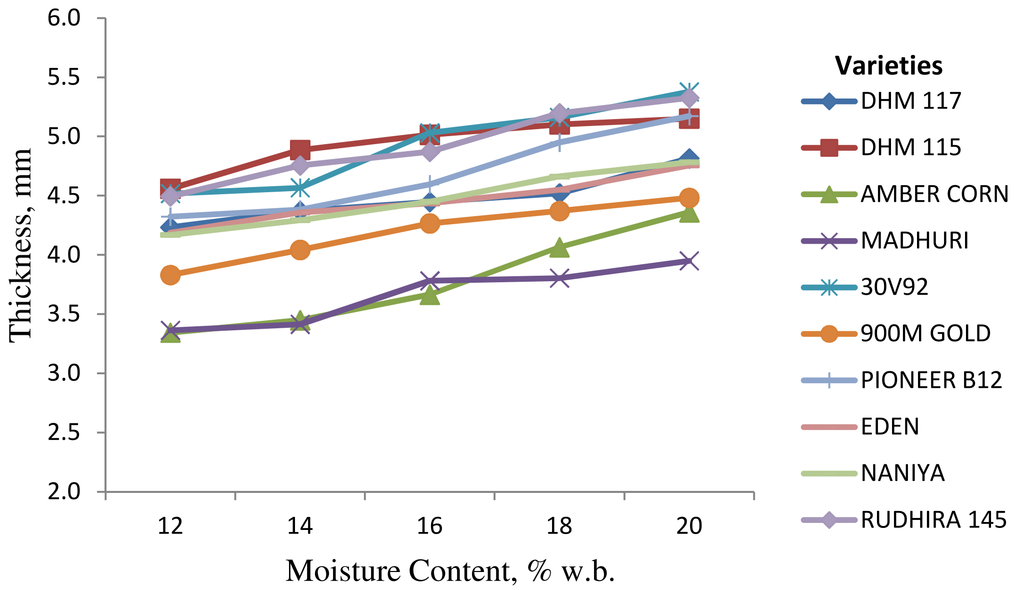


Figure 4.3. Effect of moisture content on thickness for different varieties of maize.

The percentage increase in length and thickness was maximum at 9.40% and 23.30% for AMBER CORN variety and percentage increase in length and thickness was minimum at 1.58% and 11.49% for DHM 115 variety. MADHURI variety recorded the maximum percentage increase in breadth (11.4%), while EDEN variety recorded the minimum percentage increase in breadth (4.24%) as moisture content increased from 12 to 20 % w.b.

4.1.2 Effect of Moisture Content on Sphericity of Maize Samples

The sphercity for ten varieties of maize samples viz., DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 were determined at each level of different moisture contents viz., 12, 14, 16, 18 and 20% w.b.

The sphericity of maize samples were influenced by its moisture content. It was noted that the sphericity of maize samples increased with the increase in moisture content. Since the sphericity depends on length, width and thickness of the grain, the magnitude of variation in sphericity depends on these factors only. The increase in the sphericity is due to moisture absorption and filling of capillaries and voids with moisture and subsequent swelling. As the moisture content increased, the length, width and thickness of grains were increased. Due to this, geometric mean diameter and sphercity were increased (Barnwal *et al*., 2012).

Variations in the sphericity for all the varieties of maize samples at different moisture content were shown in fig 4.4. It was observed that the sphericity for the varieties: DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 increased from 0.710 to 0.731, 0.619 to 0.649, 0.706 to 0.740, 0.594 to 0.625, 0.699 to 0.742, 0.629 to 0.662, 0.667 to 0.699, 0.672 to 0.704, 0.675 to 0.704 and 0.613 to 0.633 with increase in moisture content from 12 to 20 % w.b. Also, the variation in sphericity for different variety may be due to the physio chemical properties of the grains. Regression analysis of experimental data showed a linear correlation for sphericity with moisture content with very high coefficient of determination ($R^2 > 0.96$).

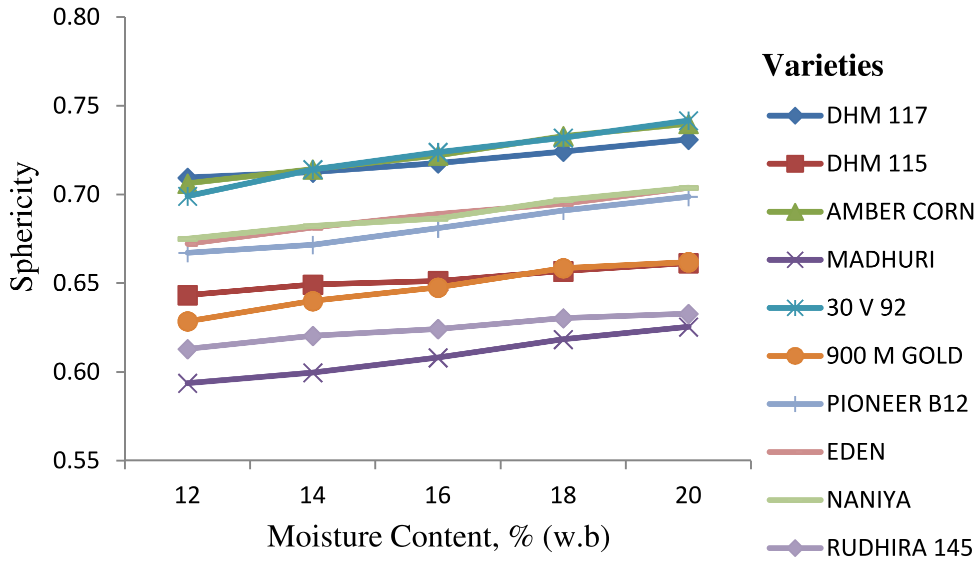


Figure 4.4. Effect of moisture content on sphercity for different varieties of maize.

The maximum and minimum per cent increment in sphericity was 5.74% and 2.73% for 30V92 and DHM 115 varieties, respectively as moisture content increased from 12 to 20 % w.b.

The sphericity versus moisture content for all the maize varaities showed linear trends (Eq No 4.1 to 4.10).

DHM 117	$\Phi = 0.0055M + 0.7026$	$R^2 = 0.9812$	**… (4.1)**
HM 115	$\Phi = 0.0075M + 0.6098$	$R^2 = 0.9693$	**… (4.2)**
AMBER CORN	$\Phi = 0.0086M + 0.6973$	$R^2 = 0.9961$	**… (4.3)**
MADHURI	$\Phi = 0.0082M + 0.5844$	$R^2 = 0.9931$	**… (4.4)**
30V92	$\Phi = 0.0103M + 0.6913$	$R^2 = 0.9854$	**… (4.5)**
900 M GOLD	$\Phi = 0.0085M + 0.6218$	$R^2 = 0.9765$	**… (4.6)**
PIONEER B12	$\Phi = 0.0083M + 0.6572$	$R^2 = 0.9874$	**… (4.7)**
EDEN	$\Phi = 0.0076M + 0.6653$	$R^2 = 0.9948$	**… (4.8)**
NANIYA	$\Phi = 0.0072M + 0.6674$	$R^2 = 0.9862$	**… (4.9)**
RUDHIRA 145	$\Phi = 0.005M + 0.6093$	$R^2 = 0.9757$	**… (4.10)**

Where M = Moisture content

The similar type of linear trend of sphericity with moisture content has been reported for maize and paddy grains (Barnwal *et al.,* 2012, Seifi *et al.,* 2010b and Zereiforush *et al.,* 2011).

4.1.3 Effect of Moisture Content on Volume of Maize Samples

The volume for ten varieties of maize samples viz., DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 were determined at each level of different moisture contents viz., 12, 14, 16, 18 and 20% w.b.

The grain volume of samples increased linearly with increase in moisture content from 12 to 20% w.b. as shown in fig 4.5. It was noted that the grain volume was increased for the varieties: DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 from 269.09 to 322.06, 269.79 to 314.48, 74.64 to 110.24, 191.11 to 260.27, 222.80 to 289.55, 199.16 to 244.26, 158.39 to 217.86, 264.68 to 310.78, 211.00 to 269.42 and 268.90 to 358.35 mm^3 with increase in moisture content from 12 to 20% w.b., respectively. This volumetric expansion may be attributed to the expansion in the dimensions which contributed to increase in weight of maize grains, thereby resulting to the increase in volume (Seifi *et al.,* 2010b). Regression analysis of experimental data showed a linear correlation for volume with moisture content with very high coefficient of determination ($R^2 > 0.95$).

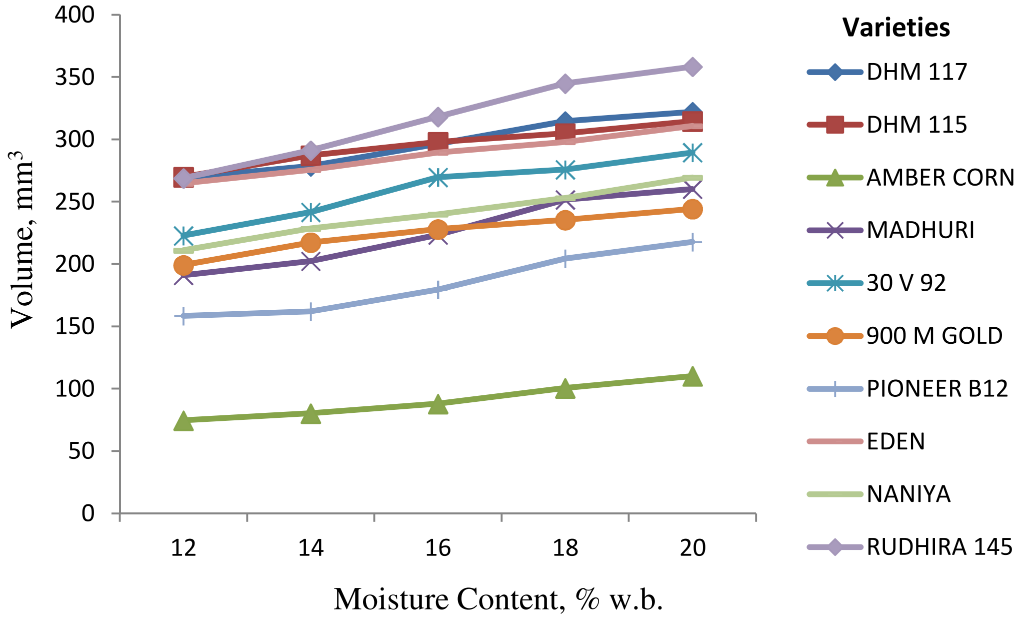


Figure 4.5. Effect of moisture content on volume for different varieties of maize.

The maximum and minimum per cent increment in volume was 26.57% and 14.21% for MADHURI and DHM 115 varieties, respectively as moisture content increased from 12 to 20% w.b.

The realtionship between volume and moisture content folllowed a linear trend for each of these varieties (Eq No 4.11 to 4.20).

DHM 117	$V = 14.194M + 253.54$	$R^2 = 0.9818$	**… (4.11)**
DHM 115	$V = 10.713M + 262.7$	$R^2 = 0.9704$	**… (4.12)**
AMBER CORN	$V = 9.1432M + 63.299$	$R^2 = 0.981$	**… (4.13)**
MADHURI	$V = 18.753M + 169.52$	$R^2 = 0.974$	**… (4.14)**
30V92	$V = 16.766M + 209.58$	$R^2 = 0.9571$	**… (4.15)**
900 M GOLD	$V = 10.82M + 192.35$	$R^2 = 0.9655$	**… (4.16)**
PIONEER B12	$V = 16.128M + 136.08$	$R^2 = 0.9565$	**… (4.17)**
EDEN	$V = 11.452M + 253.36$	$R^2 = 0.9964$	**… (4.18)**
NANIYA	$V = 14.138M + 197.93$	$R^2 = 0.9954$	**… (4.19)**
RUDHIRA 145	$V = 23.269M + 246.49$	$R^2 = 0.9897$	**… (4.20)**

The similar type of linear trend of volume with moisture content has been reported for rice, maize and soyabean (Kibar *et al.,* 2010, Seifi *et al.,* 2010.a and Kibar and Ozturk, 2008).

4.1.4 Effect of Moisture Content on Surface Area of Maize Samples

The surface area for ten varieties of maize samples viz., DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 were determined at each level of different moisture contents viz., 12, 14, 16, 18 and 20% w.b.

Surface area for all the varieties were increased linearly with increase in moisture content from 12 to 20% w.b. as shown in the fig 4.6. The increase in surface area is due to the increase in three principal dimensions of maize (Tavakoli *et al.,* 2009.b). The values of the surface area for DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 were increased from 179.36 to 206.05, 186.79 to 199.89, 81.50 to 108.24, 140.98 to 175.09, 165.82 to 201.30, 150.14 to 175.15, 135.96 to 170.04, 178.75 to 202.41, 157.62 to 187.16 and 188.06 to 232.27 mm^2 with increase in moisture content from 12 to 20% w.b., respectively. Regression analysis of experimental data showed a linear correlation for surface area with moisture content with very high coefficient of determination ($R^2 >$ 0.95).

The maximum and minimum per cent increment in surface area was 24.70% and 6.56% for AMBER CORN and DHM 115 varieties, respectively as moisture content increased from 12 to 20% w.b.

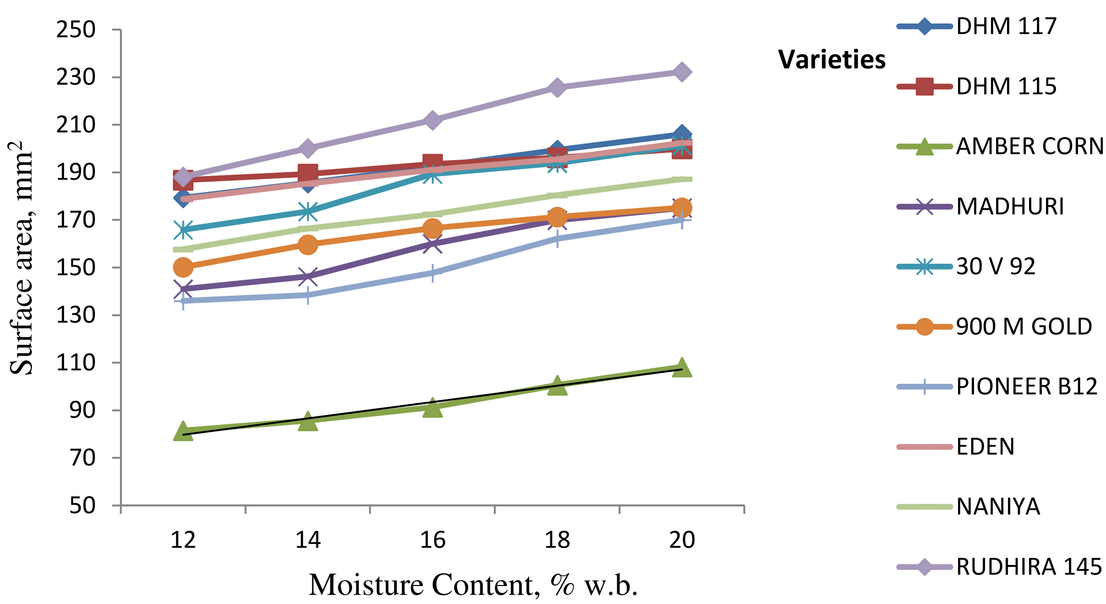


Figure 4.6. Effect of moisture content on surface area for different varieties of maize.

The realtionship between surface area and moisture content was linear and can be represented by the regression equations (4.21 to 4.30).

DHM 117	$S = 6.7277M + 172.33$	$R^2 = 0.9993$	**… (4.21)**
DHM 115	$S = 3.3036M + 183.22$	$R^2 = 0.9953$	**… (4.22)**
AMBER CORN	$S = 6.8514M + 72.899$	$R^2 = 0.9792$	**… (4.23)**
MADHURI	$S = 9.1927M + 130.84$	$R^2 = 0.976$	**… (4.24)**
30V92	$S = 9.1293M + 157.38$	$R^2 = 0.9675$	**… (4.25)**
900 M GOLD	$S = 6.1685M + 146.03$	$R^2 = 0.9671$	**… (4.26)**
PIONEER B12	$S = 9.1976M + 123.24$	$R^2 = 0.9564$	**… (4.27)**
EDEN	$S = 5.7495M + 173.31$	$R^2 = 0.9959$	**… (4.28)**
NANIYA	$S = 7.3049M + 150.89$	$R^2 = 0.9971$	**… (4.29)**
RUDHIRA 145	$S = 11.398M + 177.41$	$R^2 = 0.9906$	**… (4.30)**

The similar type of linear increasing trend in surface area with increase in moisture content has been reported for wheat, barnyard millet, barely and maize (Karimi *et al.,* 2009, Singh *et al.,* 2010, Tavakoli *et al.,* 2009.a and Seifi *et al.,* 2010.b).

4.1.5 Effect of Moisture Content on Bulk Density of Maize Samples

The bulk density for ten varieties of maize samples viz., DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 were determined at each level of different moisture contents viz., 12, 14, 16, 18 and 20% w.b.

Variations of bulk density at different levels of moisture content are shown in fig 4.7. Bulk density for all the varieties of maize grains decreased with the increase in moisture content from 12 to 20% w.b. The decrease in bulk density is due to increase in inter-granular space with increase in moisture content (Coskun *et al.,* 2005). The values of the bulk density for DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 decreased from 791.00 to 755.40, 764.76 to 755.27, 761.87 to 712.40, 440.43 to 404.65, 736.50 to 681.27, 758.80 to 721.87, 736.63 to 677.27, 831.40 to 771.17, 730.93 to 684.44 and 828.00 to 787.87 kg/m^3 with the increase in moisture content from 12 to 20% w.b., respectively. Regression analysis of experimental data showed a linear correlation for bulk density with moisture content with very high coefficient of determination ($R^2 > 0.92$).

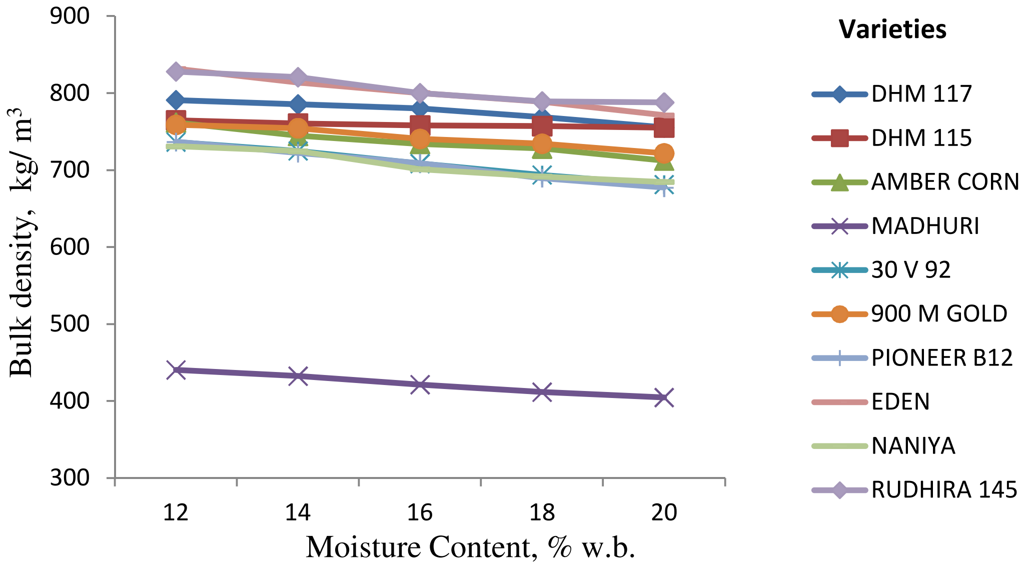


Figure 4.7. Effect of moisture content on bulk density for different varieties of maize.

The maximum and minimum per cent decrease in bulk density of 8.12% and 1.24% for MADHURI and DHM 115 varieties, respectively as moisture content increased from 12 to 20% w.b.

Equations from 4.31 to 4.40 show the linear correaltion between bulk density and its moisture contents.

DHM 117	$\rho_b = -8.77M + 802.5$	$R^2 = 0.9544$	**… (4.31)**
DHM 115	$\rho_b = -2.2393M + 765.91$	$R^2 = 0.937$	**… (4.32)**
AMBER CORN	$\rho_b = -11.529M + 770.8$	$R^2 = 0.9748$	**… (4.33)**
MADHURI	$\rho_b = -9.2267M + 449.78$	$R^2 = 0.9952$	**… (4.34)**
30V92	$\rho_b = -14.157M + 751.46$	$R^2 = 0.9973$	**… (4.35)**

900 M GOLD $\rho_b = -9.402M + 770.21$ $R^2 = 0.9779$ **… (4.36)**

PIONEER B12 $\rho_b = -15.123M + 752.28$ $R^2 = 0.9959$ **… (4.37)**

EDEN $\rho_b = -14.547M + 844.6$ $R^2 = 0.9946$ **… (4.38)**

NANIYA $\rho_b = -12.601M + 744.33$ $R^2 = 0.9545$ **… (4.39)**

RUDHIRA 145 $\rho_b = -11.18M + 838.67$ $R^2 = 0.9295$ **… (4.40)**

Similar type of linear trend decrease in bulk density with increase in moisture content have been reported for sweet corn, maize and bean seed (Coskun *et al.,* 2005 Barnwal *et al.,* 2012 and Firouzi *et al.,* 2012).

4.1.6 Effect of Moisture Content on True Density of Maize Samples

The true density for ten varieties of maize samples viz., DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 were determined at each level of different moisture contents viz., 12, 14, 16, 18 and 20% w.b.

Variations of true density at different levels moisture content are shown in fig 4.8. True density for all the varieties of maize grains were increased with increase in moisture content from 12 to 20% w.b. The increase in the true density with increase in the moisture content was mainly due to the larger increase in grain volume as compared to their masses (Kibar *et al.,* 2010). The values of true density for DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 increased from 11183.46 to 1232.57, 1109.13 to 1210.00, 971.94 to 1149.21, 811.34 to 873.51, 1050.97 to 1093.27, 1205.15 to 1230.57, 1145.46 to 1180.73, 1260.42 to 1366.67, 1142.71 to 1200.56 and 1272.13 to 1314.11 kg/m^3 with increase in moisture content from 12 to 20% w.b. respectively. Regression analysis of experimental data showed a polynomial correlation for true density with moisture content with very high coefficient of determination ($R^2 > 0.88$).

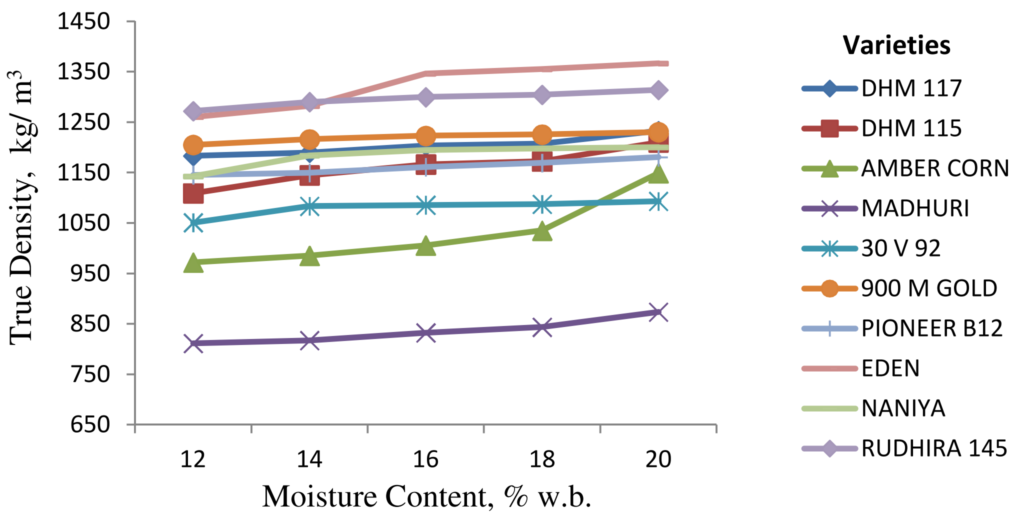


Figure 4.8. Effect of moisture content on true density for different varieties of maize.

The maximum and minimum per cent increment in true density was 15.43% and 2.07% for AMBER CORN and 900M GOLD varieties, respectively as moisture content increased from 12 to 20% w.b.

Equations from 4.41 to 4.50 show a non linear realtionship between true density and moisture contents.

DHM 117 $\rho_t = 1.9528M^2 - 0.1341M + 1182.3$ ($R^2 = 0.9632$) **… (4.41)**

DHM 115 $\rho_t = -0.8447M^2 + 28.007M + 1085.8$ ($R^2 = 0.9561$) **… (4.42)**

AMBER CORN $\rho_t = 15.022M^2 - 49.699M + 1013.3$ ($R^2 = 0.9663$) **… (4.43)**

MADHURI $\rho_t = 3.1502M^2 - 3.8475M + 812.5$ ($R^2 = 0.9885$) **… (4.44)**

30V92 $\rho_t = -3.8535M^2 + 31.975M + 1026.6$ ($R^2 = 0.8865$) **… (4.45)**

900 M GOLD $\rho_t = -1.1742M^2 + 13.079M + 1193.8$ ($R^2 = 0.9879$) **… (4.46)**

PIONEER B12 $\rho_t = 0.8361M^2 + 4.0431M + 1139.9$ ($R^2 = 0.993$) **… (4.47)**

EDEN $\rho_t = -5.4421M^2 + 61.203M + 1198.5$ ($R^2 = 0.9447$) **… (4.48)**

NANIYA $\rho_t = -6.0481M^2 + 49.206M + 1102.9$ ($R^2 = 0.9566$) **… (4.49)**

RUDHIRA 145 $\rho_t = -1.5823M^2 + 19.331M + 1255.6$ ($R^2 = 0.9821$) **… (4.50)**

Similar increasing trends in true density with increase in moisture contents were reported for rice, corn, sweet corn and barnyard millet and kernal (Kibar *et al.,* 2010, Seifi *et al.,* 2010.a, Coskun *et al.,* 2005 and Singh *et al.,* 2010).

4.1.7 Effect of Moisture Content on Porosity of Maize Samples

The porosity of maize samples viz., DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 were determined at each level of different moisture contents viz., 12, 14, 16, 18 and 20% w.b.

Since porosity depends upon the bulk density and true densities, magnitude of variation in porosity depends on these factors only. With the increase in the moisture content from 12 to 20% w.b., the porosity also increased as shown in fig 4.9. It was observed that the Porosity for DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 increased from 33.14 to 38.64, 30.70 to 37.56, 21.42 to 37.85, 45.66 to 53.22, 29.91 to 37.65, 37.01 to 41.27, 35.67 to 42.64, 33.95 to 43.57, 36.02 to 42.97 and 34.90 to 39.98 % with increase in moisture content from 12 to 20% w.b., respectively. Regression analysis of experimental data showed a linear correlation for porosity with moisture content with very high coefficient of determination ($R^2 > 0.91$).

The maximum and minimum per cent increment in porosity was 43.23% and 10.31% for AMBER CORN and 900M GOLD variety was observed as compared to other varieties as moisture content increased from 12 to 20% w.b.

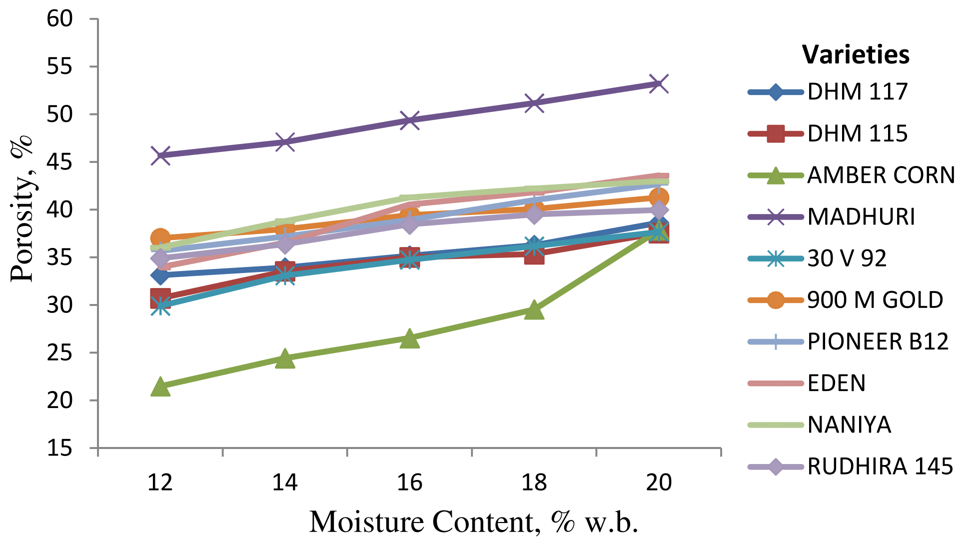


Figure 4.9. Effect of moisture content on porosity for different varieties of maize.

Equations from 4.51 to 4.60 show a linear realtionship between porosity and moisture contents.

DHM 117	$\varepsilon = 1.3359M + 31.425$	$R^2 = 0.9595$	**… (4.51)**
DHM 115	$\varepsilon = 1.5518M + 29.775$	$R^2 = 0.9392$	**… (4.52)**
AMBER CORN	$\varepsilon = 3.7841M + 16.621$	$R^2 = 0.9134$	**… (4.53)**
MADHURI	$\varepsilon = 1.9172M + 43.547$	$R^2 = 0.9963$	**… (4.54)**
30V92	$\varepsilon = 1.857M + 28.74$	$R^2 = 0.9662$	**… (4.55)**
900 M GOLD	$\varepsilon = 1.0628M + 35.962$	$R^2 = 0.9905$	**… (4.56)**
PIONEER B12	$\varepsilon = 1.7764M + 33.756$	$R^2 = 0.9974$	**… (4.57)**
EDEN	$\varepsilon = 2.451M + 31.926$	$R^2 = 0.9646$	**… (4.58)**
NANIYA	$\varepsilon = 1.7309M + 35.07$	$R^2 = 0.9272$	**… (4.59)**
RUDHIRA 145	$\varepsilon = 1.3307M + 33.846$	$R^2 = 0.9538$	**… (4.60)**

Similar increasing trends in porosity with increase in moisture content were reported by for barely, Cucurbit seeds and rice (Ozturk and Esen 2008, Milani *et al.,* 2007 and Kibar *et al.,*2010).

4.1.8 Effect of Moisture Content on Thousand Grain Weight of Maize Samples

Variations of thousand grain weight at different levels of moisture content are shown in fig 4.10. It was observed that the thousand grain weight of all varieties of maize samples increased with increase in moisture content from 12 to 20% w.b. The increase in thousand grain weight is due to the increase in absorption of moisture by the maize grains from 12 to 20% w.b. (Baryeh and Mangope, 2002). The values of thousand grain weight for DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 increased from 335.87 to 373.73, 310.81 to 349.97, 95.52 to 116.67, 127.64 to 137.97, 248.69 to 291.70, 232.87 to 270.42, 238.07 to 276.17, 204.46 to 232.47, 183.30 to 206.80 and 337.58 to 356.21 g with increase in moisture content from 12 to 20% w.b.

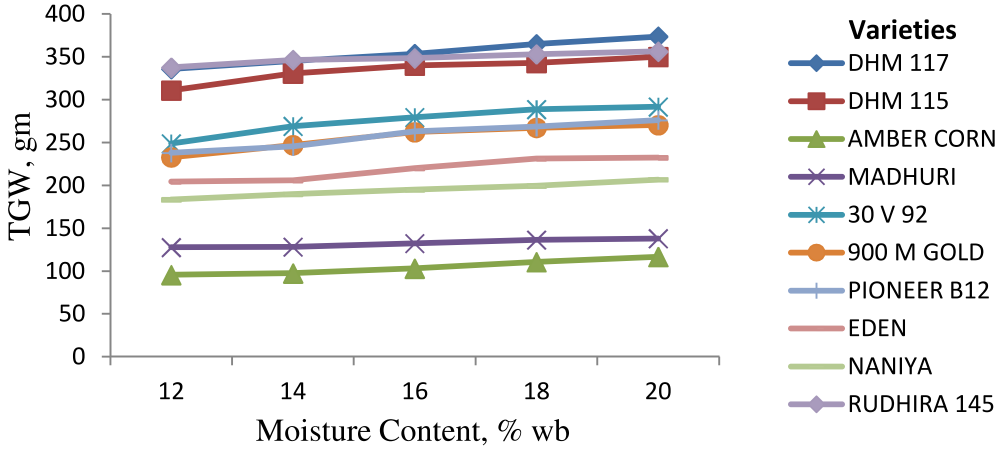


Figure 4.10. Effect of moisture content on thousand grain weight for different varieties of maize.

Regression analysis of experimental data showed a linear correlation for thousand grain weight with moisture content with very high coefficient of determination (R^2 > 0.91).

The maximum and minimum per cent increment in thousand grain weight was 18.12% and 5.23% for AMBER CORN and RUDHIRA 145 varieties, respectively as moisture content increased from 12 to 20% w.b.

Equations from 4.61 to 4.70 shows a linear realtionship between thousand grain weight and moisture contents.

DHM 117	$TGW = 9.571M + 325.92$	$R^2 = 0.9978$	**… (4.61)**
DHM 115	$TGW = 9.0477M + 307.75$	$R^2 = 0.8948$	**… (4.62)**
AMBER CORN	$TGW = 5.5553M + 87.985$	$R^2 = 0.9669$	**… (4.63)**
MADHURI	$TGW = 2.8863M + 123.86$	$R^2 = 0.9544$	**… (4.64)**
30V92	$TGW = 10.564M + 243.82$	$R^2 = 0.9209$	**… (4.65)**
900 M GOLD	$TGW = 9.5373M + 227.35$	$R^2 = 0.9192$	**… (4.66)**
PIONEER B12	$TGW = 9.9263M + 228.46$	$R^2 = 0.9646$	**… (4.67)**
EDEN	$TGW = 8.1123M + 194.44$	$R^2 = 0.9268$	**… (4.68)**
NANIYA	$TGW = 5.69M + 177.8$	$R^2 = 0.9953$	**… (4.69)**
RUDHIRA 145	$TGW = 4.3843M + 335.21$	$R^2 = 0.9445$	**… (4.70)**

Similar increasing trends in thousand grain weight with increase in moisture content were reported for pearl millet, corn, sweet corn and pigeon pea (Ojediran *et al.*, 2010, Seifi *et al.*, 2010.b, Coskun *et al.*, 2005 and Baryeh *et al.,* 2002).

4.1.9 Effect of Moisture Content on Angle of Repose with Different Surface Materials

Variations of angle of repose on mild steel surface at different levels of moisture content are shown in fig 4.11. It was noted, with increase in moisture content from 12 to 20% w.b., angle of repose for all varieties of maize increases. This is due to the fact that increasing in moisture absorption leads to create a larger surface layer of moisture surrounding the particles, holding the aggregate of grains together by producing higher surface tension (Sobukola *et al.*, 2013). The angle of repose on M.S steel surface for DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 increased from 24.33 to 38.33, 22.67 to 35, 27.33 to 34.67, 25.67 to 34.67, 25.67 to 35, 25.67 to 36.67, 28 to 39.67, 25.33 to 34, 24 to 32.33 and 20.33 to 25.33° with increase in moisture content from 12 to 20% w.b., respectively. Regression analysis of experimental data showed a linear correlation for angle of repose for mild steel with moisture content with very high coefficient of determination (R^2>0.96).

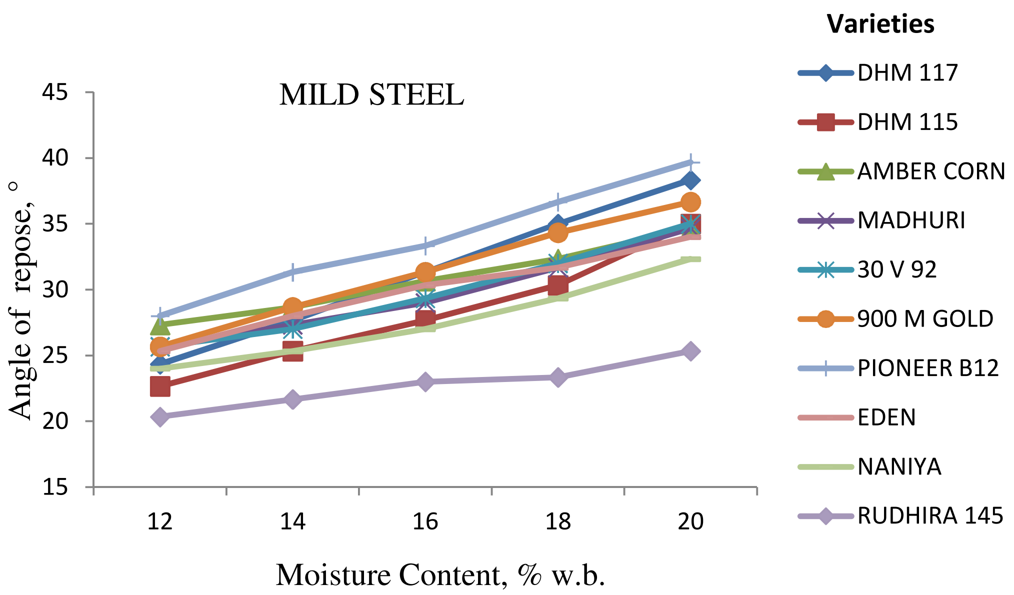


Figure 4.11. Effect of moisture content on angle of repose for different varieties of maize on M.S. Steel surface.

The maximum and minimum per cent increment in angle of repose for mild steel surface was 36.52% and 19.74% for DHM 117 and RUDHIRA 145 varieties, respectively as moisture content increased from 12 to 20% w.b.

Equations from 4.71 to 4.80 shows a linear realtionship between angle of repose and moisture contents on mild steel surface.

DHM 117	$\theta = 3.5333M + 20.733$	$R^2 = 0.9996$	**… (4.71)**
DHM 115	$\theta = 2.9667M + 19.3$	$R^2 = 0.9789$	**… (4.72)**
AMBER CORN	$\theta = 1.8333M + 25.233$	$R^2 = 0.9925$	**… (4.73)**
MADHURI	$\theta = 2.2333M + 22.967$	$R^2 = 0.9801$	**… (4.74)**
30V92	$\theta = 2.3667M + 22.7$	$R^2 = 0.9823$	**… (4.75)**
900 M GOLD	$\theta = 2.7667M + 23.033$	$R^2 = 0.9984$	**… (4.76)**
PIONEER B12	$\theta = 2.8667M + 25.2$	$R^2 = 0.9952$	**… (4.77)**
EDEN	$\theta = 2.1M + 23.567$	$R^2 = 0.9893$	**… (4.78)**
NANIYA	$\theta = 2.0667M + 21.4$	$R^2 = 0.9737$	**… (4.79)**
RUDHIRA 145	$\theta = 1.1667M + 19.233$	$R^2 = 0.9661$	**… (4.80)**

Variations of angle of repose on plywood surface at different levels of moisture content are shown in fig 4.12. It was noted, with increase in moisture content from 12 to 20 % w.b., angle of repose for all varieties of maize increases. The angle of repose on Plywood for DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 increased from 25.33 to 39.33, 24.33 to 38.33, 28.33 to 37.33, 27.33 to 37.67, 27.33 to 37.33, 27 to 37, 29.33 to 39.33, 26.33 to 36.67, 25.33 to 35.33 and 24.67 to 30.67° with increase in moisture content from 12 to 20% w.b., respectively. Regression analysis of experimental data showed a linear correlation for angle of repose for ply wood with moisture content with very high coefficient of determination (R^2>0.97).

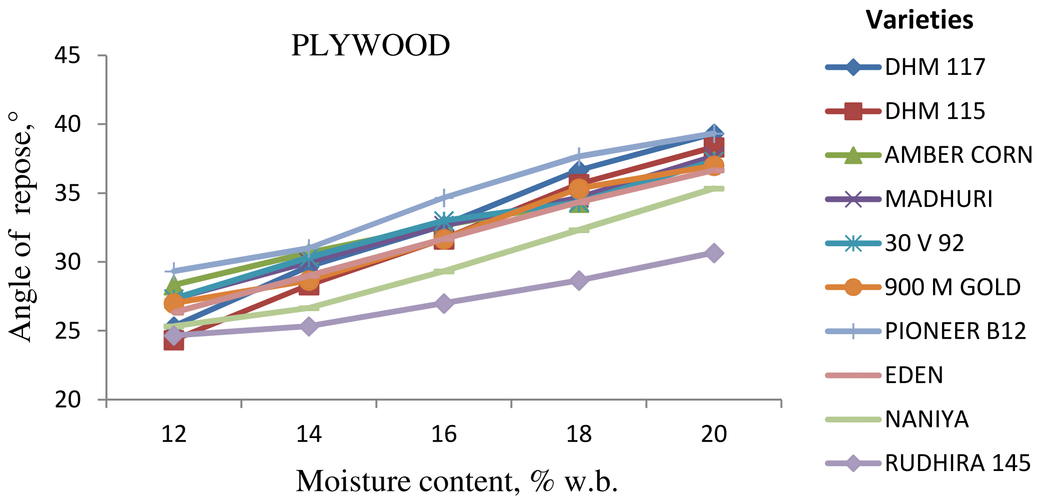


Figure 4.12. Effect of moisture content on angle of repose for different varieties of maize on plywood surface.

The maximum and minimum per cent increment in angle of repose for ply wood surface was 36.52% and 19.57% for DHM 115 and RUDHIRA 145 varieties, respectively as moisture content increased from 12 to 20% w.b.

Equations from 4.81 to 4.90 shows a linear realtionship between between angle of repose and moisture contents on plywood surface.

DHM 117	$\theta = 3.5M + 22.233$	$R^2 = 0.9943$	**… (4.81)**
DHM 115	$\theta = 3.5333M + 21.067$	$R^2 = 0.9961$	**… (4.82)**
AMBER CORN	$\theta = 2.1667M + 26.167$	$R^2 = 0.9918$	**… (4.83)**
MADHURI	$\theta = 2.5333M + 24.867$	$R^2 = 0.9972$	**… (4.84)**
30V92	$\theta = 2.4M + 25.267$	$R^2 = 0.9871$	**… (4.85)**
900 M GOLD	$\theta = 2.6667M + 23.933$	$R^2 = 0.9834$	**… (4.86)**
PIONEER B12	$\theta = 2.6667M + 26.4$	$R^2 = 0.9834$	**… (4.87)**
EDEN	$\theta = 2.6M + 23.8$	$R^2 = 0.9993$	**… (4.88)**
NANIYA	$\theta = 2.5667M + 22.1$	$R^2 = 0.9829$	**… (4.89)**
RUDHIRA 145	$\theta = 1.5333M + 22.667$	$R^2 = 0.976$	**… (4.90)**

Variations of angle of repose on glass surface at different levels of moisture content are shown in fig 4.13. It was observed that the angle of repose was increased with increase in moisture content from 12 to 20% w.b. The values of angle of repose on glass surface for DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 increased from 24 to 32, 21 to 27.33, 26.67 to 33.33, 24.33 to 31.67, 24.33 to 31.67, 24 to 30.67, 26.33 to 32, 24 to 31.33, 23.67 to 30 and 17.33 to 22° with increase in moisture content from 12 to 20% w.b., respectively. Regression analysis of experimental data showed a linear correlation for angle of repose for glass with moisture content with very high coefficient of determination ($R^2 > 0.92$).

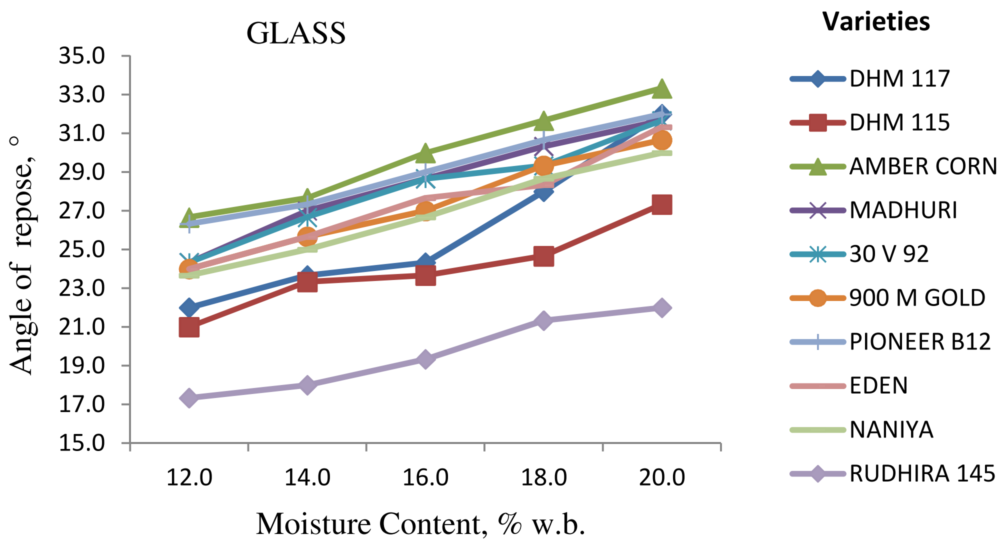


Figure 4.13. Effect of moisture content on angle of repose for different varieties of maize on glass surface.

The maximum and minimum per cent increment in angle of repose for glass surface was 31.25% and 19.71% for DHM 117 and PIONEER B12 varieties, respectively as moisture content increased from 12 to 20 % w.b.

Equations from 4.91 to 4.100 shows a linear realtionship between angle of repose and moisture contents on glass surface.

DHM 117	$\theta = 2.4333M + 18.7$	$R^2 = 0.922$	**… (4.91)**
DHM 115	$\theta = 1.4M + 19.8$	$R^2 = 0.9284$	**… (4.92)**
AMBER CORN	$\theta = 1.7333M + 24.667$	$R^2 = 0.9898$	**… (4.93)**

MADHURI	$\theta = 1.8M + 23$	$R^2 = 0.9825$	**… (4.94)**
30V92	$\theta = 1.7333M + 22.933$	$R^2 = 0.9755$	**… (4.95)**
900 M GOLD	$\theta = 1.7M + 22.233$	$R^2 = 0.9927$	**… (4.96)**
PIONEER B12	$\theta = 1.4667M + 24.667$	$R^2 = 0.9938$	**… (4.97)**
EDEN	$\theta = 1.7333M + 22.2$	$R^2 = 0.9699$	**… (4.98)**
NANIYA	$\theta = 1.6333M + 21.9$	$R^2 =0.9954$	**… (4.99)**
RUDHIRA 145	$\theta = 1.2667M + 15.8$	$R^2 = 0.9704$	**… (4.100)**

Similar increasing trends in angle of repose with increase in moisture contents were reported for maize by (Sobukola *et al.*, 2013, Seifi *et al.*, 2010.a, Barnwal *et al.,* 2012).

4.1.10 Effect of Moisture Content on Coefficient of Static Friction with Different Surface Materials

Variations of coefficient of static friction on mild steel surface at different levels of moisture content are shown in fig 4.14. It was noted, with increase in moisture content from 12 to 20% w.b., coefficient of static friction for all varieties of maize increases. This is so because of increased moisture content may result in an increase in adhesion characteristics and roughness of the surface of maize (Sobukola *et al.*, 2013). The Coefficient of static friction for DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 increased from 0.45 to 0.79, 0.42 to 0.70, 0.52 to 0.69, 0.48 to 0.69, 0.48 to 0.70, 0.48 to 0.75, 0.53 to 0.83, 0.47 to 0.68, 0.45 to 0.63 and 0.37 to 0.47 with increase in moisture content from 12 to 20% w.b., respectively. Regression analysis of experimental data showed a linear correlation for coefficient of static friction for mild steel with moisture content with very high coefficient of determination ($R^2 > 0.96$).

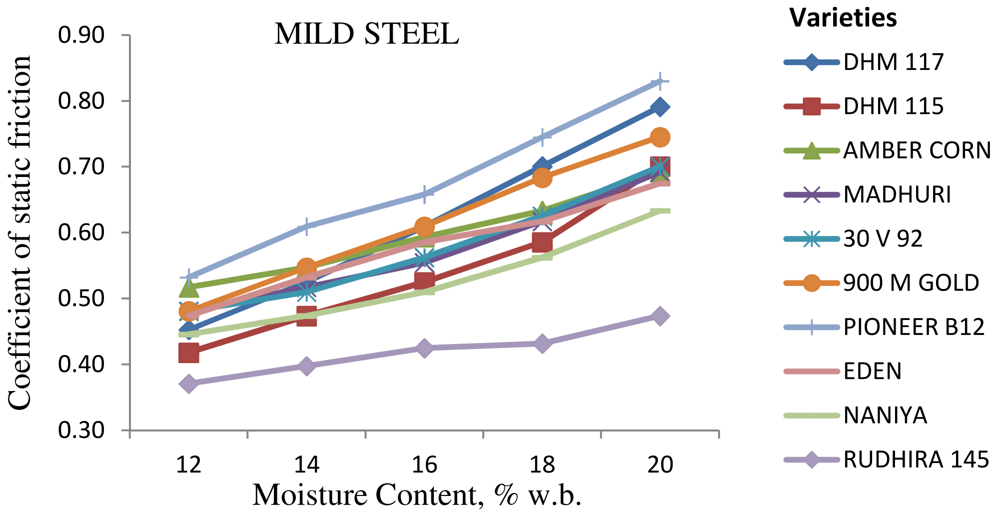


Figure 4.14. Effect of moisture content on coefficient of static friction for different varieties of maize on M.S. Steel surface.

The maximum and minimum per cent increment in coefficient of static friction for mild steel surface was 42.81% and 21.75% for DHM 117 and PIONEER B12 varieties, respectively as moisture content increased from 12 to 20 % w.b.

Equations from 4.101 to 4.110 shows a linear realtionship between static coefficient of friction and moisture content on mild steel surface.

DHM 117	$\mu_{st} = 0.0854M + 0.3595$	$R^2 = 0.9979$	**… (4.101)**
DHM 115	$\mu_{st} = 0.0677M + 0.3372$	$R^2 = 0.9675$	… **(4.102)**
AMBER CORN	$\mu_{st} = 0.0436M + 0.4658$	$R^2 = 0.9886$	**… (4.103)**
MADHURI	$\mu_{st} = 0.0522M + 0.4156$	$R^2 = 0.9723$	**… (4.104)**
30V92	$\mu_{st} = 0.0555M + 0.4092$	$R^2 = 0.9752$	**… (4.105)**
900 M GOLD	$\mu_{st} = 0.0665M + 0.4136$	$R^2 = 0.9993$	**… (4.106)**
PIONEER B12	$\mu_{st} = 0.0732M + 0.4552$	$R^2 = 0.9919$	**… (4.107)**
EDEN	$\mu_{st} = 0.0488M + 0.4303$	$R^2 = 0.992$	**… (4.108)**
NANIYA	$\mu_{st} = 0.0464M + 0.3856$	$R^2 = 0.9663$	**… (4.109)**
RUDHIRA 145	$\mu_{st} = 0.024M + 0.3477$	$R^2 = 0.9646$	**… (4.110)**

Similarly, with increase in moisture content from 12 to 20% w.b., the Coefficient of static friction for maize grains on ply wood surface were increased as shown in the fig 4.15. The Coefficient of static friction for DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 increased from 0.47 to 0.82, 0.45 to 0.79, 0.54 to 0.76, 0.52 to 0.77, 0.52 to 0.76, 0.51 to 0.75, 0.56 to 0.82, 0.50 to 0.75, 0.47 to 0.71 and 0.46 to 0.59 with increase in moisture content from 12 to 20% w.b., respectively. Regression analysis of experimental data showed a linear correlation for coefficient of static friction for plywood with moisture content with very high coefficient of determination ($R^2 > 0.97$).

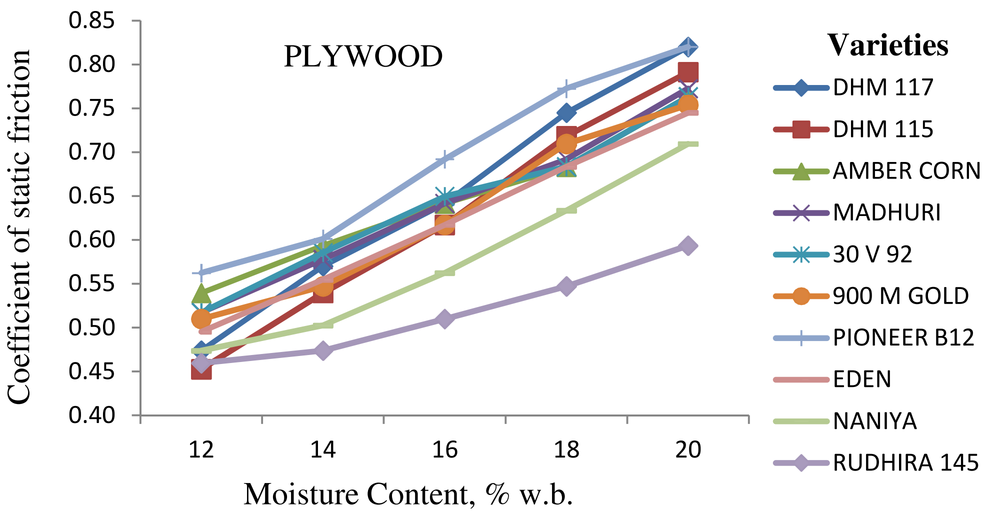


Figure 4.15. Effect of moisture content on coefficient of static friction for different varieties of maize on plywood surface.

The maximum and minimum per cent increment in coefficient of static friction for ply wood surface was 42.81% and 22.56% for DHM 115 and PIONEER B12 varieties, respectively as moisture content increased from 12 to 20% w.b.

Equations from 4.111 to 4.120 shows a linear realtionship between coefficient of static friction on plywood surface and moisture contents.

DHM 117 $\mu_{pw} = 0.0868M + 0.3897$ $R^2 = 0.9973$ **… (4.111)**

DHM 115 $\mu_{pw} = 0.0856M + 0.3668$ $R^2 = 0.9981$ **… (4.112)**

AMBER CORN $\mu_{pw} = 0.0538M + 0.4829$ $R^2 = 0.9875$ **… (4.113)**

MADHURI $\mu_{pw} = 0.0625M + 0.4527$ $R^2 = 0.9956$ **… (4.114)**

30V92	$\mu_{pw} = 0.059M + 0.4628$	$R^2 = 0.9884$	**… (4.115)**
900 M GOLD	$\mu_{pw} = 0.065M + 0.4323$	$R^2 = 0.9815$	**… (4.116)**
PIONEER B12	$\mu_{pw} = 0.0687M + 0.4835$	$R^2 = 0.9844$	**… (4.117)**
EDEN	$\mu_{pw} = 0.0628M + 0.4306$	$R^2 = 0.9997$	**… (4.118)**
NANIYA	$\mu_{pw} = 0.0602M + 0.3956$	$R^2 = 0.9766$	**… (4.119)**
RUDHIRA 145	$\mu_{pw} = 0.0341M + 0.4143$	$R^2 = 0.9721$	**… (4.120)**

Similarly, with increase in moisture content from 12 to 20% w.b., the Coefficent of static friction for maize grains on glass surface were increased as shown in the fig 4.16. The Coefficent of static friction for DHM 117, DHMM 115, AMBER CORN, MADHURI, 30V92, 900M GOLD, PIONEER B12, EDEN, NANIYA and RUDHIRA 145 increased from 0.40 to 0.63, 0.38 to 0.52, 0.50 to 0.66, 0.45 to 0.62, 0.45 to 0.62, 0.45 to 0.59, 0.50 to 0.63, 0.45 to 0.61, 0.44 to 0.58 and 0.31 to 0.40 with increase in moisture content from 12 to 20% w.b., respectively. Regression analysis of experimental data showed a linear correlation for coefficient of static friction for glass with moisture content with very high coefficient of determination ($R^2 > 0.91$).

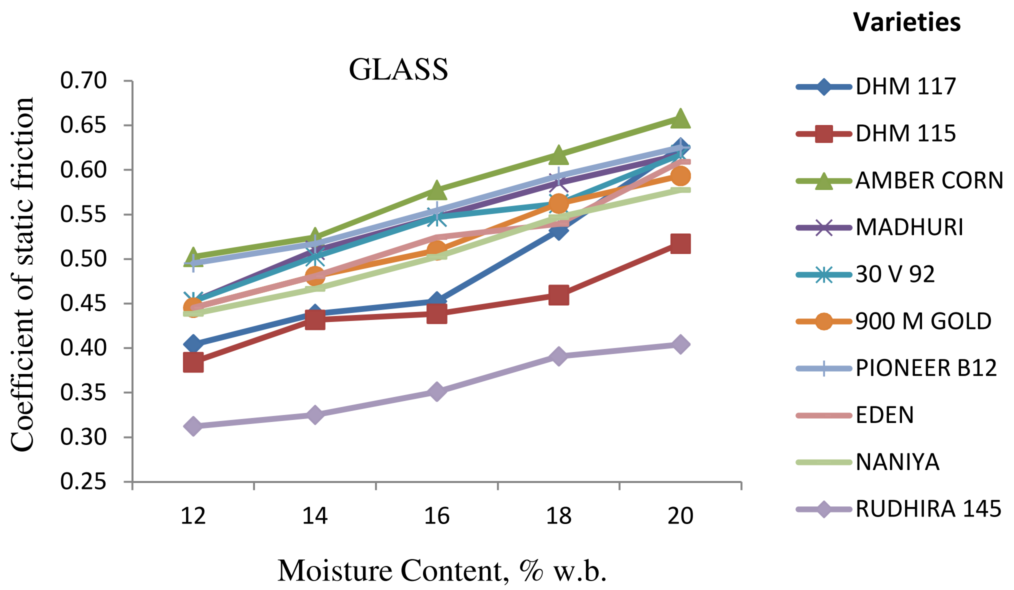


Figure 4.16. Effect of moisture content on coefficient of static friction for different varieties of maize on glass surface.

The maximum and minimum per cent increment in coefficient of static friction for glass surface was 35.35% and 20.79% for DHM 117 and PIONEER B12 varieties, respectively as moisture content increased from 12 to 20% w.b.

Equations from 4.121 to 4.130 shows a linear realtionship between static coefficient of friction on glass surface and moisture contents.

DHM 117	$\mu_{gl} = 0.0535M + 0.3298$	$R^2 = 0.9113$	**… (4.121)**
DHM 115	$\mu_{gl} = 0.0294M + 0.358$	$R^2 = 0.9251$	**… (4.122)**
AMBER CORN	$\mu_{gl} = 0.0404M + 0.4548$	$R^2 = 0.9891$	**… (4.123)**
MADHURI	$\mu_{gl} = 0.0405M + 0.4208$	$R^2 = 0.9874$	**… (4.124)**
30V92	$\mu_{gl} = 0.0389M + 0.4195$	$R^2 = 0.9771$	**… (4.125)**
900 M GOLD	$\mu_{gl} = 0.0377M + 0.4052$	$R^2 = 0.9917$	**… (4.126)**
PIONEER B12	$\mu_{gl} = 0.0336M + 0.4563$	$R^2 = 0.9927$	**… (4.127)**
EDEN	$\mu_{gl} = 0.0386M + 0.404$	$R^2 = 0.9657$	**… (4.128)**
NANIYA	$\mu_{gl} = 0.0359M + 0.3988$	$R^2 = 0.9947$	**… (4.129)**
RUDHIRA 145	$\mu_{gl} = 0.025M + 0.2818$	$R^2 = 0.9696$	**… (4.130)**

Similar increasing trends in coefficient of static friction with increase in moisture contents were reported for maize by (Sobukola *et al.*, 2013, Seifi *et al.*, 2010.a and Barnwal *et al.,* 2012).

4.2. PERFORMANCE EVALUATION OF EXISTING AND MODIFIED ANGRAU HAND OPERATED MAIZE SHELLER

The existing and modified ANGRAU hand operated maize sheller were tested at six levels of moisture contents ranging from 10 to 20% w.b. at feed rate of 65 kg/h. The results were analysed for shelling efficiency, unshelled grain (%) and visible damage (%) with respect to different moisture contents.

4.2.1 Shelling Efficiency

The shelling efficiency of modified ANGRAU hand operated maize sheller was found to be higher as compared to existing ANGRAU hand operated maize sheller at all moisture contents at feed rate of 65 kg/h. The shelling efficiency (99.31%) is higher as compared to existing ANGRAU hand operated maize sheller (80.06%) at moisture content of 10 % w.b. Similarly the shelling efficiency percentages for existing and modified shellers are 98.75% & 79.97%, 97.96% & 79.00%, 95.84% & 77.77%, 90.33% & 75.98%, and 88.05% & 74.58% at moisture contents of 12, 14, 16, 18 and 20 % w.b., respectively.

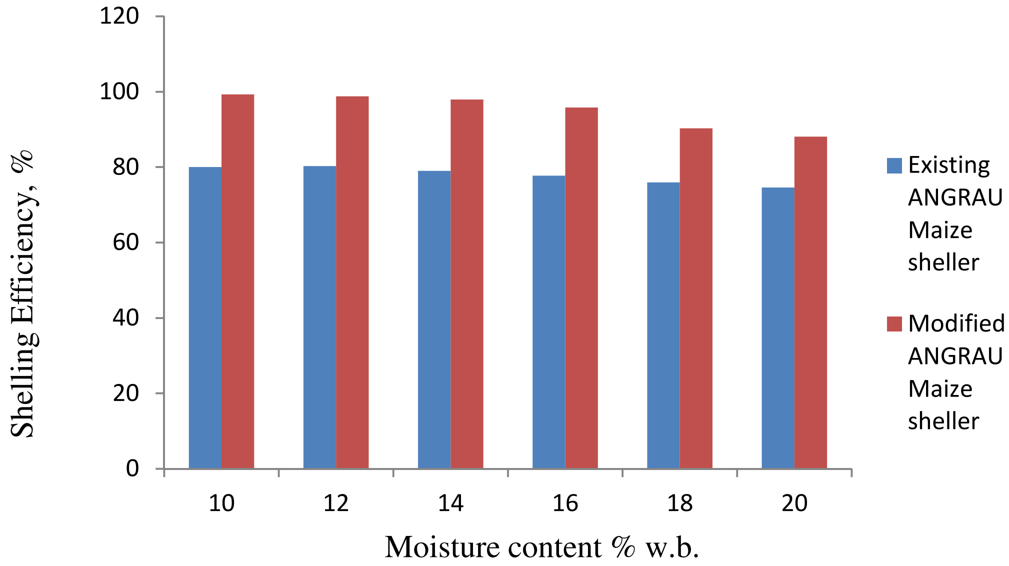


Figure 4.17. Shelling efficiency at different moisture contents for both existing and modified ANGRAU maize sheller.

4.2.2 Unshelled Grains Percentage

The unshelled grains percentage of modified ANGRAU hand operated maize sheller was found to be lower as compared to existing ANGRAU hand operated maize sheller at all moisture contents at feed rate of 65 kg/h. The unshelled grains percentage (0.69%) is lower as compared to existing ANGRAU hand operated maize sheller (19.94%) at moisture content of 10 % w.b. Similarly the unshelled grains percentages for existing and modified shellers are 1.25% & 19.74%, 2.04% & 20.99%, 4.16% & 22.23%, 9.67% & 24.02% and 11.95% & 25.42% at moisture contents of 12, 14, 16, 18 and 20 % w.b., respectively.

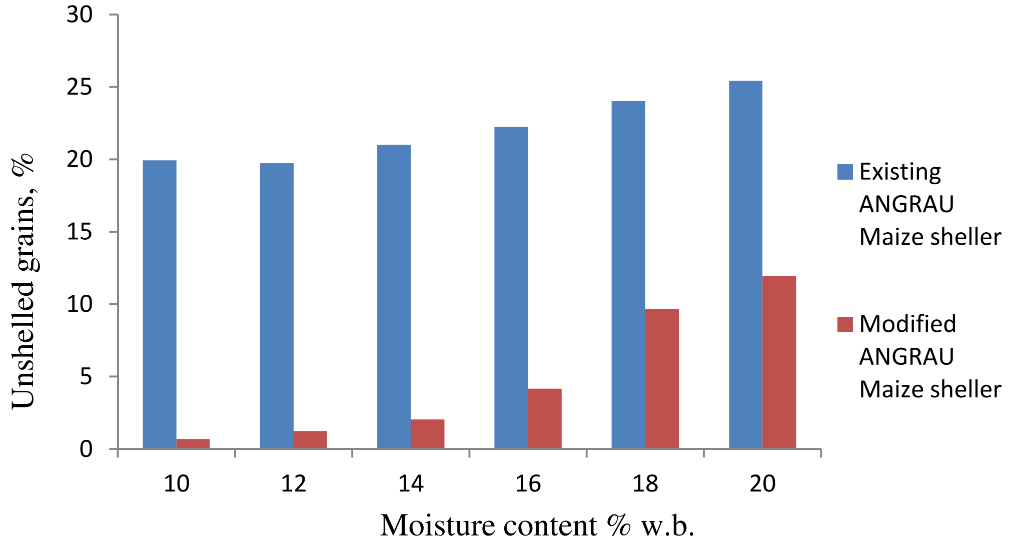


Figure 4.18. Unshelled grain percentage at different moisture contents for both existing and modified ANGRAU maize sheller.

4.2.3 Visible Damage Percentage

The visible damage percentage of modified ANGRAU hand operated maize sheller was found to be lower as compared to existing ANGRAU hand operated maize sheller at all moisture contents at feed rate of 65 kg/h. The visible damage percentage (1.21%) is lower as compared to existing ANGRAU hand operated maize sheller (2.05%) at moisture content of 12 % w.b. Similarly the visible damage percentages for existing and modified shellers are 2.09% & 2.42%, 2.36% & 3.17%, 3.52% & 5.12%, 4.17% & 7.32%, and 5.70% & 9.71% at moisture contents of 10, 14, 16, 18 and 20 % w.b., respectively.

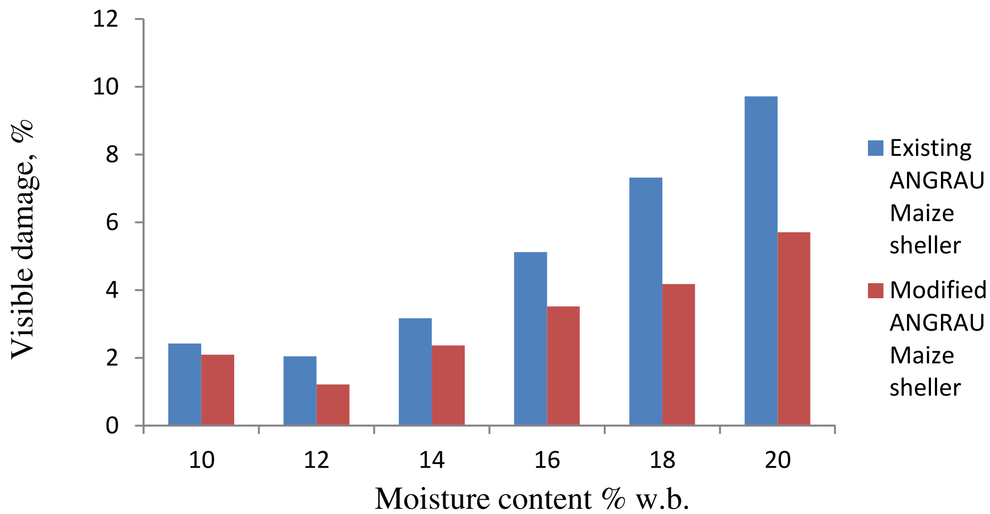


Figure 4.19. Visible damage percentage at different moisture contents for both existing and modified ANGRAU maize sheller.

4.2.2 Performance Evaluation of Modified ANGRAU Hand Operated Maize Sheller

The results were analysed with respect to effect of different moisture content and different feeding rate on shelling efficiency, unshelled grain (%) and visible damage (%).

4.2.2.1 Shelling efficiency at different feed rates

Variations in maize shelling efficiency with respect to different treatment combinations were shown in fig. 4.20. The shelling efficiency was found higher (99.71%) maize at moisture content 10% w.b. with feeding rate of 130 kg/h as compared to other combination treatments. The shelling efficiency decreased with increase in moisture content at each feeding rate (Alonge and Adegbulugbe, 2000). Shelling efficiency decreased by increasing grain moisture content were the grains cannot be separated easily and as a result, the percentage at unshelled grains increased. It was also observed that at each moisture content, the shelling efficiency at 130 kg/h feed rate is higher, followed by 140 kg/h and 120 kg/h feed rates.

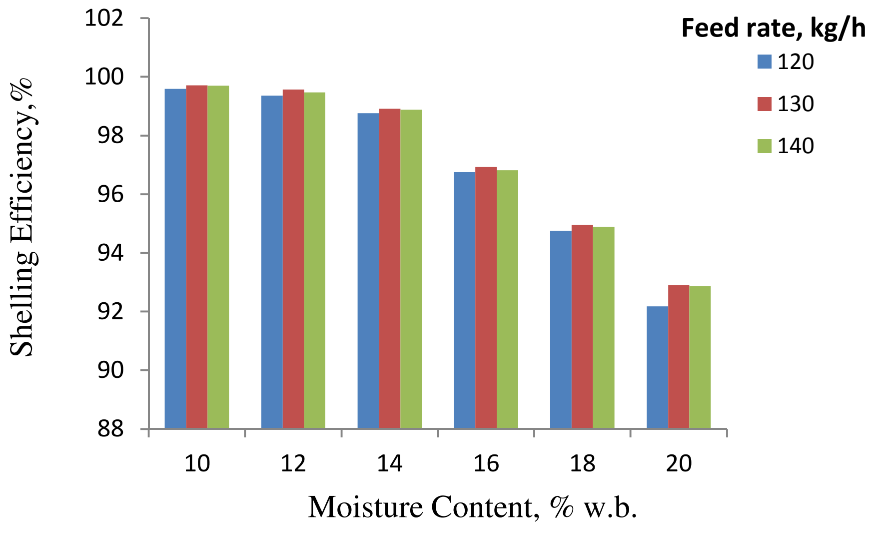


Figure 4.20. Shelling efficiency under different feed rates.

4.2.2.2 Unshelled grains

Variations in unshelled grains with respect to different treatment combinations were shown in fig. 4.21. The unshelled grains of maize (0.44%) was found lower when maize at moisture content of 12% w.b. and feed rate of 130 kg/h as compared to other combination treatments. The unshelled grains increased with increase in moisture content at each feeding rate. The increasing of unshelled grain losses at high moisture content is due to the elastic conditions of high moisture content this may be due to decrease of grain cohesion force with decreasing grain moisture content. It was also observed that at each moisture content, the unshelled efficiency at 130 kg/h feed rate is lower than followed by 140 kg/h and 120 kg/h feed rates, respectively.

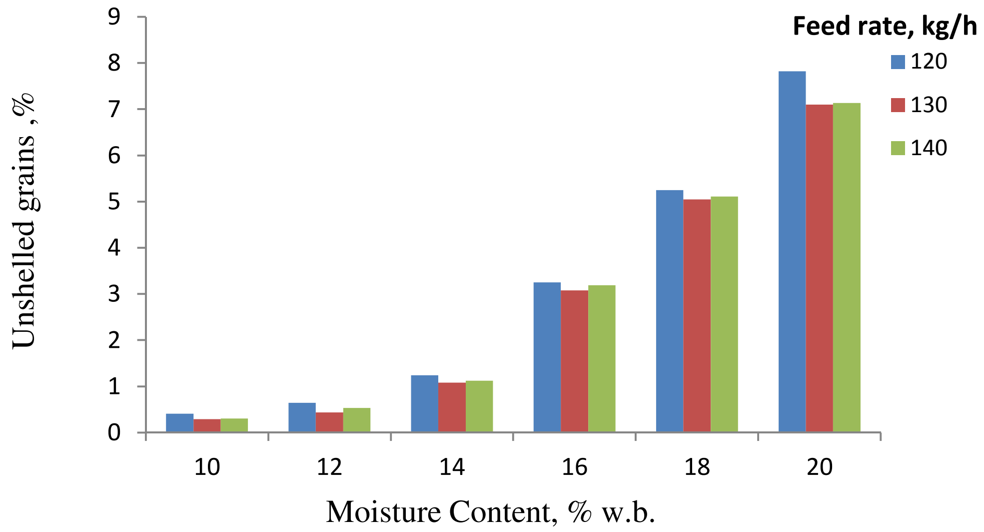


Figure 4.21. Unshelled grains under different feed rates.

4.2.2.3 Visible damage percentage

Variations in visible damage percentage with respect to different treatment combinations were shown in fig. 4.22. The visible damage percentage of maize (1.07%) was found lower when maize at moisture content of 12% w.b. and feed rate of 130 kg/h as compared to other combination treatments. The visible damage percentage increased with increase in moisture content at each feeding rate. This result may be attributed to the fact that the grain is soft at the higher grain moisture content level and becomes more brittle at low moisture content level, so that it could damage easily by the shelling process.It was also observed that at each moisture content, visible damage percentage at 130 kg/h feed rate is lower than followed by 140 kg/h and 120 kg/h feed rates, respectively.

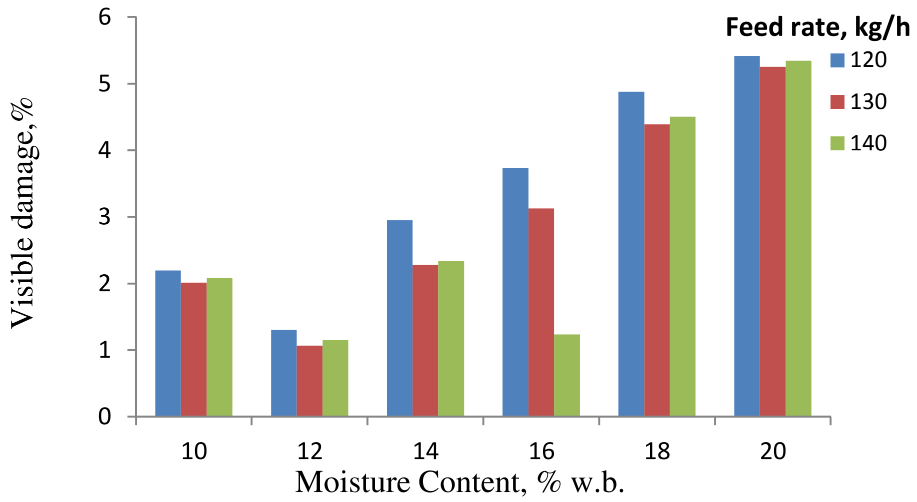


Figure 4.22. Visible damage efficiency under different feed rates.

4.3 DETERMINATION OF OUTPUT CAPACITY OF MODIFIED TUBULAR MAIZE SHELLER

The main drawback of the existing tubular maize sheller is that when the cobs are more than 40 mm, the cob will get choked during operation and cobs less than 30 mm diameter will come without getting shelled.

Modified tubular hand maize sheller was a simple metal pipe of 18 gauge thick mild steel sheet of diameter 55 mm and length 75 mm with four tapering blades or vanes welded on the inner surface of the pipe equally spaced at 90^o angle.

Table 4.1. Specifications of modified tubular maize sheller

Particulars	Specifications
Diameter	55 mm
Length	75 mm
Fin length	75 mm
Fin tapering	15 to 10 mm
Feeding end diameter	25 mm
Outlet end diameter	35 mm

The output of the modified tubular maize sheller was evaluated to different diameters of cobs (29.60 to 48.01 mm) and the output capacity was around 22 to 24 kg/h with a visible damage of 1.2%. It was observed that the modified tubular maize sheller was suitable for all varying diameters. The results of performance of modified tubular hand maize sheller were presented in appendix. H.7.

Table 4.2. Performance evaluation of modified tubular maize sheller

Particulars	**Specifications**
Diameters of the cobs	29.60 to 48.01 mm
Output capacity	22 to 24 kg/h
Visible damage	1.2%

Chapter V

SUMMARY AND CONCLUSIONS

1. The three axial dimensions, sphericity, volume, surface area and thousand grain weight were increased with increase in moisture content from 12 to 20% w.b. for all ten varieties. The true density and porosity of maize samples increased with increase in moisture content from 12 to 20% w.b., whereas bulk density decreased with increase in moisture content from 12 to 20% w.b. The angle of repose and static coefficient of friction of maize samples increased with increase in moisture content from 12 to 20% w.b. on all the three surfaces viz., mild steel, plywood and glass.

2. It is observed that the shelling efficiency of modified ANGRAU hand operated maize sheller is found to be higher as compared to existing ANGRAU hand operated maize sheller at all moisture content levels ranging from 10 to 20% w.b. at a feed rate of 65 kg/h.

3. It was observed that for modified ANGRAU hand operated maize sheller at a moisture content of 12% w.b., and at a feed rate of 130kg/h the shelling efficiency, unshelled percentage and visible damage is found to be 99.56%, 0.44% and 1.07% respectively.

4. It was observed that modified tubular hand maize sheller is suitable for diameters (29.60 to 48.01 mm) with a visible damage of 1.2% at moisture content of 12% w.b.

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Note: The pattern of Literature Cited presented above is in accordance with the guidelines for thesis presentation, Acharya N. G. Ranga Agricultural University, Hyderabad.

Appendix A.1: Determination of axial dimensions for DHM 117 variety at 12% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness(mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume (mm^3)
1	10.570	9.340	4.210	7.448	0.705	174.175	254.067
2	11.740	9.830	3.900	7.648	0.651	183.662	289.737
3	10.410	9.700	4.400	7.615	0.732	182.088	270.947
4	10.490	10.010	4.020	7.486	0.714	175.983	270.325
5	11.880	9.290	4.070	7.643	0.643	183.420	277.603
6	9.450	9.650	4.910	7.635	0.808	183.030	262.271
7	11.400	9.890	3.790	7.517	0.659	177.420	279.301
8	10.470	9.360	4.780	7.750	0.740	188.618	274.057
9	10.140	9.860	4.320	7.544	0.744	178.692	266.923
10	10.420	9.490	3.930	7.283	0.699	166.554	245.679
Average	**10.697**	**9.642**	**4.233**	**7.557**	**0.710**	**179.364**	**269.091**

Appendix A.2: Determination of axial dimensions for DHM 117 variety at 14% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume (mm^3)
1	11.500	9.970	4.780	8.166	0.710	209.404	327.549
2	11.010	8.690	4.250	7.409	0.673	172.343	241.352
3	12.650	9.410	4.160	7.911	0.625	196.537	304.962
4	10.500	9.900	4.210	7.592	0.723	180.995	273.677
5	10.970	9.500	4.670	7.866	0.717	194.280	288.364
6	11.060	10.180	3.610	7.407	0.670	172.294	275.346
7	11.110	10.330	4.100	7.778	0.700	189.960	302.860
8	9.780	9.500	4.810	7.645	0.782	183.542	262.188
9	10.240	9.380	4.600	7.616	0.744	182.153	262.005
10	9.510	9.600	4.510	7.439	0.782	173.786	247.873
Average	**10.833**	**9.646**	**4.370**	**7.683**	**0.713**	**185.529**	**278.618**

Appendix A.3: Determination of axial dimensions for DHM 117 variety at 16% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area (mm^2)	Volume (mm^3)
1	11.810	10.410	4.420	8.143	0.690	208.220	340.038
2	10.850	9.980	4.780	8.012	0.738	201.579	309.455
3	11.220	10.600	4.170	7.899	0.704	195.925	320.442
4	10.250	10.240	4.630	7.846	0.765	193.290	296.716
5	10.480	9.790	4.040	7.441	0.710	173.861	262.422
6	10.640	10.070	4.250	7.678	0.722	185.096	285.642
7	10.830	10.420	4.750	8.106	0.748	206.334	326.283
8	11.420	9.340	4.590	7.865	0.689	194.247	290.110
9	11.670	9.140	4.130	7.593	0.651	181.056	269.034
10	10.020	9.430	4.710	7.619	0.760	182.291	262.278
Average	**10.919**	**9.942**	**4.447**	**7.820**	**0.718**	**192.190**	**296.242**

Appendix A.4: Determination of axial dimensions for DHM 117 variety at 18% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area (mm^2)	Volume (mm^3)
1	11.500	10.810	4.150	8.004	0.696	201.142	336.943
2	11.230	10.650	4.610	8.183	0.729	210.243	342.361
3	10.280	10.700	4.450	7.865	0.765	194.220	308.897
4	11.000	10.080	4.910	8.148	0.741	208.479	323.587
5	11.490	9.830	4.990	8.243	0.717	213.343	330.378
6	11.200	9.850	4.400	7.843	0.700	193.142	297.744
7	11.930	9.920	4.510	8.095	0.679	205.746	325.213
8	10.800	10.330	4.370	7.854	0.727	193.705	305.530
9	10.630	9.750	4.060	7.478	0.704	175.613	265.409
10	10.130	10.550	4.740	7.955	0.785	198.710	310.041
Average	**11.019**	**10.247**	**4.519**	**7.967**	**0.724**	**199.434**	**314.610**

Appendix A.5: Determination of axial dimensions for DHM 117 variety at 20% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area (mm^2)	Volume (mm^3)
1	11.960	10.440	4.750	8.384	0.701	220.715	361.278
2	10.370	9.950	5.200	8.109	0.782	206.465	311.601
3	11.180	10.450	4.400	7.994	0.715	200.661	322.767
4	11.690	10.080	4.090	7.824	0.669	192.224	307.291
5	11.740	10.690	4.640	8.333	0.710	218.036	361.200
6	10.790	10.300	4.420	7.874	0.730	194.681	306.078
7	10.850	10.350	4.640	8.030	0.740	202.478	319.174
8	10.550	9.380	5.790	8.288	0.786	215.698	317.847
9	11.000	9.980	4.680	7.993	0.727	200.587	309.496
10	10.860	9.080	5.540	8.158	0.751	208.956	303.892
Average	**11.099**	**10.070**	**4.815**	**8.099**	**0.731**	**206.050**	**322.062**

Appendix A.6: Determination of axial dimensions for DHM 115 variety at 12% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area (mm^2)	Volume (mm^3)
1	11.850	8.700	4.320	7.621	0.643	182.380	262.988
2	11.750	8.780	4.550	7.756	0.660	188.876	273.334
3	12.030	8.880	4.000	7.517	0.625	177.420	261.272
4	11.810	8.770	4.840	7.927	0.671	197.330	286.392
5	12.370	8.420	4.440	7.717	0.624	187.009	267.822
6	12.000	8.370	4.820	7.836	0.653	192.801	273.316
7	12.160	9.050	4.810	8.072	0.664	204.612	305.812
8	12.510	8.650	4.980	8.121	0.649	207.067	304.259
9	13.890	9.670	4.180	8.232	0.593	212.798	348.816
10	12.660	9.610	4.650	8.253	0.652	213.879	337.029
Average	**12.303**	**8.890**	**4.559**	**7.905**	**0.643**	**196.417**	**292.104**

Appendix A.7: Determination of axial dimensions for DHM 115 variety at 14% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area (mm^2)	Volume (mm^3)
1	11.080	9.520	5.620	8.224	0.742	212.350	332.496
2	12.480	8.770	4.200	7.562	0.606	179.538	274.846
3	11.470	8.280	4.470	7.366	0.642	170.351	244.106
4	12.660	9.560	5.130	8.350	0.660	218.935	357.662
5	12.710	9.980	4.380	8.049	0.633	203.453	343.123
6	12.150	9.180	4.630	7.858	0.647	193.870	303.360
7	12.740	9.720	4.950	8.315	0.653	217.090	358.942
8	12.360	8.740	4.830	7.884	0.638	195.193	297.970
9	13.050	8.580	4.920	8.027	0.615	202.316	311.367
10	12.880	8.780	5.730	8.469	0.658	225.197	355.014
Average	**12.358**	**9.111**	**4.886**	**8.010**	**0.649**	**201.829**	**317.889**

Appendix A.8: Determination of axial dimensions for DHM 115 variety at 16% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area (mm^2)	Volume (mm^3)
1	12.360	9.170	4.950	8.075	0.653	204.769	322.614
2	12.680	8.870	4.620	7.874	0.621	194.662	302.091
3	12.550	8.980	5.480	8.335	0.664	218.169	343.538
4	11.610	9.000	5.990	8.372	0.721	220.100	341.531
5	12.400	8.220	4.260	7.421	0.598	172.907	252.840
6	12.540	9.810	5.510	8.595	0.685	231.989	385.310
7	12.540	9.930	4.030	7.784	0.621	190.237	319.936
8	12.550	8.890	5.440	8.288	0.660	215.678	337.389
9	12.660	9.190	4.190	7.710	0.609	186.632	296.716
10	12.670	9.500	5.670	8.615	0.680	233.037	381.718
Average	**12.456**	**9.156**	**5.014**	**8.107**	**0.651**	**206.818**	**328.368**

Appendix A.9: Determination of axial dimensions for DHM 115 variety at 18% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area (mm^2)	Volume (mm^3)
1	12.670	9.740	5.780	8.741	0.690	239.929	399.535
2	12.640	8.580	4.490	7.707	0.610	186.495	282.679
3	12.350	10.030	4.980	8.332	0.675	218.002	364.270
4	13.010	9.210	5.860	8.696	0.668	237.452	386.811
5	12.580	8.420	4.690	7.758	0.617	188.973	283.062
6	12.010	9.950	4.900	8.190	0.682	210.630	346.730
7	13.080	9.920	4.850	8.387	0.641	220.891	373.563
8	12.950	8.990	5.300	8.333	0.643	218.037	346.202
9	12.110	8.520	4.590	7.636	0.631	183.101	272.486
10	11.290	8.760	5.580	8.032	0.711	202.553	303.940
Average	**12.469**	**9.212**	**5.102**	**8.181**	**0.657**	**210.606**	**335.928**

Appendix A.10: Determination of axial dimensions for DHM 115 variety at 20% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area (mm^2)	Volume (mm^3)
1	12.820	8.940	5.060	8.164	0.637	209.295	328.957
2	11.760	9.200	5.760	8.360	0.711	219.471	344.560
3	11.510	9.700	5.220	8.178	0.710	209.977	335.435
4	12.600	9.070	4.420	7.800	0.619	191.062	300.185
5	12.330	8.730	5.410	8.175	0.663	209.867	322.743
6	12.780	10.500	4.370	8.194	0.641	210.835	369.954
7	11.880	8.000	4.850	7.568	0.637	179.861	256.813
8	13.170	10.650	4.920	8.646	0.657	234.749	417.982
9	13.000	9.920	5.800	8.879	0.683	247.567	420.575
10	13.160	9.150	5.700	8.631	0.656	233.913	379.930
Average	**12.501**	**9.386**	**5.151**	**8.260**	**0.661**	**214.660**	**347.714**

Appendix A.11: Determination of axial dimensions for AMBER CORN variety at 12% w.b. moisture content

Replications	Length (mm) (mm)	Breadth (mm) (mm)	Thickness (mm) (mm)	Geometric Mean Diameter	Sphericity	Surface area (mm^2)	Volume (mm^3)
1	7.190	5.590	3.230	5.055	0.703	80.245	73.225
2	6.850	5.930	3.490	5.206	0.760	85.089	79.577
3	7.370	6.320	3.500	5.454	0.740	93.388	93.043
4	7.310	5.840	3.190	5.136	0.703	82.843	78.035
5	7.000	6.230	3.400	5.284	0.755	87.672	84.986
6	7.210	4.920	3.570	5.014	0.695	78.930	68.037
7	7.290	5.990	3.410	5.291	0.726	87.920	84.329
8	7.130	4.250	3.170	4.573	0.641	65.660	51.392
9	7.340	4.760	3.360	4.889	0.666	75.043	63.358
10	7.410	5.400	3.120	4.990	0.673	78.183	70.419
Average	**7.210**	**5.523**	**3.344**	**5.089**	**0.706**	**81.497**	**74.640**

Appendix A.12: Determination of axial dimensions for AMBER CORN variety at 14% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area (mm^2)	Volume (mm^3)
1	7.900	5.560	4.270	5.714	0.723	102.526	99.938
2	6.720	5.510	3.620	5.109	0.760	81.972	73.334
3	6.660	5.570	3.730	5.164	0.775	83.726	75.411
4	6.820	5.810	2.670	4.722	0.692	70.021	64.205
5	7.260	5.720	3.360	5.178	0.713	84.194	78.362
6	7.160	5.120	3.460	5.016	0.701	79.013	69.005
7	7.890	5.760	3.800	5.559	0.705	97.042	94.403
8	7.190	5.890	3.230	5.144	0.715	83.088	78.291
9	7.670	6.000	3.110	5.222	0.681	85.631	83.335
10	7.860	5.950	3.230	5.317	0.676	88.764	86.717
Average	**7.313**	**5.689**	**3.448**	**5.215**	**0.714**	**85.598**	**80.300**

Appendix A.13: Determination of axial dimensions for AMBER CORN variety at 16% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume (mm^3)
1	6.940	5.620	4.010	5.379	0.775	90.843	84.257
2	7.210	5.120	3.620	5.104	0.708	81.807	72.103
3	6.960	6.010	3.810	5.413	0.778	91.989	87.867
4	8.670	6.870	3.280	5.792	0.668	105.350	116.935
5	8.780	5.340	3.910	5.671	0.646	100.979	98.350
6	7.350	5.140	3.600	5.134	0.699	82.771	73.503
7	7.260	6.970	3.260	5.475	0.754	94.126	99.468
8	6.920	5.340	3.190	4.895	0.707	75.250	65.917
9	7.890	5.830	3.840	5.601	0.710	98.511	96.588
10	6.950	5.510	4.120	5.394	0.776	91.373	84.379
Average	**7.493**	**5.775**	**3.664**	**5.386**	**0.722**	**91.300**	**87.937**

Appendix A.14: Determination of axial dimensions for AMBER CORN variety at 18% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	7.190	6.490	3.150	5.269	0.733	87.165	87.474
2	7.320	5.310	4.120	5.421	0.741	92.284	85.218
3	9.150	5.200	4.900	6.144	0.671	118.513	122.197
4	7.560	5.100	3.700	5.217	0.690	85.446	76.645
5	8.670	5.350	4.130	5.755	0.664	103.982	102.007
6	7.020	6.550	3.460	5.409	0.771	91.882	92.087
7	7.210	5.290	4.450	5.527	0.767	95.928	89.546
8	7.020	5.440	4.620	5.599	0.798	98.435	93.010
9	9.310	6.570	4.700	6.587	0.708	136.259	154.808
10	7.030	7.120	3.420	5.543	0.788	96.475	102.243
Average	**7.748**	**5.842**	**4.065**	**5.647**	**0.733**	**100.637**	**100.523**

Appendix A.15: Determination of axial dimensions for AMBER CORN variety at 20% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	8.850	6.660	3.750	6.035	0.682	114.375	125.557
2	7.280	5.350	3.440	5.109	0.702	81.948	73.638
3	7.730	6.990	4.950	6.431	0.832	129.863	144.272
4	8.460	5.310	3.750	5.513	0.652	95.450	90.912
5	7.380	5.530	4.630	5.728	0.776	103.036	99.733
6	8.970	5.610	3.910	5.806	0.647	105.849	106.429
7	8.450	6.450	4.350	6.178	0.731	119.844	129.033
8	7.660	5.760	4.980	6.023	0.786	113.926	115.673
9	7.410	5.980	5.330	6.170	0.833	119.540	124.090
10	7.390	5.300	4.510	5.601	0.758	98.514	93.106
Average	**7.958**	**5.894**	**4.360**	**5.860**	**0.740**	**108.235**	**110.244**

Appendix A.16: Determination of axial dimensions for MADHURI variety at 12% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	11.130	7.230	3.990	6.834	0.614	146.666	183.432
2	10.300	7.840	3.210	6.364	0.618	127.182	164.648
3	11.320	8.360	3.280	6.758	0.597	143.401	200.792
4	10.930	8.300	3.630	6.892	0.631	149.161	203.655
5	11.380	7.990	3.010	6.480	0.569	131.869	180.270
6	11.640	7.670	3.220	6.587	0.566	136.257	180.719
7	11.040	8.840	3.120	6.715	0.608	141.577	206.741
8	11.880	7.670	3.830	7.027	0.591	155.039	205.687
9	11.800	8.590	3.290	6.921	0.587	150.416	218.027
10	11.490	7.490	3.050	6.391	0.556	128.248	167.108
Average	**11.291**	**7.998**	**3.363**	**6.697**	**0.594**	**140.982**	**191.108**

Appendix A.17: Determination of axial dimensions for MADHURI variety at 14% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	11.600	8.670	3.520	7.060	0.609	156.523	225.663
2	11.300	7.980	3.740	6.947	0.615	151.547	203.202
3	11.720	8.130	2.780	6.410	0.547	129.030	182.630
4	12.090	8.000	3.300	6.821	0.564	146.088	202.105
5	11.690	8.440	3.490	6.995	0.598	153.660	217.816
6	10.780	8.310	3.160	6.554	0.608	134.865	185.669
7	11.510	8.450	3.320	6.847	0.595	147.221	208.748
8	11.010	8.010	3.810	6.939	0.630	151.173	201.380
9	10.980	8.020	3.410	6.684	0.609	140.270	187.797
10	11.160	8.350	3.610	6.941	0.622	151.292	208.988
Average	**11.384**	**8.236**	**3.414**	**6.820**	**0.600**	**146.167**	**202.400**

Appendix A.18: Determination of axial dimensions for MADHURI variety at 16% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	11.200	7.980	3.520	6.788	0.606	144.691	193.914
2	10.700	8.820	4.130	7.290	0.681	166.880	234.919
3	12.000	8.910	3.880	7.443	0.620	173.958	256.991
4	11.200	8.320	3.840	7.086	0.633	157.643	216.810
5	10.980	8.110	3.270	6.616	0.603	137.426	186.158
6	11.580	8.410	3.290	6.830	0.590	146.462	207.527
7	12.200	7.940	4.780	7.721	0.633	187.165	258.422
8	12.780	7.680	4.110	7.374	0.577	170.745	232.570
9	12.870	8.210	3.780	7.350	0.571	169.618	242.221
10	11.990	8.230	3.210	6.804	0.567	145.349	205.431
Average	**11.750**	**8.261**	**3.781**	**7.130**	**0.608**	**159.994**	**223.496**

Appendix A.19: Determination of axial dimensions for MADHURI variety at 18% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	11.980	8.560	3.450	7.059	0.589	156.458	226.224
2	12.350	8.210	4.780	7.839	0.635	192.944	272.823
3	11.780	8.880	4.090	7.520	0.638	177.567	259.430
4	11.450	8.990	4.320	7.617	0.665	182.192	265.556
5	12.780	9.890	3.950	7.917	0.619	196.795	320.478
6	11.340	8.760	3.880	7.263	0.640	165.642	237.193
7	11.560	8.920	3.250	6.933	0.600	150.910	224.148
8	11.940	9.880	3.340	7.317	0.613	168.088	273.188
9	11.800	8.340	3.770	7.171	0.608	161.489	226.551
10	11.870	8.430	3.210	6.835	0.576	146.706	210.548
Average	**11.885**	**8.886**	**3.804**	**7.347**	**0.618**	**169.879**	**251.614**

Appendix A.20: Determination of axial dimensions for MADHURI variety at 20% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	12.580	8.980	4.890	8.188	0.651	210.513	316.832
2	11.890	8.980	3.980	7.503	0.631	176.769	261.449
3	12.670	7.980	3.320	6.936	0.547	151.074	211.801
4	11.070	8.560	4.560	7.545	0.682	178.743	249.465
5	11.890	8.450	3.870	7.284	0.613	166.611	236.264
6	11.560	9.560	3.330	7.152	0.619	160.617	251.454
7	11.670	8.560	4.660	7.734	0.663	187.833	267.011
8	12.890	9.330	3.230	7.282	0.565	166.505	266.212
9	10.780	8.870	3.780	7.109	0.659	158.701	225.837
10	12.560	9.990	3.880	7.851	0.625	193.522	316.328
Average	**11.956**	**8.926**	**3.950**	**7.458**	**0.625**	**175.089**	**260.265**

Appendix A.21: Determination of axial dimensions for 30V92 variety at 12% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.820	8.170	4.370	7.269	0.672	165.892	222.750
2	10.310	8.010	4.170	6.996	0.679	153.670	200.239
3	10.890	7.280	4.360	7.004	0.643	154.052	193.165
4	9.780	7.890	4.310	6.915	0.707	150.145	190.570
5	9.810	7.630	4.700	7.046	0.718	155.869	195.250
6	10.600	7.250	4.720	7.118	0.671	159.079	198.833
7	9.890	8.140	4.290	7.002	0.708	153.965	200.048
8	10.380	9.580	5.460	8.141	0.784	208.102	307.389
9	10.250	8.390	4.390	7.213	0.704	163.372	219.170
10	11.150	9.940	4.410	7.861	0.705	194.031	300.589
Average	**10.388**	**8.228**	**4.518**	**7.256**	**0.699**	**165.818**	**222.800**

Appendix A.22: Determination of axial dimensions for 30V92 variety at 14% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.060	9.670	4.770	7.726	0.768	187.433	274.617
2	9.430	9.470	4.560	7.397	0.784	171.820	243.009
3	9.730	9.120	4.190	7.177	0.738	161.720	225.665
4	10.390	8.140	4.660	7.317	0.704	168.119	222.859
5	10.200	7.240	5.150	7.231	0.709	164.175	204.992
6	10.700	8.830	4.920	7.731	0.722	187.654	264.840
7	10.750	8.550	4.670	7.528	0.700	177.952	245.961
8	10.470	9.430	4.360	7.535	0.720	178.294	260.657
9	11.240	7.300	4.050	6.913	0.615	150.065	189.563
10	11.370	9.470	4.340	7.744	0.681	188.314	283.885
Average	**10.434**	**8.722**	**4.567**	**7.430**	**0.714**	**173.555**	**241.605**

Appendix A.23: Determination of axial dimensions for 30V92 variety at 16% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.920	9.120	7.290	8.968	0.821	252.534	384.977
2	9.820	8.120	5.800	7.718	0.786	187.018	249.106
3	10.240	8.350	4.470	7.243	0.707	164.717	220.329
4	11.660	9.040	4.670	7.879	0.676	194.950	286.925
5	10.720	8.360	5.640	7.949	0.742	198.418	275.072
6	10.960	8.870	4.260	7.439	0.679	173.759	247.363
7	10.910	8.780	4.740	7.670	0.703	184.738	261.080
8	10.840	9.980	4.420	7.804	0.720	191.219	294.272
9	10.720	8.500	4.810	7.581	0.707	180.443	248.626
10	10.370	8.780	4.200	7.244	0.699	164.774	228.730
Average	**10.716**	**8.790**	**5.030**	**7.749**	**0.724**	**189.257**	**269.648**

Appendix A.24: Determination of axial dimensions for 30V92 variety at 18% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.130	8.930	4.690	7.499	0.740	176.577	246.013
2	10.670	8.780	4.666	7.574	0.710	180.124	252.549
3	11.190	9.680	5.530	8.412	0.752	222.177	338.909
4	10.640	8.690	5.150	7.793	0.732	190.688	266.814
5	10.950	8.590	5.960	8.228	0.751	212.585	303.483
6	10.550	8.630	4.540	7.434	0.705	173.539	239.563
7	10.910	8.690	5.830	8.189	0.751	210.593	301.129
8	9.890	8.980	5.920	8.054	0.814	203.694	287.451
9	11.750	8.890	4.740	7.895	0.672	195.709	285.775
10	10.730	8.370	4.590	7.427	0.692	173.225	235.942
Average	**10.741**	**8.823**	**5.162**	**7.851**	**0.732**	**193.891**	**275.763**

Appendix A.25: Determination of axial dimensions for 30V92 variety at 20% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.910	8.960	5.220	7.974	0.731	199.676	287.192
2	11.730	8.740	5.300	8.143	0.694	208.208	302.710
3	10.270	8.940	5.440	7.918	0.771	196.850	278.025
4	9.670	8.120	4.320	6.961	0.720	152.132	195.913
5	9.820	8.170	5.900	7.777	0.792	189.934	254.504
6	11.780	9.640	5.500	8.530	0.724	228.449	353.502
7	9.970	8.840	5.790	7.975	0.800	199.683	279.369
8	11.530	8.970	5.480	8.258	0.716	214.139	315.181
9	11.590	8.850	4.840	7.902	0.682	196.056	284.371
10	10.820	9.630	5.970	8.518	0.787	227.834	344.724
Average	**10.809**	**8.886**	**5.376**	**7.996**	**0.742**	**201.296**	**289.549**

Appendix A.26: Determination of axial dimensions for 900M GOLD variety at 12% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	11.260	8.480	3.800	7.118	0.632	159.112	222.295
2	10.540	7.680	4.230	6.982	0.662	153.086	195.731
3	11.340	8.540	3.470	6.939	0.612	151.186	214.138
4	10.290	7.290	3.880	6.615	0.643	137.384	168.080
5	11.200	8.520	3.670	7.035	0.628	155.399	217.882
6	11.060	6.980	3.940	6.712	0.607	141.475	172.661
7	10.970	8.100	3.880	6.998	0.638	153.787	206.118
8	11.660	8.160	4.410	7.471	0.641	175.280	241.193
9	11.590	7.510	3.380	6.638	0.573	138.371	179.943
10	10.130	7.800	3.640	6.588	0.650	136.299	173.563
Average	**11.004**	**7.906**	**3.830**	**6.910**	**0.629**	**150.138**	**199.160**

Appendix A.27: Determination of axial dimensions for 900M GOLD variety at 14% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.030	8.460	4.130	7.037	0.702	155.470	208.136
2	11.320	7.840	4.030	7.084	0.626	157.594	208.806
3	10.750	7.540	4.030	6.874	0.639	148.358	188.395
4	11.490	7.100	4.130	6.945	0.604	151.448	189.703
5	11.400	8.650	3.890	7.252	0.636	165.115	234.690
6	11.790	8.000	3.860	7.127	0.604	159.471	217.109
7	12.860	8.730	3.230	7.117	0.553	159.048	240.823
8	11.500	8.720	4.200	7.481	0.651	175.720	251.315
9	10.110	8.190	3.400	6.542	0.647	134.371	177.792
10	10.540	8.120	5.520	7.772	0.737	189.687	256.723
Average	**11.179**	**8.135**	**4.042**	**7.123**	**0.640**	**159.628**	**217.349**

Appendix A.28: Determination of axial dimensions for 900M GOLD variety at 16% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	12.630	7.970	5.690	8.287	0.656	215.645	308.532
2	11.120	8.530	3.860	7.140	0.642	160.072	223.482
3	11.120	7.000	3.350	6.377	0.573	127.688	155.948
4	10.970	8.250	3.560	6.842	0.624	147.005	200.309
5	10.590	8.750	4.300	7.344	0.693	169.347	236.109
6	11.350	8.950	3.610	7.144	0.629	160.240	234.407
7	10.930	7.790	4.140	7.050	0.645	156.076	203.655
8	10.700	8.400	4.590	7.429	0.694	173.315	236.373
9	11.460	7.460	5.230	7.631	0.666	182.858	241.603
10	11.360	8.340	4.330	7.415	0.653	172.667	238.741
Average	**11.223**	**8.144**	**4.266**	**7.266**	**0.648**	**166.491**	**227.916**

Appendix A.29: Determination of axial dimensions for 900M GOLD variety at 18% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.570	8.070	4.860	7.441	0.704	173.877	231.349
2	11.140	8.280	4.280	7.321	0.657	168.308	230.070
3	12.560	7.920	3.770	7.197	0.573	162.649	224.705
4	11.860	7.330	4.420	7.256	0.612	165.303	214.366
5	11.370	8.630	4.550	7.627	0.671	182.677	258.575
6	10.460	8.910	4.600	7.525	0.719	177.809	249.941
7	11.910	8.130	4.410	7.515	0.631	177.339	245.189
8	10.870	8.810	4.970	7.792	0.717	190.628	270.223
9	10.800	8.550	3.840	7.064	0.654	156.691	217.051
10	10.940	8.170	4.000	7.084	0.647	157.553	212.126
Average	**11.248**	**8.280**	**4.370**	**7.382**	**0.659**	**171.283**	**235.359**

Appendix A.30: Determination of axial dimensions for 900M GOLD variety at 20% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness(mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.820	8.870	4.010	7.259	0.671	165.476	234.992
2	11.490	8.450	5.760	8.221	0.716	212.242	303.741
3	12.650	8.600	3.190	7.014	0.554	154.462	230.204
4	11.610	8.630	4.650	7.736	0.666	187.938	268.055
5	11.180	7.160	4.290	6.989	0.625	153.384	191.888
6	11.810	7.790	5.610	8.005	0.678	201.197	277.622
7	10.790	8.830	4.560	7.559	0.701	179.392	253.266
8	10.910	8.360	4.820	7.588	0.696	180.809	248.114
9	10.930	8.420	4.410	7.389	0.676	171.437	235.542
10	10.670	8.420	3.520	6.800	0.637	145.192	199.144
Average	**11.286**	**8.353**	**4.482**	**7.456**	**0.662**	**175.153**	**244.257**

Appendix A.31: Determination of axial dimensions for PIONEER B12 variety at 12% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness(mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	9.210	7.090	4.630	6.699	0.727	140.907	165.619
2	9.360	6.090	4.220	6.208	0.663	121.008	130.253
3	9.360	7.050	4.470	6.644	0.710	138.611	162.621
4	10.140	6.170	4.120	6.352	0.626	126.708	140.561
5	10.260	6.850	4.020	6.549	0.638	134.691	158.709
6	10.090	6.840	4.120	6.563	0.650	135.266	158.675
7	9.410	6.000	4.580	6.359	0.676	126.977	137.897
8	9.700	7.200	3.580	6.288	0.648	124.162	147.572
9	10.150	6.860	4.600	6.829	0.673	146.428	174.514
10	10.990	7.120	4.890	7.245	0.659	164.841	207.529
Average	**9.867**	**6.727**	**4.323**	**6.574**	**0.667**	**135.960**	**158.395**

Appendix A.32: Determination of axial dimensions for PIONEER B12 variety at 14% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness(mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.150	6.990	4.510	6.827	0.673	146.332	175.734
2	9.980	6.800	4.790	6.863	0.688	147.878	175.506
3	10.180	6.890	4.730	6.909	0.679	149.900	179.951
4	9.020	6.900	4.750	6.649	0.737	138.819	160.270
5	10.060	7.050	3.910	6.509	0.647	133.028	158.203
6	9.780	6.310	4.510	6.517	0.666	133.351	149.895
7	10.970	6.660	4.480	6.878	0.627	148.557	178.226
8	9.340	7.040	3.670	6.214	0.665	121.264	140.256
9	9.290	7.110	4.390	6.606	0.711	137.042	160.845
10	10.210	6.240	4.080	6.370	0.624	127.419	142.357
Average	**9.898**	**6.799**	**4.382**	**6.634**	**0.672**	**138.359**	**162.124**

Appendix A.33: Determination of axial dimensions for PIONEER B12 variety at 16% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.770	7.290	3.510	6.495	0.603	132.476	164.459
2	10.450	7.800	3.960	6.846	0.655	147.184	189.202
3	10.930	7.410	4.690	7.228	0.661	164.040	209.501
4	9.150	6.490	4.200	6.283	0.687	123.958	136.890
5	10.330	6.900	4.860	7.009	0.679	154.274	187.029
6	9.930	7.220	5.800	7.449	0.750	174.231	220.377
7	10.000	6.980	4.830	6.946	0.695	151.512	182.597
8	9.420	7.100	4.470	6.674	0.708	139.859	165.087
9	10.390	6.340	5.410	7.076	0.681	157.216	187.796
10	9.370	6.890	4.230	6.476	0.691	131.675	151.686
Average	**10.074**	**7.042**	**4.596**	**6.848**	**0.681**	**147.643**	**179.462**

Appendix A.34: Determination of axial dimensions for PIONEER B12 variety at 18% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness(mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.660	7.860	5.780	7.837	0.735	192.846	259.646
2	10.770	7.680	4.110	6.966	0.647	152.354	195.992
3	9.380	7.450	5.500	7.256	0.774	165.331	205.938
4	10.230	6.760	4.210	6.615	0.647	137.412	161.170
5	10.630	7.150	4.170	6.805	0.640	145.405	178.329
6	10.530	7.290	5.750	7.598	0.722	181.294	234.411
7	10.390	7.130	4.990	7.163	0.689	161.097	199.809
8	10.480	6.460	5.120	7.011	0.669	154.340	183.981
9	10.180	7.860	5.740	7.700	0.756	186.156	246.502
10	10.780	7.140	4.120	6.806	0.631	145.458	178.933
Average	**10.403**	**7.278**	**4.949**	**7.176**	**0.691**	**162.169**	**204.471**

Appendix A.35: Determination of axial dimensions for PIONEER B12 variety at 20% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness(mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.670	7.150	5.820	7.613	0.714	182.009	234.985
2	10.940	7.450	4.650	7.222	0.660	163.793	209.693
3	10.670	7.400	5.760	7.675	0.719	184.943	241.920
4	9.060	7.910	4.440	6.814	0.752	145.787	180.908
5	10.120	7.740	5.310	7.450	0.736	174.259	225.630
6	11.950	7.450	4.680	7.454	0.624	174.460	230.189
7	10.240	7.640	4.970	7.284	0.711	166.611	213.170
8	10.900	6.850	5.850	7.572	0.695	180.033	230.159
9	10.360	7.920	5.060	7.445	0.719	174.050	228.509
10	10.650	6.280	5.190	7.014	0.659	154.485	183.430
Average	**10.556**	**7.379**	**5.173**	**7.354**	**0.699**	**170.043**	**217.859**

Appendix A.36: Determination of axial dimensions for EDEN variety at 12% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	11.600	9.400	4.300	7.753	0.668	188.735	285.032
2	10.900	9.760	4.360	7.725	0.709	187.382	284.506
3	11.260	9.250	4.380	7.682	0.682	185.322	273.858
4	11.450	9.010	4.280	7.599	0.664	181.335	264.759
5	10.980	9.870	4.500	7.855	0.715	193.743	296.832
6	11.200	8.610	4.760	7.698	0.687	186.083	262.105
7	11.140	9.140	3.870	7.317	0.657	168.097	246.851
8	11.560	8.400	3.660	7.070	0.612	156.931	220.114
9	11.000	9.760	3.200	6.990	0.635	153.427	241.879
10	11.120	9.080	4.560	7.706	0.693	186.462	270.850
Average	**11.221**	**9.228**	**4.187**	**7.540**	**0.672**	**178.752**	**264.679**

Appendix A.37: Determination of axial dimensions for EDEN variety at 14% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.890	9.680	4.280	7.654	0.703	183.961	277.839
2	11.780	8.860	4.470	7.740	0.657	188.108	274.032
3	11.780	9.450	4.230	7.764	0.659	189.275	288.611
4	10.980	9.870	4.560	7.890	0.719	195.459	299.316
5	11.060	9.950	4.950	8.150	0.737	208.558	321.457
6	11.350	9.180	4.250	7.607	0.670	181.684	268.005
7	11.990	9.040	3.270	7.063	0.589	156.646	237.865
8	11.070	9.460	4.780	7.924	0.716	197.140	293.875
9	11.990	8.560	4.230	7.557	0.630	179.305	256.776
10	10.090	8.890	4.560	7.408	0.734	172.330	238.963
Average	**11.298**	**9.294**	**4.358**	**7.676**	**0.681**	**185.247**	**275.674**

Appendix A.38: Determination of axial dimensions for EDEN variety at 16% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	11.570	9.300	4.630	7.911	0.684	196.515	293.921
2	10.900	10.330	4.040	7.675	0.704	184.968	294.669
3	11.630	9.870	4.090	7.756	0.667	188.899	296.719
4	10.500	7.960	4.340	7.118	0.678	159.081	207.967
5	11.820	9.860	4.250	7.896	0.668	195.759	308.082
6	11.890	9.700	4.920	8.261	0.695	214.309	332.714
7	10.620	9.920	4.620	7.850	0.739	193.489	293.933
8	12.960	8.810	4.160	7.786	0.601	190.368	285.417
9	10.650	9.580	4.330	7.601	0.714	181.399	269.773
10	10.910	9.790	4.970	8.080	0.741	205.001	311.166
Average	**11.345**	**9.512**	**4.435**	**7.793**	**0.689**	**190.979**	**289.436**

Appendix A.39: Determination of axial dimensions for EDEN variety at 18% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	11.620	9.160	5.920	8.555	0.736	229.798	345.942
2	10.420	9.620	4.190	7.474	0.717	175.396	260.166
3	11.630	9.930	3.950	7.682	0.661	185.314	293.328
4	11.780	9.740	4.890	8.230	0.699	212.702	330.087
5	12.160	9.780	5.200	8.501	0.699	226.944	357.233
6	11.670	9.510	4.090	7.670	0.657	184.703	282.581
7	10.410	9.800	4.040	7.427	0.713	173.204	261.046
8	11.450	9.410	4.730	7.971	0.696	199.509	299.709
9	10.910	9.760	4.410	7.757	0.711	188.926	286.787
10	11.440	9.160	4.090	7.524	0.658	177.775	262.938
Average	**11.349**	**9.587**	**4.551**	**7.879**	**0.695**	**195.427**	**297.982**

Appendix A.40: Determination of axial dimensions for EDEN variety at 20% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	11.910	10.720	4.560	8.332	0.700	218.005	364.044
2	12.670	9.780	4.970	8.490	0.670	226.317	360.874
3	11.870	8.960	5.510	8.351	0.703	218.957	325.374
4	10.760	10.570	4.090	7.732	0.719	187.741	302.744
5	12.440	9.100	4.120	7.739	0.622	188.072	284.628
6	11.050	9.480	4.260	7.626	0.690	182.621	273.106
7	10.160	9.220	4.040	7.219	0.711	163.637	233.871
8	11.520	9.970	4.620	8.079	0.701	204.946	321.039
9	10.590	9.250	5.640	8.188	0.773	210.529	307.383
10	11.260	9.320	5.750	8.432	0.749	223.267	334.780
Average	**11.423**	**9.637**	**4.756**	**8.019**	**0.704**	**202.409**	**310.784**

Appendix A.41: Determination of axial dimensions for NANIYA variety at 12% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.170	9.100	3.610	6.925	0.681	150.601	215.083
2	10.800	7.440	3.570	6.583	0.610	136.061	171.393
3	10.410	8.610	3.840	6.994	0.672	153.613	211.244
4	10.610	8.560	4.090	7.174	0.676	161.619	222.275
5	10.330	7.970	5.310	7.574	0.733	180.138	238.502
6	10.020	8.000	4.030	6.848	0.683	147.265	189.843
7	10.550	8.220	4.300	7.184	0.681	162.036	216.499
8	10.500	7.260	3.970	6.701	0.638	141.000	173.358
9	10.670	8.830	4.460	7.475	0.701	175.450	246.723
10	10.830	8.090	4.510	7.324	0.676	168.410	225.094
Average	**10.489**	**8.208**	**4.169**	**7.078**	**0.675**	**157.619**	**211.001**

Appendix A.42: Determination of axial dimensions for NANIYA variety at 14% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.380	8.760	3.980	7.112	0.685	158.835	220.562
2	10.240	8.870	4.130	7.198	0.703	162.678	226.559
3	10.440	8.130	4.630	7.310	0.700	167.796	222.534
4	10.500	8.300	4.170	7.122	0.678	159.279	213.755
5	10.480	8.370	3.610	6.803	0.649	145.320	196.911
6	10.070	8.240	4.290	7.073	0.702	157.098	206.979
7	11.660	8.740	4.070	7.443	0.638	173.935	250.491
8	10.380	8.970	4.780	7.619	0.734	182.295	256.920
9	11.810	8.320	4.620	7.670	0.649	184.715	258.889
10	10.840	8.100	4.660	7.409	0.683	172.367	231.060
Average	**10.680**	**8.480**	**4.294**	**7.276**	**0.682**	**166.432**	**228.466**

Appendix A.43: Determination of axial dimensions for NANIYA variety at 16% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.390	8.570	4.290	7.241	0.697	164.656	224.953
2	10.990	8.260	3.710	6.944	0.632	151.407	206.149
3	10.190	9.980	4.010	7.401	0.726	171.984	261.099
4	10.190	8.500	3.770	6.873	0.674	148.324	200.844
5	10.460	8.300	4.260	7.164	0.685	161.150	216.026
6	11.400	8.600	4.130	7.383	0.648	171.170	241.856
7	10.850	8.060	4.350	7.231	0.666	164.202	218.760
8	10.890	8.450	5.190	7.801	0.716	191.064	265.248
9	10.860	8.860	5.370	8.008	0.737	201.347	287.895
10	11.640	8.020	5.420	7.952	0.683	198.554	275.262
Average	**10.786**	**8.560**	**4.450**	**7.400**	**0.687**	**172.386**	**239.809**

Appendix A.44: Determination of axial dimensions for NANIYA variety at 18% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.160	7.950	4.820	7.287	0.717	166.753	216.905
2	10.910	8.950	4.400	7.530	0.690	178.063	254.555
3	10.860	8.530	4.480	7.444	0.685	174.003	240.646
4	11.930	8.020	4.540	7.558	0.634	179.371	246.385
5	10.330	9.680	5.900	8.369	0.810	219.938	328.269
6	11.710	8.750	4.960	7.964	0.680	199.139	288.155
7	10.150	8.410	4.090	7.028	0.692	155.081	207.626
8	10.750	8.720	4.520	7.496	0.697	176.422	246.706
9	10.600	8.960	4.720	7.638	0.721	183.175	259.701
10	11.530	8.450	4.190	7.403	0.642	172.103	241.167
Average	**10.893**	**8.642**	**4.662**	**7.572**	**0.697**	**180.405**	**253.012**

Appendix A.45: Determination of axial dimensions for NANIYA variety at 20% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness(mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	10.380	9.900	4.100	7.482	0.721	175.762	266.347
2	10.880	8.970	5.980	8.339	0.766	218.357	318.351
3	10.370	8.820	4.010	7.144	0.689	160.256	223.474
4	11.950	8.170	5.960	8.331	0.697	217.927	312.354
5	10.960	8.600	4.220	7.340	0.670	169.152	235.820
6	10.410	8.760	5.930	8.130	0.781	207.546	294.096
7	10.880	8.920	4.050	7.311	0.672	167.816	239.609
8	11.650	9.800	4.910	8.228	0.706	212.579	330.025
9	10.530	8.160	4.030	7.009	0.666	154.236	204.848
10	11.540	8.720	4.630	7.737	0.670	187.940	269.255
Average	**10.955**	**8.882**	**4.782**	**7.705**	**0.704**	**187.157**	**269.418**

Appendix A.46: Determination of axial dimensions for RUDHIRA 145 variety at 12% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness(mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	12.810	7.650	4.600	7.652	0.597	183.854	251.661
2	13.080	7.740	4.020	7.396	0.565	171.754	236.819
3	14.110	8.350	4.440	8.041	0.570	203.009	302.178
4	11.050	8.990	5.240	8.027	0.726	202.343	292.932
5	11.960	8.330	4.610	7.700	0.644	186.154	262.177
6	12.000	7.450	4.720	7.485	0.624	175.940	232.679
7	12.280	9.030	4.180	7.723	0.629	187.295	280.543
8	12.630	8.690	4.250	7.740	0.613	188.087	276.864
9	13.030	9.120	4.050	7.821	0.600	192.046	295.877
10	13.900	7.060	4.830	7.781	0.560	190.104	257.261
Average	**12.685**	**8.241**	**4.494**	**7.737**	**0.613**	**188.059**	**268.899**

Appendix A.47: Determination of axial dimensions for RUDHIRA 145 variety at 14% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness(mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	11.930	8.470	4.850	7.868	0.660	194.378	277.105
2	12.840	8.590	4.550	7.930	0.618	197.474	290.236
3	12.330	8.590	4.180	7.606	0.617	181.658	263.233
4	12.760	8.930	5.060	8.305	0.651	216.600	326.950
5	14.370	7.890	4.890	8.198	0.570	211.023	307.265
6	12.580	8.400	5.160	8.153	0.648	208.695	302.827
7	12.780	9.200	4.720	8.200	0.642	211.158	324.193
8	13.700	8.030	4.160	7.691	0.561	185.713	266.516
9	13.700	8.030	5.160	8.262	0.603	214.363	312.036
10	11.930	7.600	4.820	7.573	0.635	180.096	240.923
Average	**12.892**	**8.373**	**4.755**	**7.979**	**0.620**	**200.116**	**291.128**

Appendix A.48: Determination of axial dimensions for RUDHIRA 145 variety at 16% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness(mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	12.890	8.440	4.760	8.014	0.622	201.645	294.033
2	13.890	8.340	4.890	8.257	0.594	214.065	318.286
3	12.860	8.900	5.040	8.307	0.646	216.669	327.161
4	13.070	9.030	5.320	8.545	0.654	229.253	352.350
5	13.450	8.190	4.760	8.047	0.598	203.326	295.295
6	13.090	8.880	5.040	8.350	0.638	218.914	332.057
7	12.990	8.900	4.320	7.918	0.610	196.843	297.212
8	13.840	8.670	5.020	8.427	0.609	223.006	339.577
9	13.660	8.010	5.010	8.167	0.598	209.436	303.157
10	12.000	9.780	4.550	8.096	0.675	205.810	322.603
Average	**13.174**	**8.714**	**4.871**	**8.213**	**0.624**	**211.897**	**318.173**

Appendix A.49: Determination of axial dimensions for RUDHIRA 145 variety at 18% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness(mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	13.880	8.780	4.550	8.198	0.591	211.040	322.883
2	13.990	8.990	5.040	8.572	0.613	230.710	360.519
3	13.560	8.690	5.730	8.754	0.646	240.621	369.135
4	13.430	8.560	4.780	8.174	0.609	209.776	312.883
5	13.890	8.670	5.090	8.477	0.610	225.613	344.298
6	13.070	7.990	4.990	8.030	0.614	202.488	288.284
7	13.890	9.060	5.760	8.963	0.645	252.266	399.387
8	12.080	8.540	5.070	8.040	0.666	202.989	292.940
9	13.960	8.790	5.870	8.944	0.641	251.208	392.779
10	12.780	9.700	5.090	8.559	0.670	230.008	365.984
Average	**13.453**	**8.777**	**5.197**	**8.471**	**0.630**	**225.672**	**344.909**

Appendix A.50: Determination of axial dimensions for RUDHIRA 145 variety at 20% w.b. moisture content

Replications	Length (mm)	Breadth (mm)	Thickness(mm)	Geometric Mean Diameter	Sphericity	Surface area(mm^2)	Volume(mm^3)
1	14.900	8.980	5.060	8.762	0.588	241.056	384.517
2	13.760	8.970	4.870	8.421	0.612	222.691	345.053
3	12.980	9.080	5.890	8.835	0.681	245.105	380.814
4	13.670	8.170	5.840	8.654	0.633	235.138	351.269
5	13.650	9.000	5.080	8.527	0.625	228.328	354.269
6	13.690	8.380	5.340	8.475	0.619	225.526	337.370
7	14.050	8.650	4.870	8.378	0.596	220.409	336.221
8	13.470	8.780	5.760	8.780	0.652	242.046	372.813
9	13.060	9.050	5.320	8.549	0.655	229.474	353.063
10	12.890	9.540	5.230	8.613	0.668	232.948	368.136
Average	**13.612**	**8.860**	**5.326**	**8.599**	**0.633**	**232.272**	**358.352**

Appendix B.1: Determination of Bulk Density for DHM 117 Variety at different moisture contents

Moisture content % w.b. (	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	
12.00	79.620	100.000	**796.200**	79.650	100.000	**796.500**	78.030	100.000	**780.300**	**791.000**
14.00	78.960	100.000	**789.600**	78.090	100.000	**780.900**	78.570	100.000	**785.700**	**785.400**
16.00	78.560	100.000	**785.600**	77.950	100.000	**779.500**	77.560	100.000	**775.600**	**780.233**
18.00	76.890	100.000	**768.900**	77.260	100.000	**772.600**	76.520	100.000	**765.200**	**768.900**
20.00	75.950	100.000	**759.500**	75.690	100.000	**756.900**	74.980	100.000	**749.800**	**755.400**

Appendix B.2: Determination of Bulk Density for DHM 115 Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	
12.00	76.280	100.000	**762.800**	76.660	100.000	**766.600**	76.489	100.000	**764.890**	**764.763**
14.00	76.480	100.000	**764.800**	75.900	100.000	**759.000**	75.800	100.000	**758.000**	**760.600**
16.00	75.980	100.000	**759.800**	75.680	100.000	**756.800**	75.780	100.000	**757.800**	**758.133**
18.00	75.760	100.000	**757.600**	75.640	100.000	**756.400**	75.760	100.000	**757.600**	**757.200**
20.00	75.680	100.000	**756.800**	75.400	100.000	**754.000**	75.500	100.000	**755.000**	**755.267**

Appendix B.3: Determination of Bulk Density for AMBER CORN Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	Bulk Density (Kg/m3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m3)	
12.00	**75.220**	**100.000**	**752.200**	**77.580**	**100.000**	**775.800**	**75.760**	**100.000**	**757.600**	**761.867**
14.00	**74.900**	**100.000**	**749.000**	**74.567**	**100.000**	**745.670**	**73.890**	**100.000**	**738.900**	**744.523**
16.00	**73.587**	**100.000**	**735.870**	**73.680**	**100.000**	**736.800**	**72.960**	**100.000**	**729.600**	**734.090**
18.00	**72.140**	**100.000**	**721.400**	**73.800**	**100.000**	**738.000**	**72.510**	**100.000**	**725.100**	**728.167**
20.00	**71.080**	**100.000**	**710.800**	**70.960**	**100.000**	**709.600**	**71.680**	**100.000**	**716.800**	**712.400**

Appendix B.4: Determination of Bulk Density for MADHURI Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	
12.00	44.570	100.000	**445.700**	43.980	100.000	**439.800**	43.580	100.000	**435.800**	**440.433**
14.00	43.680	100.000	**436.800**	42.980	100.000	**429.800**	43.050	100.000	**430.500**	**432.367**
16.00	42.030	100.000	**420.300**	42.520	100.000	**425.200**	41.860	100.000	**418.600**	**421.367**
18.00	41.077	100.000	**410.770**	40.880	100.000	**408.800**	41.543	100.000	**415.430**	**411.667**
20.00	39.998	100.000	**399.980**	40.543	100.000	**405.430**	40.854	100.000	**408.540**	**404.650**

Appendix B.5: Determination of Bulk Density for 30V92 Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	
12.00	72.550	100.000	**725.500**	73.800	100.000	**738.000**	74.600	100.000	**746.000**	**736.500**
14.00	72.110	100.000	**721.100**	72.080	100.000	**720.800**	73.280	100.000	**732.800**	**724.900**
16.00	70.840	100.000	**708.400**	71.250	100.000	**712.500**	70.460	100.000	**704.600**	**708.500**
18.00	69.990	100.000	**699.900**	69.290	100.000	**692.900**	68.860	100.000	**688.600**	**693.800**
20.00	68.040	100.000	**680.400**	67.750	100.000	**677.500**	68.590	100.000	**685.900**	**681.267**

Appendix B.6: Determination of Bulk Density for 900M GOLD Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	
12.00	77.200	100.000	**772.000**	74.190	100.000	**741.900**	76.250	100.000	**762.500**	**758.800**
14.00	75.110	100.000	**751.100**	75.650	100.000	**756.500**	75.576	100.000	**755.760**	**754.453**
16.00	74.010	100.000	**740.100**	74.190	100.000	**741.900**	73.980	100.000	**739.800**	**740.600**
18.00	73.740	100.000	**737.400**	73.560	100.000	**735.600**	72.990	100.000	**729.900**	**734.300**
20.00	72.050	100.000	**720.500**	72.470	100.000	**724.700**	72.040	100.000	**720.400**	**721.867**

Appendix B.6: Determination of Bulk Density for PIONEER B12 Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	
12.00	74.860	100.000	**748.600**	72.150	100.000	**721.500**	73.980	100.000	**739.800**	**736.633**
14.00	71.180	100.000	**711.800**	72.560	100.000	**725.600**	72.890	100.000	**728.900**	**722.100**
16.00	70.360	100.000	**703.600**	71.240	100.000	**712.400**	71.080	100.000	**710.800**	**708.933**
18.00	68.180	100.000	**681.800**	69.850	100.000	**698.500**	68.850	100.000	**688.500**	**689.600**
20.00	67.940	100.000	**679.400**	67.660	100.000	**676.600**	67.580	100.000	**675.800**	**677.267**

Appendix B.7: Determination of Bulk Density for EDEN Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	
12.00	83.020	100.000	**830.200**	83.760	100.000	**837.600**	82.640	100.000	**826.400**	**831.400**
14.00	81.100	100.000	**811.000**	81.500	100.000	**815.000**	81.480	100.000	**814.800**	**813.600**
16.00	79.610	100.000	**796.100**	80.140	100.000	**801.400**	80.260	100.000	**802.600**	**800.033**
18.00	78.660	100.000	**786.600**	79.180	100.000	**791.800**	78.740	100.000	**787.400**	**788.600**
20.00	76.800	100.000	**768.000**	77.400	100.000	**774.000**	77.150	100.000	**771.500**	**771.167**

Appendix B.8: Determination of Bulk Density for NANIYA Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	
12.00	72.880	100.000	**728.800**	73.400	100.000	**734.000**	73.000	100.000	**730.000**	**730.933**
14.00	72.330	100.000	**723.300**	72.560	100.000	**725.600**	72.490	100.000	**724.900**	**724.600**
16.00	69.410	100.000	**694.100**	69.870	100.000	**698.700**	71.040	100.000	**710.400**	**701.067**
18.00	68.070	100.000	**680.700**	69.560	100.000	**695.600**	69.840	100.000	**698.400**	**691.567**
20.00	67.954	100.000	**679.540**	68.589	100.000	**685.890**	68.790	100.000	**687.900**	**684.443**

Appendix B.9: Determination of Bulk Density for RUDHIRA 145 Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	Weight (gm)	Volume (ml)	Bulk Density (Kg/m^3)	
12.00	82.930	100.000	**829.300**	82.310	100.000	**823.100**	83.160	100.000	**831.600**	**828.000**
14.00	82.140	100.000	**821.400**	81.980	100.000	**819.800**	82.080	100.000	**820.800**	**820.667**
16.00	80.460	100.000	**804.600**	79.640	100.000	**796.400**	79.900	100.000	**799.000**	**800.000**
18.00	79.320	100.000	**793.200**	78.780	100.000	**787.800**	78.640	100.000	**786.400**	**789.133**
20.00	78.660	100.000	**786.600**	78.740	100.000	**787.400**	78.960	100.000	**789.600**	**787.867**

Appendix C.1: Determination of True Density for DHM 117 Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	
12.00	3.230	2.800	**1153.571**	3.380	2.800	**1207.143**	3.450	2.900	**1189.655**	**1183.456**
14.00	3.470	2.800	**1239.286**	3.420	2.900	**1179.310**	3.450	3.000	**1150.000**	**1189.532**
16.00	3.620	3.000	**1206.667**	3.670	3.000	**1223.333**	3.650	3.100	**1177.419**	**1202.473**
18.00	3.510	3.000	**1170.000**	3.540	2.900	**1220.690**	3.560	2.900	**1227.586**	**1206.092**
20.00	3.710	3.100	**1196.774**	3.750	3.100	**1209.677**	3.860	3.000	**1286.667**	**1231.039**

Appendix C.2: Determination of True Density for DHM 115 Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	
12.00	2.900	2.900	**1000.000**	3.250	2.800	**1160.714**	3.150	2.700	**1166.667**	**1109.127**
14.00	3.370	3.000	**1123.333**	3.420	3.000	**1140.000**	3.510	3.000	**1170.000**	**1144.444**
16.00	3.520	3.000	**1173.333**	3.480	3.000	**1160.000**	3.490	3.000	**1163.333**	**1165.556**
18.00	3.440	2.900	**1186.207**	3.240	2.900	**1117.241**	3.510	2.900	**1210.345**	**1171.264**
20.00	3.480	2.800	**1242.857**	3.320	2.800	**1185.714**	3.480	2.900	**1200.000**	**1209.524**

Appendix C.3: Determination of True Density for AMBER CORN Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	
12.00	1.100	1.200	**916.667**	1.230	1.200	**1025.000**	1.150	1.200	**958.333**	**966.667**
14.00	0.980	1.000	**980.000**	0.990	1.000	**990.000**	0.990	1.000	**990.000**	**986.667**
16.00	1.010	1.000	**1010.000**	0.990	1.100	**900.000**	1.100	1.000	**1100.000**	**1003.333**
18.00	1.090	1.100	**990.909**	1.120	1.100	**1018.182**	1.200	1.100	**1090.909**	**1033.333**
20.00	0.960	0.900	**1066.667**	0.950	0.800	**1187.500**	0.960	0.800	**1200.000**	**1151.389**

Appendix C.4: Determination of True Density for MADHURI Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	
12.00	1.450	1.800	**805.556**	1.410	1.800	**783.333**	1.430	1.700	**841.176**	**810.022**
14.00	1.380	1.700	**811.765**	1.300	1.600	**812.500**	1.400	1.700	**823.529**	**815.931**
16.00	1.540	1.900	**810.526**	1.500	1.800	**833.333**	1.530	1.800	**850.000**	**831.287**
18.00	1.600	1.900	**842.105**	1.650	1.900	**868.421**	1.640	2.000	**820.000**	**843.509**
20.00	1.210	1.600	**756.250**	1.250	1.400	**892.857**	1.360	1.400	**971.429**	**873.512**

Appendix C.5: Determination of True Density for 30V92 Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	
12.00	2.530	2.400	**1054.167**	2.440	2.300	**1060.870**	2.480	2.400	**1033.333**	**1049.457**
14.00	2.690	2.500	**1076.000**	2.670	2.500	**1068.000**	2.760	2.500	**1104.000**	**1082.667**
16.00	2.830	2.600	**1088.462**	2.790	2.600	**1073.077**	2.840	2.600	**1092.308**	**1084.615**
18.00	2.880	2.600	**1107.692**	2.870	2.600	**1103.846**	2.840	2.700	**1051.852**	**1087.797**
20.00	2.890	2.700	**1070.370**	2.900	2.700	**1074.074**	2.950	2.600	**1134.615**	**1093.020**

Appendix C.6: Determination of True Density for 900M GOLD Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	
12.00	2.340	1.900	**1231.579**	2.310	2.000	**1155.000**	2.330	1.900	**1226.316**	**1204.298**
14.00	2.420	2.000	**1210.000**	2.440	2.000	**1220.000**	2.420	2.000	**1210.000**	**1213.333**
16.00	2.520	2.100	**1200.000**	2.630	2.100	**1252.381**	2.540	2.100	**1209.524**	**1220.635**
18.00	2.740	2.200	**1245.455**	2.690	2.200	**1222.727**	2.770	2.300	**1204.348**	**1224.177**
20.00	2.780	2.300	**1208.696**	2.740	2.300	**1191.304**	2.830	2.200	**1286.364**	**1228.788**

Appendix C.7: Determination of True Density for PIONEER B12 Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	
12.00	2.490	2.200	**1131.818**	2.480	2.200	**1127.273**	2.590	2.200	**1177.273**	**1145.455**
14.00	2.750	2.400	**1145.833**	2.760	2.400	**1150.000**	2.750	2.400	**1145.833**	**1147.222**
16.00	2.670	2.300	**1160.870**	2.690	2.300	**1169.565**	2.650	2.300	**1152.174**	**1160.870**
18.00	2.610	2.300	**1134.783**	2.680	2.300	**1165.217**	2.650	2.200	**1204.545**	**1168.182**
20.00	2.350	2.000	**1175.000**	2.360	2.000	**1180.000**	2.360	2.000	**1180.000**	**1178.333**

Appendix C.8: Determination of True Density for EDEN Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	
12.00	1.920	1.600	**1200.000**	2.040	1.600	**1275.000**	2.090	1.600	**1306.250**	**1260.417**
14.00	2.010	1.600	**1256.250**	2.050	1.600	**1281.250**	2.090	1.600	**1306.250**	**1281.250**
16.00	2.180	1.600	**1362.500**	2.200	1.600	**1375.000**	2.190	1.700	**1288.235**	**1341.912**
18.00	2.270	1.700	**1335.294**	2.340	1.700	**1376.471**	2.290	1.700	**1347.059**	**1352.941**
20.00	2.440	1.800	**1355.556**	2.470	1.800	**1372.222**	2.460	1.800	**1366.667**	**1364.815**

Appendix C.9: Determination of True Density for PIONEER B12 Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	
12.00	1.820	1.600	**1137.500**	1.805	1.600	**1128.125**	1.860	1.600	**1162.500**	**1142.708**
14.00	1.884	1.600	**1177.500**	1.910	1.600	**1193.750**	1.890	1.600	**1181.250**	**1184.167**
16.00	1.951	1.600	**1219.375**	1.920	1.600	**1200.000**	1.980	1.700	**1164.706**	**1194.694**
18.00	2.006	1.700	**1180.000**	1.990	1.700	**1170.588**	2.112	1.700	**1242.353**	**1197.647**
20.00	2.096	1.800	**1164.444**	2.189	1.800	**1216.111**	2.198	1.800	**1221.111**	**1200.556**

Appendix C.10: Determination of True Density for RUDHIRA 145 Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	Weight (gm)	Volume (ml)	True Density (Kg/m^3)	
12.00	3.590	2.800	**1282.143**	3.600	2.900	**1241.379**	3.620	2.800	**1292.857**	**1272.126**
14.00	3.730	2.900	**1286.207**	3.840	2.900	**1324.138**	3.780	3.000	**1260.000**	**1290.115**
16.00	3.880	3.000	**1293.333**	3.960	3.000	**1320.000**	3.860	3.000	**1286.667**	**1300.000**
18.00	4.030	3.100	**1300.000**	4.010	3.100	**1293.548**	3.960	3.000	**1320.000**	**1304.516**
20.00	4.010	3.200	**1253.125**	4.270	3.200	**1334.375**	4.200	3.100	**1354.839**	**1314.113**

Appendix D.1: Determination of porosity for DHM 117 Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	
12.00	796.200	1153.571	**30.980**	796.500	1207.143	**34.018**	780.300	1189.655	**34.410**	**33.136**
14.00	789.600	1239.286	**36.286**	780.900	1179.310	**33.783**	785.700	1150.000	**31.678**	**33.916**
16.00	785.600	1206.667	**34.895**	779.500	1223.333	**36.281**	775.600	1177.419	**34.127**	**35.101**
18.00	768.900	1170.000	**34.282**	772.600	1220.690	**36.708**	765.200	1227.586	**37.666**	**36.219**
20.00	759.500	1196.774	**36.538**	756.900	1209.677	**37.430**	749.800	1286.667	**41.725**	**38.564**

Appendix D.2: Determination of porosity for DHM 115 Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	
12.00	762.800	1000.000	**23.720**	766.600	1160.714	**33.954**	764.890	1166.667	**34.438**	**30.704**
14.00	764.800	1123.333	**31.917**	759.000	1140.000	**33.421**	758.000	1170.000	**35.214**	**33.517**
16.00	759.800	1173.333	**35.244**	756.800	1160.000	**34.759**	757.800	1163.333	**34.860**	**34.954**
18.00	757.600	1186.207	**36.133**	756.400	1117.241	**32.298**	757.600	1210.345	**37.406**	**35.279**
20.00	756.800	1242.857	**39.108**	754.000	1185.714	**36.410**	755.000	1200.000	**37.083**	**37.534**

Appendix D.3: Determination of porosity for AMBER CORN Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	
12.00	752.200	916.667	**17.942**	775.800	1025.000	**24.312**	757.600	958.333	**20.946**	**21.067**
14.00	749.000	980.000	**23.571**	745.670	990.000	**24.680**	738.900	990.000	**25.364**	**24.538**
16.00	735.870	1010.000	**27.142**	736.800	900.000	**18.133**	729.600	1100.000	**33.673**	**26.316**
18.00	721.400	990.909	**27.198**	738.000	1018.182	**27.518**	725.100	1090.909	**33.533**	**29.416**
20.00	710.800	1066.667	**33.363**	709.600	1187.500	**40.244**	716.800	1200.000	**40.267**	**37.958**

Appendix D.4: Determination of porosity for MADHURI Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	
12.00	445.700	805.556	**44.672**	439.800	783.333	**43.855**	435.800	841.176	**48.192**	**45.573**
14.00	436.800	811.765	**46.191**	429.800	812.500	**47.102**	430.500	823.529	**47.725**	**47.006**
16.00	420.300	810.526	**48.145**	425.200	833.333	**48.976**	418.600	850.000	**50.753**	**49.291**
18.00	410.770	842.105	**51.221**	408.800	868.421	**52.926**	415.430	820.000	**49.338**	**51.162**
20.00	399.980	756.250	**47.110**	405.430	892.857	**54.592**	408.540	971.429	**57.944**	**53.215**

Appendix D.5: Determination of porosity for 30V92 Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	
12.00	725.500	1054.167	**31.178**	738.000	1060.870	**30.434**	746.000	1033.333	**27.806**	**29.806**
14.00	721.100	1076.000	**32.983**	720.800	1068.000	**32.509**	732.800	1104.000	**33.623**	**33.039**
16.00	708.400	1088.462	**34.917**	712.500	1073.077	**33.602**	704.600	1092.308	**35.494**	**34.671**
18.00	699.900	1107.692	**36.815**	692.900	1103.846	**37.229**	688.600	1051.852	**34.535**	**36.193**
20.00	680.400	1070.370	**36.433**	677.500	1074.074	**36.922**	685.900	1134.615	**39.548**	**37.634**

Appendix D.6: Determination of porosity for 900M GOLD Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	
12.00	772.000	1231.579	**37.316**	741.900	1155.000	**35.766**	762.500	1226.316	**37.822**	**36.968**
14.00	751.100	1210.000	**37.926**	756.500	1220.000	**37.992**	755.760	1210.000	**37.540**	**37.819**
16.00	740.100	1200.000	**38.325**	741.900	1252.381	**40.761**	739.800	1209.524	**38.835**	**39.307**
18.00	737.400	1245.455	**40.793**	735.600	1222.727	**39.839**	729.900	1204.348	**39.395**	**40.009**
20.00	720.500	1208.696	**40.390**	724.700	1191.304	**39.168**	720.400	1286.364	**43.997**	**41.185**

Appendix D.7: Determination of porosity for PIONEER B12 Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	
12.00	748.600	1131.818	**33.859**	721.500	1127.273	**35.996**	739.800	1177.273	**37.160**	**35.671**
14.00	711.800	1145.833	**37.879**	725.600	1150.000	**36.904**	728.900	1145.833	**36.387**	**37.057**
16.00	703.600	1160.870	**39.390**	712.400	1169.565	**39.088**	710.800	1152.174	**38.308**	**38.929**
18.00	681.800	1134.783	**39.918**	698.500	1165.217	**40.054**	688.500	1204.545	**42.842**	**40.938**
20.00	679.400	1175.000	**42.179**	676.600	1180.000	**42.661**	675.800	1180.000	**42.729**	**42.523**

Appendix D.8: Determination of porosity for EDEN Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	
12.00	830.200	1200.000	**30.817**	837.600	1275.000	**34.306**	826.400	1306.250	**36.735**	**33.952**
14.00	811.000	1256.250	**35.443**	815.000	1281.250	**36.390**	814.800	1306.250	**37.623**	**36.485**
16.00	796.100	1362.500	**41.571**	801.400	1375.000	**41.716**	802.600	1288.235	**37.698**	**40.328**
18.00	786.600	1335.294	**41.092**	791.800	1376.471	**42.476**	787.400	1347.059	**41.547**	**41.705**
20.00	768.000	1355.556	**43.344**	774.000	1372.222	**43.595**	771.500	1366.667	**43.549**	**43.496**

Appendix D.9: Determination of porosity for NANIYA Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	
12.00	728.800	1137.500	**35.930**	734.000	1128.125	**34.936**	730.000	1162.500	**37.204**	**36.023**
14.00	723.300	1177.500	**38.573**	725.600	1193.750	**39.217**	724.900	1181.250	**38.633**	**38.808**
16.00	694.100	1219.375	**43.077**	698.700	1200.000	**41.775**	710.400	1164.706	**39.006**	**41.286**
18.00	680.700	1180.000	**42.314**	695.600	1170.588	**40.577**	698.400	1242.353	**43.784**	**42.225**
20.00	679.540	1164.444	**41.643**	685.890	1216.111	**43.600**	687.900	1221.111	**43.666**	**42.969**

Appendix D.10: Determination of porosity for RUDHIRA 145 Variety at different moisture contents

Moisture content % w.b.	Replications									Average
	1			2			3			
	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (% w.b.)	
12.00	829.300	1282.143	**35.319**	823.100	1241.379	**33.695**	831.600	1292.857	**35.677**	**34.897**
14.00	821.400	1286.207	**36.138**	819.800	1324.138	**38.088**	820.800	1260.000	**34.857**	**36.361**
16.00	804.600	1293.333	**37.789**	796.400	1320.000	**39.667**	799.000	1286.667	**37.902**	**38.452**
18.00	793.200	1300.000	**38.985**	787.800	1293.548	**39.098**	786.400	1320.000	**40.424**	**39.502**
20.00	786.600	1253.125	**37.229**	787.400	1334.375	**40.991**	789.600	1354.839	**41.720**	**39.980**

Appendix E.1: Determination of thousand grain weight for different varieties of maize at different moisture contents

	DHM 117				DHM115			
Moisture content % w.b.	**Replications (gm)**			**Average**	**Replications (gm)**			**Average**
	1	**2**	**3**		**1**	**2**	**3**	
12.0	323.560	345.590	338.470	**335.873**	290.850	325.910	315.680	**310.813**
14.0	347.000	342.300	345.760	**345.020**	347.900	332.500	311.890	**330.763**
16.0	350.900	354.600	355.120	**353.540**	344.700	324.500	350.800	**340.000**
18.0	361.900	367.800	365.330	**365.010**	347.500	341.800	339.500	**342.933**
20.0	371.000	375.700	374.500	**373.733**	352.000	348.000	349.900	**349.967**

	AMBER CORN				MADHURI			
Moisture content % w.b.	**Replications (gm)**			**Average**	**Replications (gm)**			**Average**
	1	**2**	**3**		**1**	**2**	**3**	
12.0	96.220	94.750	95.600	**95.523**	121.320	125.480	136.120	**127.640**
14.0	98.540	96.230	97.430	**97.400**	126.880	129.900	127.900	**128.227**
16.0	101.300	103.800	103.900	**103.000**	130.670	132.400	133.900	**132.323**
18.0	109.300	112.200	110.500	**110.667**	136.900	135.870	136.540	**136.437**
20.0	123.800	115.800	110.400	**116.667**	138.600	137.800	137.500	**137.967**

Appendix E.2: Determination of thousand grain weight for different varieties of maize at different moisture contents

30V92					900M GOLD			
Moisture content % w.b	Replications (gm)			Average	Replications (gm)			Average
	1	2	3		1	2	3	
12.0	253.260	244.680	248.120	**248.687**	234.160	231.300	233.140	**232.867**
14.0	269.000	267.100	271.200	**269.100**	247.600	246.900	246.600	**247.033**
16.0	284.100	274.100	279.880	**279.360**	263.400	256.600	266.600	**262.200**
18.0	287.900	288.800	289.440	**288.713**	267.000	266.800	268.100	**267.300**
20.0	289.100	290.100	295.900	**291.700**	269.000	271.600	270.660	**270.420**

PIONEER B12					EDEN			
Moisture content % w.b.	Replications (gm)			Average	Replications (gm)			Average
	1	2	3		1	2	3	
12.0	238.950	236.140	239.110	**238.067**	209.260	198.370	205.760	**204.463**
14.0	245.440	246.100	244.650	**245.397**	201.880	205.500	210.430	**205.937**
16.0	261.600	263.100	264.650	**263.117**	218.500	220.800	220.500	**219.933**
18.0	267.100	269.400	268.880	**268.460**	227.800	234.000	231.600	**231.133**
20.0	274.600	276.500	277.400	**276.167**	238.500	223.100	235.680	**232.427**

Appendix E.3: Determination of thousand grain weight for different varieties of maize at different moisture contents

NANIYA					RUDHIRA 145			
Moisture content % w.b.	**Replications (gm)**			**Average**	**Replications (gm)**			**Average**
	1	**2**	**3**		**1**	**2**	**3**	
12.0	182.450	180.570	186.880	**183.300**	337.420	342.480	332.840	**337.580**
14.0	188.400	191.000	189.700	**189.700**	346.780	348.120	344.560	**346.487**
16.0	190.100	199.200	195.600	**194.967**	347.780	348.120	349.560	**348.487**
18.0	200.600	198.500	199.700	**199.600**	351.560	352.760	354.870	**353.063**
20.0	202.600	208.400	209.400	**206.800**	352.600	358.900	357.140	**356.213**

Appendix F.1: Determination of angle of repose and coefficient of static friction for DHM 117 variety at different moisture contents

Angle of repose						coefficient of static friction			
	Moisture Content % w.b.	Replications			Average	Replications			Average
		1	2	3		1	2	3	
MILD STEEL	**12.0**	24.000	24.000	25.000	**24.333**	0.445	0.445	0.467	**0.452**
	14.0	28.000	27.000	28.000	**27.667**	0.532	0.510	0.532	**0.525**
	16.0	32.000	30.000	32.000	**31.333**	0.625	0.578	0.625	**0.609**
	18.0	35.000	36.000	34.000	**35.000**	0.701	0.727	0.675	**0.701**
	20.0	38.000	39.000	38.000	**38.333**	0.782	0.810	0.782	**0.791**
	Moisture Content % w.b.	Replications			Average	Replications			Average
		1	2	3		1	2	3	
PLYWOOD	**12.0**	26.000	25.000	25.000	**25.333**	0.488	0.467	0.467	**0.474**
	14.0	29.000	30.000	30.000	**29.667**	0.555	0.578	0.578	**0.570**
	16.0	33.000	33.000	32.000	**32.667**	0.650	0.650	0.625	**0.642**
	18.0	37.000	37.000	36.000	**36.667**	0.754	0.754	0.727	**0.745**
	20.0	40.000	39.000	39.000	**39.333**	0.840	0.810	0.810	**0.820**
	Moisture Content % w.b.	Replications			Average	Replications			Average
		1	2	3		1	2	3	
GLASS	**12.0**	22.000	22.000	22.000	**22.000**	0.404	0.404	0.404	**0.404**
	14.0	24.000	24.000	23.000	**23.667**	0.445	0.445	0.425	**0.439**
	16.0	25.000	24.000	24.000	**24.333**	0.467	0.445	0.445	**0.452**
	18.0	28.000	28.000	28.000	**28.000**	0.532	0.532	0.532	**0.532**
	20.0	32.000	32.000	32.000	**32.000**	0.625	0.625	0.625	**0.625**

Appendix F.2: Determination of angle of repose and coefficient of static friction for DHM 115 variety at different conditions

	Angle of repose					coefficient of static friction			
	Moisture Content % w.b.	**Replications**			**Average**	**Replications**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
MILD STEEL	**12.0**	23.000	22.000	23.000	**22.667**	0.425	0.404	0.425	**0.418**
	14.0	26.000	25.000	25.000	**25.333**	0.488	0.467	0.467	**0.474**
	16.0	28.000	28.000	27.000	**27.667**	0.532	0.532	0.510	**0.525**
	18.0	31.000	30.000	30.000	**30.333**	0.601	0.578	0.578	**0.585**
	20.0	35.000	35.000	35.000	**35.000**	0.701	0.701	0.701	**0.701**
	Moisture Content % w.b.	**Replications**			**Average**	**Replications**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
PLYWOOD	**12.0**	25.000	24.000	24.000	**24.333**	0.467	0.445	0.445	**0.452**
	14.0	28.000	28.000	29.000	**28.333**	0.532	0.532	0.555	**0.539**
	16.0	32.000	32.000	31.000	**31.667**	0.625	0.625	0.601	**0.617**
	18.0	36.000	36.000	35.000	**35.667**	0.727	0.727	0.701	**0.718**
	20.0	39.000	38.000	38.000	**38.333**	0.810	0.782	0.782	**0.791**
	Moisture Content % w.b.	**Replications**			**Average**	**Replications**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
GLASS	**12.0**	20.000	21.000	22.000	**21.000**	0.364	0.384	0.404	**0.384**
	14.0	22.000	24.000	24.000	**23.333**	0.404	0.445	0.445	**0.432**
	16.0	23.000	24.000	24.000	**23.667**	0.425	0.445	0.445	**0.439**
	18.0	25.000	25.000	24.000	**24.667**	0.467	0.467	0.445	**0.459**
	20.0	27.000	27.000	28.000	**27.333**	0.510	0.510	0.532	**0.517**

Appendix F.3: Determination of angle of repose and coefficient of static friction for AMBER CORN variety at different conditions

Angle of repose						coefficient of static friction			
	Moisture Content % w.b.	**Replications**			**Average**	**Replications**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
MILD STEEL	**12.0**	27.000	28.000	27.000	**27.333**	0.510	0.532	0.510	**0.517**
	14.0	28.000	29.000	29.000	**28.667**	0.532	0.555	0.555	**0.547**
	16.0	30.000	30.000	32.000	**30.667**	0.578	0.578	0.625	**0.593**
	18.0	32.000	32.000	33.000	**32.333**	0.625	0.625	0.650	**0.633**
	20.0	34.000	35.000	35.000	**34.667**	0.675	0.701	0.701	**0.692**
PLYWOOD	**Moisture Content % w.b.**	**Replications**			**Average**	**Replications**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
	12.0	28.000	29.000	28.000	**28.333**	0.532	0.555	0.532	**0.539**
	14.0	31.000	31.000	30.000	**30.667**	0.601	0.601	0.578	**0.593**
	16.0	32.000	33.000	33.000	**32.667**	0.625	0.650	0.650	**0.642**
	18.0	34.000	34.000	35.000	**34.333**	0.675	0.675	0.701	**0.683**
	20.0	37.000	38.000	37.000	**37.333**	0.754	0.782	0.754	**0.763**
GLASS	**Moisture Content % w.b.**	**Replications**			**Average**	**Replications**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
	12.0	27.000	27.000	26.000	**26.667**	0.510	0.510	0.488	**0.502**
	14.0	28.000	28.000	27.000	**27.667**	0.532	0.532	0.510	**0.525**
	16.0	30.000	30.000	30.000	**30.000**	0.578	0.578	0.578	**0.578**
	18.0	32.000	32.000	31.000	**31.667**	0.625	0.625	0.601	**0.617**
	20.0	33.000	34.000	33.000	**33.333**	0.650	0.675	0.650	**0.658**

Appendix F.4: Determination of angle of repose and coefficient of static friction for MADHURI variety at different conditions

Angle of repose						coefficient of static friction			
	Moisture Content % w.b.	**Replications**			**Average**	**Replications**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
MILD STEEL	**12.0**	26.000	25.000	26.000	**25.667**	0.488	0.467	0.488	**0.481**
	14.0	27.000	27.000	28.000	**27.333**	0.510	0.510	0.532	**0.517**
	16.0	29.000	29.000	29.000	**29.000**	0.555	0.555	0.555	**0.555**
	18.0	32.000	32.000	31.000	**31.667**	0.625	0.625	0.601	**0.617**
	20.0	35.000	35.000	34.000	**34.667**	0.701	0.701	0.675	**0.692**
	Moisture Content % w.b.	**Replications**			**Average**	**Replications**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
PLYWOOD	**12.0**	27.000	28.000	27.000	**27.333**	0.510	0.532	0.510	**0.517**
	14.0	30.000	30.000	30.000	**30.000**	0.578	0.578	0.578	**0.578**
	16.0	33.000	33.000	32.000	**32.667**	0.650	0.650	0.625	**0.642**
	18.0	35.000	35.000	34.000	**34.667**	0.701	0.701	0.675	**0.692**
	20.0	37.000	38.000	38.000	**37.667**	0.754	0.782	0.782	**0.772**
	Moisture Content % w.b.	**Replications**			**Average**	**Replications**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
GLASS	**12.0**	24.000	24.000	25.000	**24.333**	0.445	0.445	0.467	**0.452**
	14.0	27.000	27.000	27.000	**27.000**	0.510	0.510	0.510	**0.510**
	16.0	28.000	29.000	29.000	**28.667**	0.532	0.555	0.555	**0.547**
	18.0	30.000	31.000	30.000	**30.333**	0.578	0.601	0.578	**0.585**
	20.0	32.000	32.000	31.000	**31.667**	0.625	0.625	0.601	**0.617**

Appendix F.5: Determination of angle of repose and coefficient of static friction for 30V92 variety at different conditions

Angle of repose						coefficient of static friction			
	Moisture Content % w.b.	Replications			Average	Replications			Average
		1	2	3		1	2	3	
MILD STEEL	**12.0**	26.000	25.000	26.000	**25.667**	0.488	0.467	0.488	**0.481**
	14.0	27.000	27.000	27.000	**27.000**	0.510	0.510	0.510	**0.510**
	16.0	29.000	29.000	30.000	**29.333**	0.555	0.555	0.578	**0.562**
	18.0	32.000	32.000	32.000	**32.000**	0.625	0.625	0.625	**0.625**
	20.0	35.000	36.000	34.000	**35.000**	0.701	0.727	0.675	**0.701**
PLYWOOD	Moisture Content % w.b.	Replications			Average	Replications			Average
		1	2	3		1	2	3	
	12.0	28.000	27.000	27.000	**27.333**	0.532	0.510	0.510	**0.517**
	14.0	30.000	30.000	31.000	**30.333**	0.578	0.578	0.601	**0.585**
	16.0	33.000	33.000	33.000	**33.000**	0.650	0.650	0.650	**0.650**
	18.0	35.000	34.000	34.000	**34.333**	0.701	0.675	0.675	**0.683**
	20.0	37.000	37.000	38.000	**37.333**	0.754	0.754	0.782	**0.763**
GLASS	Moisture Content % w.b.	Replications			Average	Replications			Average
		1	2	3		1	2	3	
	12.0	25.000	24.000	24.000	**24.333**	0.467	0.445	0.445	**0.452**
	14.0	27.000	27.000	26.000	**26.667**	0.510	0.510	0.488	**0.502**
	16.0	29.000	29.000	28.000	**28.667**	0.555	0.555	0.532	**0.547**
	18.0	30.000	29.000	29.000	**29.333**	0.578	0.555	0.555	**0.562**
	20.0	32.000	32.000	31.000	**31.667**	0.625	0.625	0.601	**0.617**

Appendix F.6: Determination of angle of repose and coefficient of static friction for 900M GOLD variety at different conditions

Angle of repose						coefficient of static friction			
	Moisture Content % w.b.	**Replications**			**Average**	**Replications**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
MILD STEEL	**12.0**	25.000	26.000	26.000	**25.667**	0.467	0.488	0.488	**0.481**
	14.0	28.000	29.000	29.000	**28.667**	0.532	0.555	0.555	**0.547**
	16.0	31.000	31.000	32.000	**31.333**	0.601	0.601	0.625	**0.609**
	18.0	34.000	34.000	35.000	**34.333**	0.675	0.675	0.701	**0.683**
	20.0	36.000	36.000	38.000	**36.667**	0.727	0.727	0.782	**0.745**
	Moisture Content % w.b.	**Replications**			**Average**	**Replications**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
PLYWOOD	**12.0**	26.000	27.000	28.000	**27.000**	0.488	0.510	0.532	**0.510**
	14.0	29.000	29.000	28.000	**28.667**	0.555	0.555	0.532	**0.547**
	16.0	32.000	32.000	31.000	**31.667**	0.625	0.625	0.601	**0.617**
	18.0	35.000	35.000	36.000	**35.333**	0.701	0.701	0.727	**0.709**
	20.0	37.000	37.000	37.000	**37.000**	0.754	0.754	0.754	**0.754**
	Moisture Content % w.b.	**Replications**			**Average**	**Replications**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
GLASS	**12.0**	24.000	24.000	24.000	**24.000**	0.445	0.445	0.445	**0.445**
	14.0	26.000	26.000	25.000	**25.667**	0.488	0.488	0.467	**0.481**
	16.0	27.000	27.000	27.000	**27.000**	0.510	0.510	0.510	**0.510**
	18.0	29.000	29.000	30.000	**29.333**	0.555	0.555	0.578	**0.562**
	20.0	31.000	31.000	30.000	**30.667**	0.601	0.601	0.578	**0.593**

Appendix F.7: Determination of angle of repose and coefficient of static friction for PIONEER B12 variety at different conditions

Angle of repose						coefficient of static friction			
	Moisture Content % w.b.	Replications			Average	Replications			Average
		1	2	3		1	2	3	
MILD STEEL	12.0	28.000	28.000	28.000	**28.000**	0.532	0.532	0.532	**0.532**
	14.0	31.000	31.000	32.000	**31.333**	0.601	0.601	0.625	**0.609**
	16.0	33.000	33.000	34.000	**33.333**	0.650	0.650	0.675	**0.658**
	18.0	36.000	37.000	37.000	**36.667**	0.727	0.754	0.754	**0.745**
	20.0	39.000	39.000	41.000	**39.667**	0.810	0.810	0.870	**0.830**
PLYWOOD	Moisture Content % w.b.	Replications			Average	Replications			Average
		1	2	3		1	2	3	
	12.0	29.000	29.000	30.000	**29.333**	0.555	0.555	0.578	**0.562**
	14.0	31.000	31.000	31.000	**31.000**	0.601	0.601	0.601	**0.601**
	16.0	35.000	35.000	34.000	**34.667**	0.701	0.701	0.675	**0.692**
	18.0	38.000	38.000	37.000	**37.667**	0.782	0.782	0.754	**0.772**
	20.0	40.000	39.000	39.000	**39.333**	0.840	0.810	0.810	**0.820**
GLASS	Moisture Content % w.b.	Replications			Average	Replications			Average
		1	2	3		1	2	3	
	12.0	26.000	26.000	27.000	**26.333**	0.488	0.488	0.510	**0.495**
	14.0	27.000	27.000	28.000	**27.333**	0.510	0.510	0.532	**0.517**
	16.0	29.000	29.000	29.000	**29.000**	0.555	0.555	0.555	**0.555**
	18.0	31.000	31.000	30.000	**30.667**	0.601	0.601	0.578	**0.593**
	20.0	32.000	32.000	32.000	**32.000**	0.625	0.625	0.625	**0.625**

Appendix F.8: Determination of angle of repose and coefficient of static friction for EDEN variety at different conditions

	Angle of repose					coefficient of static friction			
	Moisture Content % w.b.	Replications			Average	Replications			Average
		1	2	3		1	2	3	
MILD STEEL	**12.0**	25.000	26.000	25.000	**25.333**	0.467	0.488	0.467	**0.474**
	14.0	28.000	28.000	28.000	**28.000**	0.532	0.532	0.532	**0.532**
	16.0	31.000	30.000	30.000	**30.333**	0.601	0.578	0.578	**0.585**
	18.0	32.000	32.000	31.000	**31.667**	0.625	0.625	0.601	**0.617**
	20.0	34.000	33.000	35.000	**34.000**	0.675	0.650	0.701	**0.675**
PLYWOOD	Moisture Content % w.b.	Replications			Average	Replications			Average
		1	2	3		1	2	3	
	12.0	26.000	27.000	26.000	**26.333**	0.488	0.510	0.488	**0.495**
	14.0	29.000	29.000	29.000	**29.000**	0.555	0.555	0.555	**0.555**
	16.0	32.000	32.000	31.000	**31.667**	0.625	0.625	0.601	**0.617**
	18.0	35.000	34.000	34.000	**34.333**	0.701	0.675	0.675	**0.683**
	20.0	37.000	37.000	36.000	**36.667**	0.754	0.754	0.727	**0.745**
GLASS	Moisture Content % w.b.	Replications			Average	Replications			Average
		1	2	3		1	2	3	
	12.0	24.000	24.000	24.000	**24.000**	0.445	0.445	0.445	**0.445**
	14.0	26.000	26.000	25.000	**25.667**	0.488	0.488	0.467	**0.481**
	16.0	28.000	28.000	27.000	**27.667**	0.532	0.532	0.510	**0.525**
	18.0	29.000	29.000	27.000	**28.333**	0.555	0.555	0.510	**0.540**
	20.0	31.000	31.000	32.000	**31.333**	0.601	0.601	0.625	**0.609**

Appendix F.9: Determination of angle of repose and coefficient of static friction for NANIYA variety at different conditions

Angle of repose						coefficient of static friction			
	Moisture Content % w.b.	**Replications**			**Average**	**Replications**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
MILD STEEL	**12.0**	24.000	24.000	24.000	**24.000**	0.445	0.445	0.445	**0.445**
	14.0	25.000	25.000	26.000	**25.333**	0.467	0.467	0.488	**0.474**
	16.0	27.000	28.000	26.000	**27.000**	0.510	0.532	0.488	**0.510**
	18.0	29.000	29.000	30.000	**29.333**	0.555	0.555	0.578	**0.562**
	20.0	32.000	32.000	33.000	**32.333**	0.625	0.625	0.650	**0.633**
	Moisture Content % w.b.	**Replications**			**Average**	**Replications**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
PLYWOOD	**12.0**	25.000	25.000	26.000	**25.333**	0.467	0.467	0.488	**0.474**
	14.0	27.000	27.000	26.000	**26.667**	0.510	0.510	0.488	**0.502**
	16.0	29.000	29.000	30.000	**29.333**	0.555	0.555	0.578	**0.562**
	18.0	33.000	32.000	32.000	**32.333**	0.650	0.625	0.625	**0.633**
	20.0	35.000	35.000	36.000	**35.333**	0.701	0.701	0.727	**0.709**
	Moisture Content % w.b.	**Replications**			**Average**	**Replications**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
GLASS	**12.0**	24.000	23.000	24.000	**23.667**	0.445	0.425	0.445	**0.439**
	14.0	25.000	25.000	25.000	**25.000**	0.467	0.467	0.467	**0.467**
	16.0	27.000	27.000	26.000	**26.667**	0.510	0.510	0.488	**0.502**
	18.0	29.000	29.000	28.000	**28.667**	0.555	0.555	0.532	**0.547**
	20.0	30.000	30.000	30.000	**30.000**	0.578	0.578	0.578	**0.578**

Appendix F.10: Determination of angle of repose and coefficient of static friction for RUDHIRA 145 Variety at different conditions

	Angle of repose					coefficient of static friction			
	Moisture Content % w.b.	**Replication (gm)**			**Average**	**Replication (gm)**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
MILD STEEL	**12.0**	21.000	20.000	20.000	**20.333**	0.384	0.364	0.364	**0.371**
	14.0	22.000	21.000	22.000	**21.667**	0.404	0.384	0.404	**0.397**
	16.0	23.000	23.000	23.000	**23.000**	0.425	0.425	0.425	**0.425**
	18.0	24.000	23.000	23.000	**23.333**	0.445	0.425	0.425	**0.432**
	20.0	25.000	25.000	26.000	**25.333**	0.467	0.467	0.488	**0.474**
	Moisture Content % w.b.	**Replication (gm)**			**Average**	**Replication (gm)**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
PLYWOOD	**12.0**	24.000	25.000	25.000	**24.667**	0.445	0.467	0.467	**0.459**
	14.0	25.000	25.000	26.000	**25.333**	0.467	0.467	0.488	**0.474**
	16.0	27.000	27.000	27.000	**27.000**	0.510	0.510	0.510	**0.510**
	18.0	28.000	29.000	29.000	**28.667**	0.532	0.555	0.555	**0.547**
	20.0	30.000	31.000	31.000	**30.667**	0.578	0.601	0.601	**0.593**
	Moisture Content % w.b.	**Replication (gm)**			**Average**	**Replication (gm)**			**Average**
		1	**2**	**3**		**1**	**2**	**3**	
GLASS	**12.0**	17.000	17.000	18.000	**17.333**	0.306	0.306	0.325	**0.312**
	14.0	18.000	18.000	18.000	**18.000**	0.325	0.325	0.325	**0.325**
	16.0	20.000	19.000	19.000	**19.333**	0.364	0.344	0.344	**0.351**
	18.0	21.000	22.000	21.000	**21.333**	0.384	0.404	0.384	**0.391**
	20.0	22.000	22.000	22.000	**22.000**	0.404	0.404	0.404	**0.404**

Appendix G.1: Determination of performance evaluation of existing ANGRAU maize sheller at feed rate of 65 kg/h for different moisture contents

	Moisture content 10 % w.b.				Moisture content 12 % w.b.				Moisture content 14 % w.b.			
	REPLICATIONS			**Average**	**REPLICATIONS**			**Average**	**REPLICATIONS**			**Average**
	1	**2**	**3**		**1**	**2**	**3**		**1**	**2**	**3**	
Intial weight of unshelled cobs	2.167	2.168	2.167	**2.167**	2.168	2.168	2.168	**2.168**	2.168	2.167	2.166	**2.167**
Grain content	3.000	3.000	3.000	**3.000**	3.040	3.040	3.040	**3.040**	3.060	3.060	3.060	**3.060**
Total grain input	6.500	6.504	6.502	**6.502**	6.592	6.590	6.591	**6.591**	6.634	6.630	6.629	**6.631**
Weight of grains from outlet	0.557	0.553	0.558	**0.556**	0.544	0.550	0.552	**0.549**	0.494	0.474	0.465	**0.478**
Wastage (chaff+grains +unshelled)	1.610	1.615	1.609	**1.611**	1.624	1.618	1.616	**1.619**	1.674	1.693	1.701	**1.689**
Weight of grains blown out	0.185	0.189	0.186	**0.187**	0.182	0.185	0.172	**0.180**	0.170	0.174	0.175	**0.173**
Weight of unshelled grains	1.301	1.289	1.299	**1.296**	1.301	1.302	1.300	**1.301**	1.380	1.395	1.402	**1.392**
Weight of visible damage grains	0.016	0.020	0.018	**0.018**	0.012	0.014	0.013	**0.013**	0.020	0.021	0.021	**0.021**
Shelling efficiency % w.b.	79.986	80.181	80.020	**80.063**	80.264	80.241	80.275	**80.260**	79.198	78.961	78.851	**79.003**
Unshelled grain % w.b.	20.014	19.819	19.980	**19.937**	19.736	19.759	19.725	**19.740**	20.802	21.039	21.149	**20.997**
Visible damage % w.b.	2.156	2.695	2.419	**2.424**	1.653	1.905	1.823	**1.794**	3.060	3.198	3.256	**3.172**

Appendix G.2: Determination of performance evaluation of existing ANGRAU maize sheller at feed rate of 65 kg/h for different moisture contents

	Moisture content 16 % w.b.				Moisture content 18 % w.b.				Moisture content 20 % w.b.			
	REPLICATIONS			**Average**	**REPLICATIONS**			**Average**	**REPLICATIONS**			**Average**
	1	**2**	**3**		**1**	**2**	**3**		**1**	**2**	**3**	
Intial weight of unshelled cobs	2.168	2.167	2.166	**2.167**	2.168	2.167	2.166	**2.167**	2.168	2.167	2.166	**2.167**
Grain content	3.090	3.090	3.090	**3.090**	3.110	3.110	3.110	**3.110**	3.120	3.120	3.120	**3.120**
Total grain input	6.699	6.695	6.694	**6.696**	6.742	6.739	6.738	**6.740**	6.764	6.760	6.759	**6.761**
Weight of grains from outlet	0.378	0.394	0.426	**0.399**	0.296	0.293	0.294	**0.294**	0.218	0.211	0.204	**0.211**
Wastage (chaff+grains +unshelled)	1.790	1.773	1.740	**1.768**	1.872	1.874	1.872	**1.873**	1.950	1.956	1.962	**1.956**
Weight of grains blown out	0.152	0.154	0.161	**0.156**	0.131	0.130	0.129	**0.130**	0.110	0.112	0.117	**0.113**
Weight of unshelled grains	1.514	1.495	1.456	**1.488**	1.617	1.620	1.619	**1.619**	1.716	1.720	1.721	**1.719**
Weight of visible damage grains	0.027	0.028	0.029	**0.028**	0.033	0.028	0.032	**0.031**	0.032	0.031	0.031	**0.031**
Shelling efficiency % w.b.	77.400	77.671	78.250	**77.774**	76.018	75.960	75.970	**75.983**	74.631	74.558	74.538	**74.576**
Unshelled grain % w.b.	22.600	22.329	21.750	**22.226**	23.982	24.040	24.030	**24.017**	25.369	25.442	25.462	**25.424**
Visible damage % w.b.	5.170	5.175	5.022	**5.122**	7.700	6.695	7.565	**7.320**	9.756	9.721	9.660	**9.713**

Appendix G.3: Determination of performance evaluation of modified ANGRAU maize sheller at feed rate of 65 kg/h for different moisture contents

	10 % w.b.				12 % w.b.				14 % w.b.			
	REPLICATIONS			**Average**	**REPLICATIONS**			**Average**	**REPLICATIONS**			**Average**
	1	2	3		1	2	3		1	2	3	
Intial weight of unshelled cobs	2.205	2.150	2.190	**2.182**	2.185	2.205	2.190	**2.193**	2.185	2.205	2.190	**2.193**
Grain content	3.000	3.000	3.000	**3.000**	3.040	3.040	3.040	**3.040**	3.060	3.060	3.060	**3.060**
Total grain input	6.615	6.450	6.570	**6.545**	6.642	6.703	6.658	**6.668**	6.686	6.747	6.701	**6.712**
Weight of grains from outlet	1.689	1.697	1.696	**1.694**	1.728	1.761	1.762	**1.750**	1.598	1.573	1.601	**1.591**
Wastage (chaff+grains +unshelled)	0.532	0.473	0.494	**0.500**	0.457	0.440	0.428	**0.442**	0.587	0.632	0.589	**0.603**
Weight of grains blown out	0.140	0.148	0.145	**0.144**	0.107	0.108	0.106	**0.107**	0.125	0.144	0.135	**0.135**
Weight of unshelled grains	0.050	0.042	0.044	**0.045**	0.080	0.082	0.088	**0.083**	0.139	0.136	0.135	**0.137**
Weight of visible damage grains	0.049	0.035	0.031	**0.038**	0.023	0.021	0.024	**0.023**	0.040	0.046	0.037	**0.041**
Shelling efficiency % w.b.	99.244	99.349	99.330	**99.308**	98.796	98.777	98.678	**98.750**	97.921	97.984	97.985	**97.964**
Unshelled grain % w.b.	0.756	0.651	0.670	**0.692**	1.204	1.223	1.322	**1.250**	2.079	2.016	2.015	**2.036**
Visible damage % w.b.	2.706	1.903	1.657	**2.089**	1.253	1.097	1.285	**1.212**	2.307	2.653	2.131	**2.364**

Appendix G.4: Determination of performance evaluation of modified ANGRAU maize sheller at feed rate of 65 kg/h for different moisture contents

	16 % w.b.				18 % w.b.				20 % w.b.			
	REPLICATIONS			**Average**	**REPLICATIONS**			**Average**	**REPLICATIONS**			**Average**
	1	2	3		1	2	3		1	2	3	
Intial weight of unshelled cobs	2.165	2.200	2.180	**2.182**	2.225	2.210	2.190	**2.208**	2.175	2.200	2.175	**2.183**
Grain content	3.090	3.090	3.090	**3.090**	3.110	3.110	3.110	**3.110**	3.120	3.120	3.120	**3.120**
Total grain input	6.690	6.798	6.736	**6.741**	6.920	6.873	6.811	**6.868**	6.786	6.864	6.786	**6.812**
Weight of grains from outlet	1.125	1.283	1.057	**1.155**	0.769	0.683	0.629	**0.694**	0.454	0.446	0.390	**0.430**
Wastage (chaff+grains +unshelled)	1.040	0.917	1.023	**0.993**	1.456	1.547	1.561	**1.521**	1.721	1.754	1.795	**1.757**
Weight of grains blown out	0.133	0.155	0.130	**0.139**	0.118	0.105	0.110	**0.111**	0.081	0.084	0.075	**0.080**
Weight of unshelled grains	0.287	0.281	0.273	**0.280**	0.650	0.668	0.674	**0.664**	0.800	0.843	0.799	**0.814**
Weight of visible damage grains	0.040	0.049	0.047	**0.045**	0.035	0.028	0.038	**0.033**	0.031	0.030	0.027	**0.029**
Shelling efficiency % w.b.	95.710	95.866	95.947	**95.841**	90.607	90.281	90.104	**90.331**	88.211	87.719	88.226	**88.052**
Unshelled grain % w.b.	4.290	4.134	4.053	**4.159**	9.393	9.719	9.896	**9.669**	11.789	12.281	11.774	**11.948**
Visible damage % w.b.	3.200	3.373	3.981	**3.518**	3.918	3.490	5.115	**4.174**	5.701	5.683	5.722	**5.702**

Appendix H.1: Determination of performance evaluation of modified ANGRAU maize sheller at 10% w.b. moisture content for different feed rates

	120 kg/h				130 kg/h				140 kg/h			
	REPLICATIONS			**Average**	REPLICATIONS			**Average**	**REPLICATIONS**			**Average**
	1	2	3		1	2	3		1	2	3	
Intial weight of unshelled cobs	4.080	4.060	4.030	**4.057**	4.410	4.300	4.380	**4.363**	4.690	4.700	4.710	**4.700**
Grain content	5.820	5.820	5.820	**5.820**	5.820	5.820	5.820	**5.820**	5.820	5.820	5.820	**5.820**
Total grain input	23.746	23.629	23.455	**23.610**	25.666	25.026	25.492	**25.395**	27.296	27.354	27.412	**27.354**
Weight of grains from outlet	3.340	3.350	3.300	**3.330**	3.530	3.490	3.500	**3.507**	3.800	3.850	3.840	**3.830**
Wastage (chaff+grains +unshelled)	0.804	0.740	0.718	**0.754**	0.870	0.790	0.850	**0.837**	0.840	0.830	0.860	**0.843**
Weight of grains blown out	0.290	0.300	0.240	**0.277**	0.281	0.278	0.272	**0.277**	0.318	0.315	0.305	**0.313**
Weight of unshelled grains	0.099	0.094	0.095	**0.096**	0.078	0.072	0.073	**0.074**	0.081	0.081	0.089	**0.084**
Weight of visible damage grains	0.088	0.069	0.078	**0.078**	0.079	0.069	0.078	**0.075**	0.085	0.086	0.085	**0.085**
Shelling efficiency % w.b.	99.583	99.602	99.595	**99.593**	99.696	99.713	99.714	**99.708**	99.703	99.703	99.675	**99.694**
Unshelled grain % w.b.	0.417	0.398	0.405	**0.407**	0.304	0.287	0.286	**0.292**	0.297	0.297	0.325	**0.306**
Visible damage % w.b.	2.424	1.901	2.203	**2.176**	2.072	1.839	2.071	**1.994**	2.064	2.065	2.051	**2.060**

Appendix H.2: Determination of performance evaluation of modified ANGRAU maize sheller at 12% w.b. moisture content for different feed rates

	120 kg/h				130 kg/h				140 kg/h			
	REPLICATIONS			**Average**	**REPLICATIONS**			**Average**	**REPLICATIONS**			**Average**
	1	2	3		1	2	3		1	2	3	
Intial weight of unshelled cobs	4.020	4.020	4.000	**4.013**	4.370	4.410	4.380	**4.387**	4.680	4.690	4.680	**4.683**
Grain content	5.840	5.840	5.840	**5.840**	5.840	5.840	5.840	**5.840**	5.840	5.840	5.840	**5.840**
Total grain input	23.477	23.477	23.360	**23.438**	25.521	25.754	25.579	**25.618**	27.331	27.390	27.331	**27.351**
Weight of grains from outlet	3.300	3.230	3.290	**3.273**	3.490	3.720	3.680	**3.630**	3.700	3.790	3.750	**3.747**
Wastage (chaff+grains +unshelled)	0.672	0.760	0.713	**0.715**	0.870	0.700	0.680	**0.750**	0.950	0.870	0.920	**0.913**
Weight of grains blown out	0.160	0.250	0.200	**0.203**	0.214	0.216	0.212	**0.214**	0.225	0.220	0.250	**0.232**
Weight of unshelled grains	0.142	0.197	0.112	**0.150**	0.121	0.110	0.105	**0.112**	0.149	0.145	0.142	**0.145**
Weight of visible damage grains	0.046	0.042	0.048	**0.045**	0.043	0.041	0.039	**0.041**	0.043	0.045	0.049	**0.046**
Shelling efficiency % w.b.	99.395	99.161	99.521	**99.359**	99.526	99.573	99.590	**99.563**	99.454	99.471	99.480	**99.468**
Unshelled grain % w.b.	0.605	0.839	0.479	**0.641**	0.474	0.427	0.410	**0.437**	0.546	0.529	0.520	**0.532**
Visible damage % w.b.	1.324	1.216	1.372	**1.304**	1.158	1.047	1.002	**1.069**	1.096	1.122	1.225	**1.148**

Appendix H.3: Determination of performance evaluation of modified ANGRAU maize sheller at 14% w.b. moisture content for different feed rates

	120 kg/h				130 kg/h				140 kg/h			
	REPLICATIONS			**Average**	**REPLICATIONS**			**Average**	**REPLICATIONS**			**Average**
	1	2	3		1	2	3		1	2	3	
Intial weight of unshelled cobs	4.050	4.070	4.070	**4.063**	4.370	4.410	4.380	**4.387**	4.680	4.690	4.720	**4.697**
Grain content	5.850	5.850	5.850	**5.850**	5.850	5.850	5.850	**5.850**	5.850	5.850	5.850	**5.850**
Total grain input	23.693	23.810	23.810	**23.771**	25.565	25.799	25.623	**25.662**	27.378	27.437	27.612	**27.476**
Weight of grains from outlet	2.449	2.412	2.535	**2.465**	3.381	3.408	3.389	**3.393**	3.563	3.575	3.600	**3.579**
Wastage (chaff+grains +unshelled)	0.991	1.028	0.935	**0.985**	0.989	1.000	0.999	**0.996**	1.117	1.115	1.100	**1.111**
Weight of grains blown out	0.210	0.230	0.200	**0.213**	0.265	0.268	0.282	**0.272**	0.303	0.305	0.312	**0.307**
Weight of unshelled grains	0.291	0.298	0.295	**0.295**	0.274	0.282	0.279	**0.278**	0.314	0.310	0.300	**0.308**
Weight of visible damage grains	0.076	0.082	0.079	**0.079**	0.087	0.080	0.083	**0.083**	0.086	0.089	0.097	**0.091**
Shelling efficiency % w.b.	98.772	98.748	98.761	**98.760**	98.928	98.907	98.911	**98.915**	98.853	98.870	98.914	**98.879**
Unshelled grain % w.b.	1.228	1.252	1.239	**1.240**	1.072	1.093	1.089	**1.085**	1.147	1.130	1.086	**1.121**
Visible damage % w.b.	2.858	3.089	2.893	**2.947**	2.375	2.184	2.272	**2.277**	2.225	2.294	2.480	**2.333**

Appendix H.4: Determination of performance evaluation of modified ANGRAU maize sheller at 16% w.b. moisture content for different feed rates

	120 kg/h				130 kg/h				140 kg/h			
	REPLICATIONS			**Average**	**REPLICATIONS**			**Average**	**REPLICATIONS**			**Average**
	1	2	3		1	2	3		1	2	3	
Intial weight of unshelled cobs	4.050	4.060	4.080	**4.063**	4.330	4.400	4.360	**4.363**	4.680	4.690	4.710	**4.693**
Grain content	5.880	5.880	5.880	**5.880**	5.880	5.880	5.880	**5.880**	5.880	5.880	5.880	**5.880**
Total grain input	23.814	23.873	23.990	**23.892**	25.460	25.872	25.637	**25.656**	27.518	27.577	27.695	**27.597**
Weight of grains from outlet	2.632	2.697	2.643	**2.657**	2.819	2.886	2.834	**2.846**	2.983	2.981	2.994	**2.986**
Wastage (chaff+grains +unshelled)	1.418	1.363	1.437	**1.406**	1.511	1.514	1.524	**1.516**	1.697	1.709	1.716	**1.707**
Weight of grains blown out	0.276	0.279	0.281	**0.279**	0.273	0.278	0.280	**0.277**	0.307	0.303	0.300	**0.303**
Weight of unshelled grains	0.758	0.797	0.776	**0.777**	0.788	0.786	0.796	**0.790**	0.880	0.876	0.882	**0.879**
Weight of visible damage grains	0.110	0.118	0.101	**0.110**	0.098	0.099	0.096	**0.098**	0.040	0.043	0.039	**0.041**
Shelling efficiency % w.b.	96.817	96.661	96.765	**96.748**	96.905	96.962	96.895	**96.921**	96.802	96.823	96.815	**96.814**
Unshelled grain % w.b.	3.183	3.339	3.235	**3.252**	3.095	3.038	3.105	**3.079**	3.198	3.177	3.185	**3.186**
Visible damage % w.b.	3.783	3.965	3.454	**3.734**	3.176	3.129	3.070	**3.125**	1.216	1.309	1.184	**1.236**

Appendix H.5: Determination of performance evaluation of modified ANGRAU maize sheller at 18% w.b. moisture content for different feed rates

	120 kg/h				130 kg/h				140 kg/h			
	REPLICATIONS			**Average**	**REPLICATIONS**			**Average**	**REPLICATIONS**			**Average**
	1	2	3		1	2	3		1	2	3	
Intial weight of unshelled cobs	4.060	4.090	4.040	**4.063**	4.450	4.420	4.380	**4.417**	4.720	4.690	4.710	**4.707**
Grain content	5.900	5.900	5.900	**5.900**	5.900	5.900	5.900	**5.900**	5.900	5.900	5.900	**5.900**
Total grain input	23.954	24.131	23.836	**23.974**	26.255	26.078	25.842	**26.058**	27.848	27.671	27.789	**27.769**
Weight of grains from outlet	2.167	2.134	2.141	**2.147**	2.390	2.365	2.340	**2.365**	2.479	2.452	2.366	**2.432**
Wastage (chaff+grains +unshelled)	1.893	1.956	1.899	**1.916**	2.060	2.052	2.040	**2.051**	2.241	2.238	2.244	**2.241**
Weight of grains blown out	0.284	0.290	0.285	**0.286**	0.275	0.274	0.280	**0.276**	0.325	0.320	0.319	**0.321**
Weight of unshelled grains	1.235	1.296	1.244	**1.258**	1.321	1.317	1.310	**1.316**	1.416	1.418	1.425	**1.420**
Weight of visible damage grains	0.121	0.123	0.112	**0.119**	0.121	0.117	0.110	**0.116**	0.125	0.121	0.126	**0.124**
Shelling efficiency % w.b.	94.844	94.629	94.781	**94.752**	94.969	94.950	94.931	**94.950**	94.915	94.876	94.872	**94.888**
Unshelled grain % w.b.	5.156	5.371	5.219	**5.248**	5.031	5.050	5.069	**5.050**	5.085	5.124	5.128	**5.112**
Visible damage % w.b.	4.937	5.074	4.617	**4.876**	4.540	4.433	4.198	**4.391**	4.440	4.380	4.693	**4.504**

Appendix H.6: Determination of performance evaluation of modified ANGRAU maize sheller at 20% w.b. moisture content for different feed rates

	120 kg/h				130 kg/h				140 kg/h			
	REPLICATIONS			**Average**	**REPLICATIONS**			**Average**	**REPLICATIONS**			**Average**
	1	2	3		1	2	3		1	2	3	
Intial weight of unshelled cobs	4.060	4.090	4.040	**4.063**	4.350	4.400	4.350	**4.367**	4.710	4.690	4.720	**4.707**
Grain content	5.930	5.930	5.930	**5.930**	5.930	5.930	5.930	**5.930**	5.930	5.930	5.930	**5.930**
Total grain input	24.076	24.254	23.957	**24.096**	25.796	26.092	25.796	**25.894**	27.930	27.812	27.990	**27.911**
Weight of grains from outlet	1.533	1.484	1.543	**1.520**	1.718	1.845	1.798	**1.787**	1.898	1.880	1.879	**1.886**
Wastage (chaff+grains +unshelled)	2.527	2.606	2.497	**2.543**	2.632	2.555	2.552	**2.580**	2.812	2.810	2.821	**2.814**
Weight of grains blown out	0.260	0.252	0.265	**0.259**	0.290	0.289	0.292	**0.290**	0.312	0.319	0.316	**0.316**
Weight of unshelled grains	1.867	1.954	1.832	**1.884**	1.892	1.816	1.810	**1.839**	1.990	1.992	1.995	**1.992**
Weight of visible damage grains	0.100	0.093	0.096	**0.096**	0.109	0.106	0.112	**0.109**	0.116	0.119	0.118	**0.118**
Shelling efficiency % w.b.	92.245	91.943	92.353	**92.181**	92.665	93.040	92.983	**92.896**	92.875	92.838	92.872	**92.862**
Unshelled grain % w.b.	7.755	8.057	7.647	**7.819**	7.335	6.960	7.017	**7.104**	7.125	7.162	7.128	**7.138**
Visible damage % w.b.	5.577	5.357	5.310	**5.415**	5.428	4.968	5.359	**5.252**	5.248	5.412	5.376	**5.345**

Appendix H.7: Determination of performance evaluation of modified tubular maize sheller

Replications	Output Capacity for 5 min	Out Put capacity, Kg/h
1	2010	24.12
2	1964	23.568
3	1859	22.308
4	2156	25.872
5	2080	24.96
6	1890	22.68
7	2198	26.376
8	1799	21.588
9	1976	23.712
10	2198	26.376
Average	2013	24.156