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# A Review on Solar Powered Maize Dehusker cum Sheller for Sustainable Agriculture

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***Abstract*— *Maize (Zea mays) in India ranks third in total production and productivity and fifth in total area. Since last one decade, maize cultivation area is continuously increasing to encounter the rising demand in the world. Shelling is one of the most important post harvesting operation which is used to separate the grains from ear heads and prepare its quality for the market. Maize grain harvesting consist of the dehusking operation for removal of outer cover and shelling operation for separations of grains from ear heads. This review aims to collate and present an overview of design, fabrication, and performance of a maize dehusker cum sheller consisting of feed hopper with a flow rate control device, dehusking unit, shelling unit, cleaning unit and power system. The performance of the machine was evaluated in terms of throughput capacity, dehusking efficiency, shelling efficiency, cleaning efficiency and mechanical damage. Solar power is ideally used in India due to location factor and also gives the benefit to the environment as renewable energy. Solar power operated maize dehusker cum sheller gives a significance in many rural locations of most developing countries were grid connected electricity is either unavailable or unreliable or too expensive so using of solar power is beneficial.*

***Keywords*— Maize, Dehusking, Shelling, Solar photovoltaic, Renewable, Agriculture**

## I. INTRODUCTION

Maize (called corn in the United States, Canada, and Australia) is the most widely produced important cereal crops in the world. This cereal, which originated in Mexico, is now grown in at least 164 countries around the world with a total production of more than 1 billion metric tons in 2013.It provides staple food to many populations. In developing countries maize is a major source of income to farmers among whom many are resource poor. Maize contains approximately 72% starch, 10% protein, and 4% fat, supplying an energy density of 365 Kcal/100 g and is grown throughout the world. Maize position as third largest crop of the India after rice and wheat, and it has significance as a source of a huge number of industrial products besides its use as human food and animal feed. Maize in India, contributes nearly 9 % in the national food basket. Maize is also a versatile crops. Maize is one of the agricultural semi-finished products. Every part of maize has profitable value as the grain, leaves, main crop stalk, tassel and cob can all be used to produce a large variety of food and non-food products. Maize is called as queen of cereals because it has highest genetic yield optional in all cereals and also called as king of fodder. In India maize is grown in all the seasons.

Dehusking and shelling of maize cob are the most important operations of maize. After harvesting with sickle and dehusking of cob is done by manually that is outer cover is removed and further traditionally grain is obtained by shelling the cob i.e. by beating the dehusked cobs with sticks or with fingers or sickle, etc. This action is mostly done by farmer women. In India, most of the farmers shell maize by mainly three methods namely shelling cob grain by hand; hand operated maize sheller and beating by stick method were carried for removing maize kernel from the cob. The maize dehusker cum sheller was designed and built to improve the standards of living of people living in villages of developing countries. There are several motor or engine, tractor operated maize dehusker shelling machines for dehusking and shelling purpose. This synopsis on the design and development of solar powered maize dehusker cum sheller that will separate husk from the ear head and will remove corn from corn kernel.

Solar power operated maize sheller gives a significance in a saving of fuel cost, electrical energy & also it is a more useful in an area where electricity as a major problem.

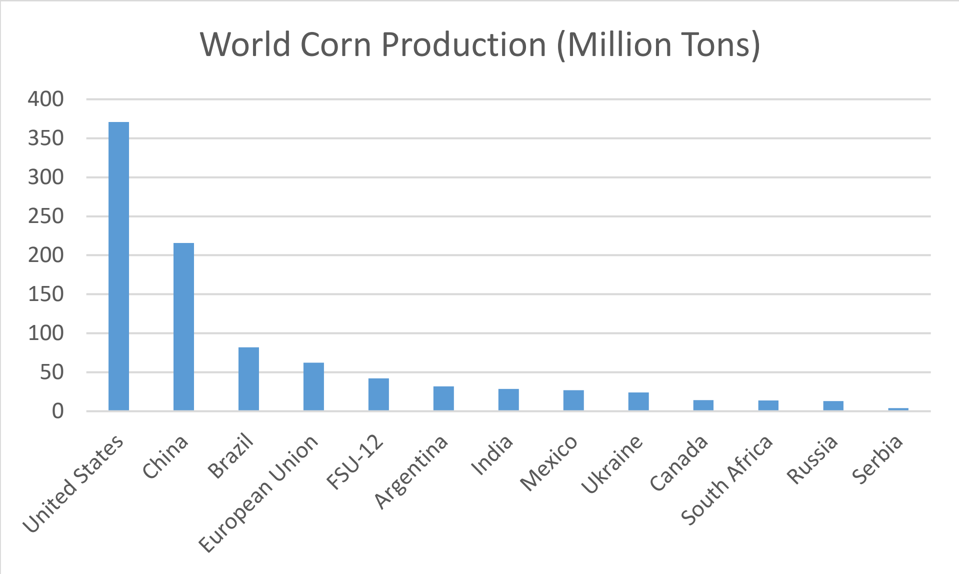


*Fig 1 World corn producing countries. (2017-2018) [70]*

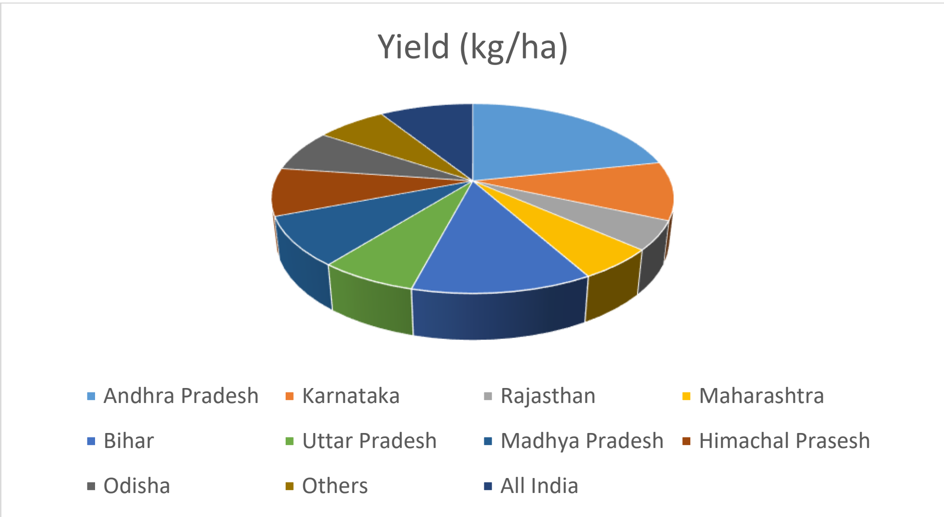


*Fig 2 Maize state wise yield of India. (2015-2016) [80]*

## II. ENGINEERING PROPERTIES OF MAIZE

The development of dehusker cum sheller for maize cobs requires the knowledge of engineering properties such as physical [shape and size, roundness, arithmetic and geometric mean diameter, sphericity, surface area, bulk density and true density], moisture content, test weight of grains and grain to dry matter [husk and grain free cob] ratio], aerodynamic [terminal velocity] and frictional [angle of repose and coefficient of friction] properties of maize grains. [6] Measurement of dimensions of materials plays a key role in deciding the volumetric capacity of hopper, clearances in concave, concave & sieve opening size, also a frictional property for deciding the tilt of sides in the hopper and sieve inclination.[6]

2.1 Physical properties of maize grains.

The physical properties of the maize samples were determined at the desired moisture content levels of 12, 14, 16, 18 and 20 (% w.b.) and they concluded that average three axial dimensions, sphericity, surface area, volume, thousand grain weight, true density, porosity and the static coefficient of friction were found to be increased and the bulk density was found to be decreased with increase in moisture content from 12 to 20 (% w.b.); all at an average temperature of 30°C.[1]

The physical properties viz., unit mass of the cob with and without husk varies from 246.92±37.49 to 371.53±68.16, linear dimension varies from 44.40±253 to 289.90, geometric mean diameter is in the range of 82.80 ± 4.92 mm to 86.60 ± 5.50 mm, arithmetic mean diameter is in the range of 123.70 ± 11.47mm to 126.20± 13.4mm, cross sectional area of the corn cobs varies from 644.50 ± 675.20mm² to 3803.4 ± 803.71mm² and shape index is in range of 5.61 ± 0.88 mm to 6.546 ± 0.96 mm also the average husk percentage content on the corn cob was in the range of 19% to 32% and thousand kernel weight of the selected corn cob verities varies from 80.50 ± 1.51g to 321.85 ± 17.18g, respectively. [2]

Three varieties of maize seed PMH-1, PMH-10 and PIONEER-3396 were evaluated for their engineering properties in the laboratory. Therefore, the physical properties of the maize seeds such as size, shape, hundred grain weight, angle of repose, bulk density and coefficient of static friction are important from engineering point of view and were studied for the development of metering mechanism of maize planter. Fifty seeds of each variety (PMH-1, PMH-10 and PIONEER-3396) were tested and observed for shape and size of the seeds. During observations their geometric mean diameter comes out to be 7.33 mm, 7.06 mm and 7.68 mm for PMH-1, PMH-10 and PIONEER-3396, respectively. The average value of angle of repose during study was observed to be 28.59°, 27.10° and 28.66° for PMH-1, PMH-10 and PIONEER-3396, respectively. The roundness observed in the laboratory was 0.74, 0.74 and 0.66 and their sphericity was 0.78, 0.79 and 0.75 for PMH-1, PMH-10 and PIONEER-3396, respectively. Bulk density for the three varieties of maize was 733.88 kgm-3, 750.01 kgm-3, 741.27 kgm-3 and the value of Coefficient of static friction was 0.64, 0.58 and 0.55 for PMH-1, PMH-10 and PIONEER3396, respectively. [3]

The physical and engineering characteristics of food material are crucial for efficient equipment design. In the present study the above characteristics were accessed for maize, pearl millet and soybean at moisture content 6.40%, 7.95% and 5.25% in the order. Data revealed that highest length, breadth and thickness (L.B.T) and geometric mean diameter (GMD) was found in maize. Test weight and thousand kernel weight ranged between 718.33 g to 791.33 g and 10.72 g to 330.21 g in the sequence, being highest for maize in both cases. The average bulk density and true density were 0.72 to 0.79 g/cc, 1.04 to 1.24 g/cc, respectively. Soybean exhibited maximum porosity trailed by maize and pearl millet. Among the grains, pearl millet had highest internal friction while maize and soybean portray the highest external friction. Referring to angle of repose, soybean showed highest value followed by maize and pearl millet. [4]

The geometric, gravimetric and frictional properties were measured at different levels of moisture content from 8.7 to 21.7% d.b. The results obtained showed that the changes in moisture content of maize kernel lead to minimum variation in geometric properties. The principle dimensions such as length, width, thickness, geometric mean diameter and surface area increased linearly while volume, 1000 kernel weight and sphericity of maize kernels increased in a non-linear manner with increase in moisture content. An increase in bulk density and true density was observed whereas the porosity decreased nonlinearly in the fixed range of moisture content (8.7, 13, 17.4 and 21.7% d.b). [5].

The physical properties such as mean linear dimensions such as length, width and thickness of maize grain were found as 10.99 mm, 8.18 mm and 5.15 mm, respectively. The mean length, diameter and weight of un-dehusked cob were 179.36 mm, 53.88 mm and 212.76 g, respectively, with a Standard Deviation [SD] of 29.56 mm, 4.37 mm and 13.56 mm, respectively. The Physical properties viz., roundness, arithmetic mean diameter, geometric mean diameter, sphericity, surface area, bulk density, true density, bulk density, true density, moisture content, test weight of grains [W1000] and grain to straw [husk and grain free cob] ratio were observed as 0.28, 8.15 mm, 7.69 mm, 0.69, 209.17 $mm^2$, 0.74 g $cc^{-1}$, 1.03 g $cc^{-1}$, 276.58 g and 3.30, respectively [6].

The physical properties that affect equipment design, processing, storage and transportation of high quality protein maize (SWAM 1) seeds as a function of moisture content varying from 9.38 to 32.7% (db). 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, 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. [7]

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The Physical and mechanical properties of maize seeds gain importance during design, improvement and optimization of separation and cleaning at a moisture content in the range of 5.15 to 22% (d. b.).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 porosity from 31.41 to 45.98%, the static angle of repose from 42 to 57º, the thousand seed mass increased from 267.7 to 305.8 g. The bulk density decreased from 679.1 to 632 kg $m^{-3}$ and true density increased from 999.33 to 1170.49 kg $m^{-3}$. [8]

The effect of moisture content on some physical properties and mechanical behavior of corn grains under compression load of two varieties of corn (Sc704 and Dc370). They used the four levels of moisture content which is ranging from 4.73-22% wet base (w.b.) for Sc704 variety and 5.15-22% w.b. for Dc 370variety. As the increasing of moisture content thousand grain weight, true density and porosity increased from 271.0 to 321.4 g & 267.7 to 305.8g, 1250 to 1325 kg/$m^3$ & 997 to 1170 kg/$m^3$ and 43.2% to 51.02% & 31.90% to 45.98% but bulk density decreased from 710 to 649 kg/$m^3$ & 679 to 632 kg/$m^3$ for Sc704 and Dc370, respectively. Also as increasing of moisture content the static coefficients of friction on various surfaces, namely, galvanized iron, plywood and plastic also increased linearly. The mechanical properties of corn like average rupture force and rupture energy calculated for both the varieties and they found that Dc370 had higher rupture force than Sc704 in all moisture content levels and the variance of rupture energy data for Sc704 was greater than those of Dc370.[9]

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11 optimization of separation and cleaning.

A database of physical and engineering properties of grains of some main and popular feed, industrial crops. The studied crops viz., fennel flower, rice (Giza 101), rice (Giza 177), broad bean, corn (hyb. 310), corn (hyb. 352), wheat (Giza 9) and wheat (Giza 168) and their selection was based on their recent coverage area and the expected future expansion of each variety. Various physical properties including grain dimensions (length, width and thickness), the weight of thousand grain, bulk density, percent of sphericity, projected area, were determined at storage moisture content 7-12% (w. b.). The physical properties of seed used to select the proper separating and cleaning equipment and the main dimensions were considered in selecting and designing the suitable size of the screen perforations. [10]

The physical properties of sweet corn seed as a function of moisture content in the range of 11.54-19.74% (d. b.). The average length, width and thickness were 10.56 mm, 7.91 mm and 3.45 mm, at moisture content of 11.54% (d. b.), respectively. The thousand seed mass increased from 131.2 to 145.5 g and the sphericity increased from 0.615 to 0.635 with the increase in moisture content from 11.54 to 19.74% d.b. The projected area increased from 59.72 to 75.57 $mm^2$ and the porosity increased from 57.48% to 61.30%. The bulk density decreased linearly from 482.1 to 474.3 kg/ $m^3$, whereas the true density increased from 1133.8 to 1225.5 kg/ $m^3$. [11]

Physical properties viz., length, breadth, surface area, roundness, equivalent diameter, sphericity, seed weight, and true density, angle of repose and coefficient of restitution maize, red gram and cotton seeds. Thickness and cell diameters of the seed metering discs were designed in reference to the maximum breadth and length of seeds. Both roundness and sphericity affect seed flow through the various components of the planter. Roundness of maize, red gram and cotton were 1.14 ± 0.14, 1.15 ± 0.10 and 1.26 ± 0.10, respectively, while sphericity of these seeds in the natural rest position were 0.621 ± 0.065, 0.75 ± 0.016 and 0.550 ± 0.016, respectively. [12]

The maize physical and mechanical properties as related to combine cylinder performance. The maize kernel damage, breakup, efficiency, shelling efficiency and concave separation were measured in stationary rasp bar-bar cylinder for three maize varieties over three harvest dates. Results were discovered important effect of the maize varieties and harvest dates on physical and mechanical properties. [13]

### a. Aerodynamic properties

The aerodynamic property, i.e. terminal velocity of maize varied from 14.56 to 15.6 m s-1 with 0.43 m s-1 SD, whereas the mean terminal velocity of husk was 1.2 m $s^{-1}$. [6] The terminal velocity of sweet corn seed increases from 5.56 to 5.79 m/s. [11]

The aerodynamic properties including terminal velocity, drag coefficient and Reynolds's number were determined at storage moisture content 7-12% (w. b.),the average terminal velocities of grains were 4.17, 7.32, 7.02, 20.16, 15.34, 14.69, 8.00 and 7.58 m/s for fennel flower, rice (Giza101), rice (Giza 177), broad bean, corn (hyb. 310), corn (hyb. 352), wheat (Giza9) and wheat (Giza 168) respectively.[10] The results showed that Reynolds's number of the terminals velocity of the studied grains exceeds the critical velocity of Reynolds's number (RN=2100) in the range of turbulent flow except the fennel flower seeds.[10]

#### b. Frictional properties

The average value of angle of repose during study was observed to be 28.59°, 27.10° and 28.66° for three varieties of maize seeds are PMH-1, PMH-10 and PIONEER-3396, respectively. The value of Coefficient of static friction was 0.64, 0.58 and 0.55 for PMH-1, PMH-10 and PIONEER3396, respectively. [3] The highest coefficients of friction were found on the concrete surface followed by wooden slab and aluminum sheet.[5]

The coefficient of friction of maize seed 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.[8] The frictional properties of maize such as angle of repose was found 22.76˚ and coefficient of friction was 0.31 [grain-grain], 0.35 [grain-fly wood], 0.44 [grain-MS sheet] and 0.50 [grain to wood]. [6] Static coefficient of friction of maize (SWAM 1) was found to increase on plywood, galvanized iron, aluminum 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, aluminum 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. [7]

The mechanical properties including angle of repose and coefficient of friction were determined at storage moisture content 7-12% (w. b.).The obtained data showed that it was the use of stainless steel or galvanized iron in manufacturing of seed hopper used in planting machines, silos and storage containers with side's inclination of 40° allow easy sliding of grains. [10]

The static coefficient of friction of sweet corn increased for all four surfaces, namely, rubber (0.402–0.494), aluminum (0.321–0.441), stainless steel (0.267–0.401) and galvanized iron (0.364– 0.477). [11]To ensure free flow of seeds (maize, red gram, cotton) the slope of the seed hopper was, therefore, fixed at 30°, which is modestly higher than the average angle of repose of seeds. [12].

## III. DESIGN & DEVELOPMENT OF MACHINE

### 3.1 Chute design

An improved design of chute for safe feeding of the crop in the thresher is based on the different test reports, research, papers, technical literature and existing threshers‟ information have been compiled for maize crop. The recommended cylinder peripheral speed was 750 to 1220 m min-1 with concave clearance of 22 to 30 mm. [32].

Design of the threshing chute on the basis of anthropometric dimensions of 95th percentile bellow height of Indian male population. The minimum height of feeding chute from standing platform was not more than 100-105 cm. They recommended minimum length of feeding chute as 100 cm and 15º inclination with base of feed chute from horizontal in standing position. [42]

### 3.2 Cylinder & Concave design

Multi-crop thresher designed by using of a spike tooth cylinder and inverted bar type closed concave. He had reported that for to breaking bunches better spike tooth concave helped and provided more complete threshing and separation whereas non meshing spike tooth concave was only practical in the inverted position where gravity provided continuous self-cleaning. [34]

Wire loop cylinder for threshing of maize grains and found that the better threshing performance with using of wire loop cylinder in place of rasp –bar cylinder [35]

Development of a low damage maize shelling consisted of three inclined rollers rotating in the same direction but at different speeds at an angle of 20° with the vertical . The ears were fed axially between the rollers through a gap of 33 mm. The test was carried out at the moisture contents of 16%, 18%, 20%, 22%, 24% at a speed of12000 rpm, 1100 rpm, 1000 rpm 900 rpm, respectively. The shelling capacity and shelling efficiency found to be 330 kg per hectare and 97.4%, respectively at 1200 rpm and moisture content below the 20%. It was found that the breakage was low in hand and high in combine shelling compared to the roller sheller. [33]

### 3.3 Power source

In many regions of the India maize shelling is done manually, this method is conventional but output and productivity from that method is low. Manual shelling of maize is a time-consuming and tedious operation. Traditionally maize is threshed by shelling cob grain by hand and beating the cob by stick. Four method of maize shelling namely shelling cob grain by hand, octagonal maize sheller, hand operated maize sheller and beating by stick method were carried for removing maize kernel from the cob. In shelling cob grain by hand agricultural worker remove the grain from cob by using his thumb first make a line, after that they rub the cob by another shelled cob to remove the grain, due to rubbing action grains were detached from the cobs.[39]

3.3.1 Human power

In a design of the hand operated axial flow maize dehusker-sheller operated by farm women, the peripheral cylinder tip speed of 5.6 to 5.7 m/s was found optimum from grain breakage point of view. The output capacity with machine was 60 kg/h at feed rate of 80 kg un-dehusked cob/h .The dehusking efficiency was 100%. Shelling efficiency 98.85% and grain breakage 0.3% at 5.6 m/s cylinder speed. [20].

The output in terms of dehusking shelling maize cob was reported that 30 kg per hectare with 8.3% grain damage in traditional system (dehusking by hand and shelling by beating wooden sticks). The hand operated maize dehusker cum sheller was most suitable for farm women workers. [21]

3.3.2 Mechanical power

Broadly speaking, mechanical power includes stationary oil engines, tractors, power tillers and self-propelled combines.

The power operated maize dehusker sheller may be suitable for strong group of farmers i.e. medium and large farmers while in the country, about 80.3% of farmers of marginal and small group operates 36% of the area. [21]

3.3.2.1 Tractors

Design and evaluation of the performance of tractor operated stationary threshing machine at Egypt for wheat crop. The feed rate decreased with the cylinder speed 900 to 1100 rpm and increased with the cylinder speed from 600 to 1100 rpm. For all cylinder speeds, the feed rate increased linearly as the hole diameter increased from 22 to 45 mm. The hole diameter not having appreciable influence on the seed damage. Increasing the cylinder speed or decreasing the hole diameter reduced the straw length under chapping section. Optimum operating condition for threshing wheat decided as 1000 rpm with concave clearance of 45 mm hole diameter [31].

Design of an axial flow thresher for seed crops. The major features of the thresher were minimum injury to seed, higher seed recovery and good seed quality, easy feeding and less fatigue to labour. It has provision of easy adjustment of concave clearance, sieve clearance and slope of sieves. At optimum combination of cylinder speed and concave clearance at different seed moisture contents to thresh oil seeds and pulse crops, the performance parameters were within acceptable ranges of visible seed damage ≤ 2% and threshing efficiency ≥ 95% with threshed seed germination of green gram (88%), black gram (90%), soybean (90%), chickpea (90%) and sunflower (86%). The unit could be operated by a 22 kW tractor or a 7.5 kW electric motor. [26]

Development and evaluation of a power operated wheat thresher. It was observed that maximum threshing efficiency of 95.3% can be achieved by threshing the wheat crop at peripheral speed of 1027 m min-1 (500 rpm) at 9.25% moisture content when the concave clearance was 1.3 cm. [30] It was also found that net unit threshing cost per quintal of wheat was Rs. 13.63 when threshed by this equipment when compared to Rs. 14.94 by traditional methods. [29]

**3.3.2.2 Power tillers**

In an impact assessment of PAU maize dehusker cum sheller observed that threshing capacity of the machine was between 400-510 kg/h at different M.C. of cob i.e. 14-20% (db.), where the Dehusking efficiency at 16% M.C. & 740 RPM was maximum 85%. The grain breakage & unthreshed grain percentage was minimum at cylinder speed of 740 RPM. [18]

**3.3.2.3 Engines**

The development of a new power sheller that could reduce grain damage and broken corn cobs. The SENAPIL sheller was operated by 6.5 to 8.5 hp diesel engine with highest shelling of capacity 4.82 t h-1 which significantly higher than the SLM's (local maize sheller operated with 6.5 hp diesel engine) effective capacity (2.57 t/h).local sheller. New machine was worked on the principle of the reduction of the normal stress during the shelling process by developing a concave system that could vibrate without causing great impact on the maize grain. To do this, the concave system was suspended using a rubber spring to minimize impact. [27]

**3.3.4 Electrical power**

Design& development a maize dehusker cum sheller (MDS) which is operated by 2.23 kW electric motor having capacity of 600 kg/h. The developed trapezium shaped MDS machine having overall dimensions of 1200× (500 & 610) × 810mm (length × (top & bottom) ×height). For machine performance & seed quality parameters the selected operational parameters viz. cylinder peripheral speed (7.1 m/s), concave clearance (25mm), & feed rate (600 kg/h) were studied. The performance of machine under these parameters were reported that the dehusking efficiency of 99.56%, shelling efficiency of 98.01%, cleaning efficiency of 99.11%, total loss of 3.63%, machine capacity of 527.11 kg/kW-h & germination percentage of 98.93%. These recommended that overall machine performance was satisfactory for maize dehusking cum shelling operation and for producing of maize grains for seeding purpose. [24]

At MPUAT, Udaipur 5.5 KW motor operated whole crop maize thresher was developed by using of spick tooth cylinder. This machine performed simultaneously the dehusking-shelling of maize cob and stalk was converted to chaff. [51]

The design and fabrication of corn shelling and threshing machine basically compromises of separate shelling chamber, threshing chamber, collecting tray and motor (2HP). The arrangement of these parts is connected by belt and pulley mechanism. The weight was only 95 Kg. After testing the machine, the production rate for threshing operation was 300 kg/h and for shelling 300 kg/hr. At last the germination test was carried out for corn seeds threshed by the machine and it were found that time required to grow from seed was about 48 hours. [19]

Design and construction of very low and affordable cost maize sheller from locally available materials. This machine was constructed for shelling of maize cob i.e. it separates the grains from the cob with its threshing efficiency was 99.2% and breakage losses were insignificant and the capacity of threshing of maize is 200 kg/h. The machine is less bulky, simple and effective with its self-cleaning ability [25]

At TNAU, Coimbatore the power operated maize dehusker-sheller was developed i.e. 10 hp motor operated and it removes the outer sheath and shellers the maize cobs simultaneously i.e. dehusking & shelling is done at the same time. The machine has lugs on dehusker-sheller cylinder of square solid blocks types and has helically louvers at start and end of cylinder. [30]

## IV. ERGONOMIC DESIGN OF MACHINE

### 4.1 Manually operated

Ergonomic evaluation of hand operated maize sheller on farm women. The results shows that the hexagonal tubular maize Sheller saves almost half the time and increases working efficiency 79.24 per cent and reduces 87.94 per cent drudgery of farm women over traditional practice. The cleaning efficiency was also found to increase 6.6%. Comparison with traditional method, Hexagonal tubular maize sheller shows easy in operation no muscle strain, low cardiac cost, less energy expenditure while using traditional practice. Hence, maize sheller is best option for the women, it saves not only the time but increases the efficiency of farm women twice. [36]

The efficiency assessment of maize sheller in context of drudgery of farm women. It is concluded from the study that manual maize shelling is a strenuous activity leading to pain in Neck, back, Shoulders, Wrist and Finger. Time taken in shelling grain from one cob quiet higher from the maize sheller. Manual maize shelling is moderately heavy work but it can be lightened by the use of maize sheller. Musculoskeletal pain is considerably reduced with maize sheller. If talking in monetary terms, maize sheller saves Rs.90/day. Hence maize sheller is good option for removing maize from the cobs, it saves not only the time but also increases the efficiency of farm women almost by twice and save cardiac cost of worker per unit of output in comparison to the hand shelling. It eliminated the chances of injury to finger and is very comfortable hand-operated tool. [38]

A physiological evaluation of different manually operated maize shelling methods. The mean oxygen consumption rate (OCR), ΔOCR, heart rate (HR), ΔHR for octagonal maize sheller was lowest among all method of maize shelling and highest for beating by stick method. The energy expenditure rate was highest for beating by stick method (3084 kcal / min) and lowest for octagonal maize for octagonal maize sheller (1.52 kcal/min). Energy expenditure rate for shelling cob grain by hand and octagonal maize shelling operation could be scaled in “Very light” category of work load. Whereas the hand operated maize sheller and beating by stick method could be scaled as in “Light” category of work load. For maize shelling operations octagonal maize sheller and hand operated maize shelling are superior than shelling cob grain by hand and beating by stick method. [39]

The effect of power output and pedaling rate on physiological responses of 12 men on computerized bicycle ergometer at five levels of power output (30-90 W) and seven levels of the pedaling rates (30-90 rpm). Analysis of data indicated that physiological responses were significantly affected with power output as well as pedaling rate. Increase in physiological responses (heart rate and oxygen consumption rate) over rest (delta values) were significantly higher when pedaling frequency was 30rpm and above 50 rpm. There was no significant difference between physiological responses at 40 and 50 rpm. Physiological responses increased linearly with power output and were significantly different at different power outputs. The delta values of physiological responses at 60 W power output and 50 rpm pedaling rate (variation in heart rate (□HR) = 40 beats min-1 and variation in oxygen consumption rate (□VO2) = 0.56 l min-1) were within acceptable limits for continuous pedaling work. From the result of the study it was concluded that for daylong pedaling work the power output of the Indian agricultural workers should be limited to 60 W and the pedaling rate should be 50 rpm. [40]

The energy expenditure of woman laborers for maize shelling using tubular, modified tubular and hand operated maize shellers and they compared the energy expenditure with the traditional method of shelling. For operating the maize sheller they were selected the three female subjects with similar anthropometric parameters and they estimated that for operating the different manual shellers the average energy expenditure was 5-6 kcal min-1. The output of the hand operated maize sheller was 23 kg/h, which is 92% higher than the hand operated, modified tubular and tubular maize sheller and which saves energy expenditure by 80%, 60% and 52%, respectively, as compared to the traditional method. For these shellers the energy requirement to work without fatigue was 2200 kcal/day. [44]

If the equipment was developed for women workers as in most of the cases the equipment like dehusker-sheller were suitable for women workers also suits to the men workers because the ergonomical characteristics like anthropometrical dimensions, muscular strength of women workers, aerobic capacity, etc. were less than men workers hence, a hand operated maize dehusker cum sheller has been designed developed and fabricated for dehusking-shelling of un-dehusked cobs. [45]

4.2 Power operated

An ergonomic evaluation of one of the commonly used maize sheller cum dehusker machine in Maharashtra state. Various key postures of the workers are analyzed and evaluated the risk during the poster. Tools like digital human manikin (DHM) & Rapid Upper Limb Assessment (RULA) are used in this study. Ergonomics analysis of maize sheller cum dehusker was performed for both $5^{th}$ and $95^{th}$ percentile male operators. DHM technique can be successfully used to develop the ergonomically sound products based on anthropometric data of user population. The ergonomically designed machines/equipment's can reduce drudgery, increase efficiency, safety and comfort. [37]

The analytical studies on strength parameters of Indian farm workers and its implication in equipment design. The strength parameters of 105 agricultural workers (75 male and 30 female) were measured on "strength measurement setup" comprising load cell with digital indicator. The average push strength for male and female workers (with both hands in standing posture) was found to be 248.2 and 171.0 N, respectively whereas the pull strength in standing posture was 232.3 and 141.7 N, respectively. These strength parameters were found to play a significant role in design of manually operated push-pull type equipment. The right hand push and pull strength for male and female agricultural workers were within the range of 49.7 to 96.5 N which prominently assist in the design of joystick, gear shift lever and handle lever. The mean value of maximum right leg strength in sitting posture for male and female workers were 394.2 and 280.5 N, respectively which were found useful in the design of clutch pedal, brake pedal, accelerator pedal, pedal operated thresher and other foot operated controls. Average torque strength of both hands in standing posture for male and female workers were found to be 209.93 and 117.72 N-m, respectively which can be used in the design of manually operated equipment like chaff cutter, sugarcane crusher, slicer, threshers etc. These parameters can be utilized in the design of manually operated push-pull equipment, workplace design, gear shift lever, handle lever, gear control lever, design of pedal for accelerator, clutch & brake, and other foot operated controls. [41]

Development of a grain threshers based on ergonomic design criteria and they resulted that thresher injuries result in crush/amputations of upper limb. Chute design has an important bearing on injuries. Increased heights and chute cover lengths are recommended for safer operations. Height of platform and work posture were found to influence the injury outcome hence the design modification of the chute & height difference of platform and chute can reduce the possibility of injury among threshers operators. The modification are under consideration for changing the thresher design standards by Bureau of Indian Standards (BIS).[28]

A cost effective, improved design for safe operation of threshers based on ergonomic principles. The study was done in villages of Sonipat district of Haryana State and Baraut district of Uttar Pradesh. They interviewed all the injured victims with serious cuts or amputations taking treatment in nearby hospitals. Found that 4% of victims were under 16 years, 82% in 16-45 years and 14% over 45 years. The right hand was involved in 80% cases, left hand was involved in 15% and other body parts 5%. Thirty-five cases involved amputations of the right hand fingers, right hand, right forearm, left hand fingers and left hand. They analyzed machine parts associated with injuries revealed that the threshing drum and the feeding system were involved in 52 cases, belt and pulley in 6 cases and rest by any other machine part. Chute design has an important bearing on injuries. Increased chute heights and chute cover lengths are recommended for safer operation. Height of platform and work posture were found to influence the injury outcome. Design modifications of the chute and a height difference of platform and chute can reduce the possibility of injury among thresher operators. The modifications are under consideration for changing the thresher design standards by Bureau of Indian Standards (BIS). [43]

## V. PERFORMANCE EVALUATION OF MACHINE

5.1Crop type, variety, moisture content

Manual shelling of maize was time consuming and tedious operation. The few existing mechanized shellers on Nigerian farms were imported and out of reach of the rural peasant farmers that were characterized by small holdings and low income. The power requirement of such shellers was high and hence, the prime mover was very expensive. The kernel damage and cob breakup decreased significantly with later harvest date. The shelling capacity was not significantly influenced by harvest date or maize variety. Generally, the performance of the maize sheller was not influenced by maize the variety; therefore, the maize sheller can comfortably be used to shell local maize varieties. [55]

The performance of threshers influenced by some known crop parameters and machine variables. Each or combination of these parameters had influencing effects on the grain damage and threshability. The influence of both threshability and grain damage translate to measurable grain losses if not properly managed. [56]

Testing of the performance of maize sheller using an international standard codes to study the general qualities and design of sheller. The results showed that the shelling efficiency of the sheller varies with feed rate, moisture content, and speed of the shelling unit. The machine had a cleaning efficiency of 93, 87, 85 % and shelling efficiency of 98, 95 and 94% when shelling of maize with a moisture content of 11, 20 and 25%, respectively, with a fan unit speed of 750 rpm and shelling unit speed of 400 rpm. The sheller had a capacity of 260 kg/h. The performance tests proved that at shelling unit speed of 450 rpm the sheller performed better with minimum losses and high efficiency. [59]

Three levels of grain moisture content and cylinder speed, three types of local maize shellers were tested. As an increase of the moisture content of maize the effective shelling capacity decreased and increased with an increase of the cylinder speed. With increasing moisture content of maize and cylinder speed mechanically damaged maize increased but the total drying cost decreased. [61]

The performance parameters of threshing unit in a single plant thresher and the results showed that the effects of variety on the on the damaged grains percent and power requirement of the threshing unit were significant at probability level of 1 % & 5 % respectively. The effect of crop moisture content was significant at probability level of 1% on the threshing loss and power requirement. With increasing of drum speed at all varieties, threshing loss decreased. At all drum speed levels, by increasing drum speed, damaged grain percent increased. At each drum speed levels, the mean of power requirement at wet condition of paddy was significantly higher than dry condition of paddy. [49]

The factors affecting corn kernel damage in combine cylinders. Concluded that as the kernel-moisture content decreased, the kernel size decreased, indicating kernel shrinkage as they dried, Kernel strength and stress increased as kernel moisture decreased. Kernel detachment force was independent of kernel moisture or other kernel properties. As the kernel moisture decreased, kernel damage decreased. No differences in kernel damage were obtained for field shelling and lab shelling of ears. Planting date did not affect kernel damage. The most important plant properties influencing mechanical damage were kernel detachment force, kernel strength, initial and final kernel thickness (kernel deformation), and cob strength. Low kernel damage was associated with low detachment force, high kernel strength, low kernel deformation, low cob strength. By changing plant characteristics, such as reducing detachment force and increasing kernel strength, it should be possible to reduce kernel damage during combining. [72]

Ear head axis parallel to cylinder axis orientation suffered the minimum damage, followed by ears fed randomly to the cylinder and the highest damage was suffered by ears fed with their axis perpendicular to the cylinder. At 20 to 22% moisture content, the minimum damage for all orientations was obtained. They found that as an increase in moisture content and cylinder velocity the corn kernel damage increased. [68]

The effect of moisture content on maize shelling speed using a manually operated hand sheller. Twenty unthreshed maize cob samples (A-J) were used for analysis. The result indicated that sample J, after sixty nine hours (69th) oven drying recorded the lowest moisture content (15.10% w. b.) and the fastest shelling speed (0.75 rpm) compared to sample. A (24 h drying time) which had the highest moisture content (28.99% w. b.) and lowest shelling speed (0.96 rpm). It was observed that sample J with the shortest shelling duration had the smallest grains weight (84.2 g), while sample A recorded larger grain weight (162.9 g) due to differing moisture content of the maize grains. The data generated was analyzed and compared using statistical means, percentages and figures for pictorial presentation. It was recommended that maize cobs be dried properly to enable easier and faster shelling operation with less fatigue and minimum grain damage. Lower the moisture content then the faster the shelling speed. [22]

5.2 Cylinder speed & concave clearance

The performance assessment & optimization of maize dehusker cum sheller. In present study, the medium sized electric motor (2.23 kW) operated maize dehusker cum sheller (MDS) was developed and evaluated for selected operational parameters, viz. cylinder peripheral speed (6.2, 6.6, 7.1 and 7.6 m/s), concave clearance (20, 25, 30 and 35 mm) and feed rate (400, 600 and 800 kg/h). The machine performance parameters revels that, the dehusking efficiency and shelling efficiency were showed increasing trend with cylinder peripheral speed (S) from 6.2 to 7.6 m/s; whereas decreasing trend against increase in Concave Clearance (C) from 20 mm to 35 mm. The total losses of grains in machine were found lowest between feasible at 25 to 30 mm of C for all feed rates (F). In seed-quality parameters, the decreased germination percentage with increase in S was observed. The increased broken grains (%) and seed-coat damage (%) were identified with increased in S and decrease in C as well as F. The highest desirability value (obtained from numerical optimization technique) was obtained for operational parameter combination of S at 7.1 m/s with C at 25 mm under 600 kg/h of F. The performance of machine was also satisfactory for producing maize seeds for seeding purpose without compromising its performance. The optimum operating conditions of cylinder peripheral speed, concave clearance, & feed rate were 7.1 m/s, 25 mm, 600kg/h, respectively. [15]

In the analysis of variance for damaged maize kernel percentages kernel moisture content and cylinder speed were highly significant The total damage increased from 26% to 41% as cylinder velocity increased from 450 to 650 rpm & the minimum total damage was sustained at 23% moisture content (w. b.). They found that for cylinder velocities, the mechanical damage by the laboratory sheller ranged between 26.3 and 42%. [66]

The Percentage of maize grain damage caused by the cylinder and concave before and after the grains were shelled from the cob. He investigated that grain damage was caused due to effect of cylinder velocity and grain moisture content. In the shellers cylinder velocity of 7 m/s and 11 m/s were used and maize varieties were shelled with grain moisture content of 15%, 20% and 15%. As an increase in moisture content and cylinder velocity damaged grain percentage were increased. The concave clearance, physical and morphological properties of maize ear and feeding rate effect on the mechanical damage. [60]

The investigation of the effective factors on threshing loss, damaged grains percent and material other than grain to grain ratio on an auto head feed threshing unit. At all tests, the stalks flow axially through the drum without clogging between drum and concave and also in chain conveyor and rail The effects of crop moisture content condition, variety and drum speed were significant on threshing loss. In general, mean of threshing loss at dry condition of crop was higher than wet condition of crop. Optimum speed of drum was 650 rpm because threshing loss and damaged grains percent were equal to zero at this level of drum speed. The main effects of crop moisture content conditions, variety (at probability level of 5%), drum speed (at probability level of 1%) and double interactions (at probability level of 1%) were significant on the damaged grains percent. Damaged grains percent at wet moisture content condition of crop was lower than at dry moisture content condition of crop. The main effects of crop moisture content conditions (at probability level of 5%), variety and drum speed and their interactions (at probability level of 5%), drum speed and interactions (at probability level 1%) were significant on the MOG/Ratio .In general, MOG to grain ratio at tests with dry crop was higher than wet crop. Increasing of drum speed increased the MOG to grain ratio significantly. [16]

The optimum clearance between the cylinder peg & concave is found to be between 1.8 cm and 2.4 cm at feeding rate of 1 or 2 maize cobs per minute and between 2.2 cm and 2.6 cm at feeding rate of 3 to 6 maize cobs per minute. It was also found that the optimum speed of the cylinder is between 600 rpm and 700 rpm, irrespective of the feeding rate. Found that a dehusking, shelling, grain cleaning efficiency about 99.5%, 98%, 99.2% respectively. The capacity of the machine varies from 10kg to 40 kg of maize cobs per hour, depending on the feeding rate. [17]

The effect of operating speed and cob size on performance of a rotary maize sheller reported that the shelling capacity of the maize sheller for all categories of maize cobs initially increased in a curvilinear fashion with increase in operating speed up to about 70 rpm and thereafter it was almost constant. Further the shelling capacity at a particular operating speed decreased with increase in maximum diameter of cobs. It is recommended that the operating speed of the maize sheller should range between 70 and 80 rpm to achieve higher shelling capacity and shelling efficiency at lower operating torque. [48]

Effect of operating factors for an axial –flow corn shelling unit on losses and power consumption. The main conclusions for the study were: the rotor speed (RS) significantly affected shelling unit loss (TL), with increased RS reducing TL; the moisture content (MC) and rotor speed (RS) significantly impacted on the grain breakage, with increased MC and RS resulting in an increased tendency for grain breakage; the moisture content (MC), feed rate (FR) and rotor speed (RS) significantly affected power consumption (P), with increased MC, FR and RS increasing consumption.[14]

Short duration test for maize thresher and his data resulted that the machine was stable and strong and its speed of operation was 60 rpm with the shelling capacity of the machine was 100.25 kg/h & cleaning and shelling efficiency of 99.37% and 99.95% respectively. The breakage was 0.406 % which was well within the prescribed limit for such machines. Also the labour requirement was reduced by 89.60%. [52]

The cylinder speed was primarily influences the damage caused to the seed than that of concave clearance although the concave clearance was an important parameter as well. Impact force was the primary threshing action for detachment of grain from the ear head. In all types of threshers the most crucial adjustment for control of impact was the cylinder tip speed. [71]

The study concluded that the shelling efficiency increased with reduction in concave clearance and increased in cylinder speed. The round and rasp bars members shelling less than the square section members and shelling decreased with grain moisture content. The grain damage was lower at lower value of the concave clearance and higher at higher cylinder speed. [69]

Nature of maize kernels damage inflected in the shelling crescent of grain combines. This study investigated the percentage of the corn kernel damage was caused by the cylinder and the concave before and after the kernels were shelled from the cob and the effects of kernel moisture contents, cylinder speeds, and the different concave zones on these two categories of damage. The sheller constructed from John Deer Model 95 combine parts. The cylinder diameter was 55.88 cm and the clearance was fixed at 2.54 cm at front and 1.59 cm in the rear. The cylinder speed of 440, 540 and 640 rpm were used. About 50% of the mechanically damaged maize kernel consists of sieved through 4.76 mm consists of embryo and pericarp damage. [64] The amount of seed damage was directly proportional to the impact energy and inversely proportional to the seed moisture content. [65]

The performance of tractor operated combine for maize shelling machine was tested on maize with and without husk. The performance of the machine was evaluated in terms cylinder loss, capacity, and grain crack age. It was concluded that the combine gave satisfactory results for husked maize at a speed of 500 rpm, concave of 25 mm and feed rate of 3 tons per hour. Whereas for the un-husked maize the satisfactory results were obtained at a cylinder speed of 575 rpm and cylinder concave clearance of 25 mm and the capacity of the machine was found to be 2- 2.5 tons per hour. The damage in case of husked and dehusked maize was found to be 2.72 (maximum) and 2%, respectively. [63]

The manually powered sheller at a speed of 60 rpm can provide a continuous flow and they achieved the shelling effectiveness of 67%, with a throughput of 6.82 kg/h and a low kernel-breakage factor of 0.09. For achieving the stripping this sheller uses abrasion between a rotating shelling-disc and stationary concave compartments. This design was preferred, because of its low breakage factor, low human energy expenditure, rapid operation for the kernels in addition to relatively little dust being emitted during shelling; hence leading to a relatively-healthier local atmosphere for the operator so its wider use was therefore recommended. [53]

5.3 Types of threshing cylinder

The power operated maize sheller was developed and its performance was evaluated. The maize sheller consisted of a cylinder and a concave. The cylinder made up of high carbon steel of size diameter 6.5 cm and length 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 7.0cm×1.0cm. The developed power operated sheller had the shelling efficiency, total recovery, breakage and shelling capacity of 98.51, 66.62, 1.60 percent and 402.01 kg/h, respectively, at a cylinder speed of 350 rpm. [47]

The development of pedal operated maize dehusker, hand operated maize dehusker, pedal operated maize dehusker cum- sheller, pedal operated maize dehusker-sheller, power operated maize dehusker and power operated maize dehusker-sheller at MPUAT, Udaipur. Dehusker unit was made up of using a pair of rubber and spirally welded MS rod on steel rollers also some serrated blades were used lengthwise to facilitate the dehusking. Half of the cylinder length with rasp bars and the other with rubber strips in octagonal cylinder to act as dehusker and sheller, respectively in one cylinder. [57]

The performance evaluation of a developed maize sheller. A simple, efficient, less tedious machine for shelling maize has been developed. Materials used in fabricating the machine are affordable and locally available. ODEDI maize shelling machine can shell maize of various sizes and has a shelling efficiency is 91.29 % and minimal 0.12 % grain damage with an average shelling capacity of 55 kg/hr. [46]

The performance of existing maize shellers in Bangladesh. At present, there are three basic designs of mechanized maize sheller models exist in the country. They are Spike-pinion (SP) type, Spiral rasp-bar cylinder (SBC) type and Parallel rasp-bar cylinder (PBC) type. The design of Binimoy (SP) and Sarker (SP) models is same and technical performances are almost similar and satisfactory. Based on the shelling capacity these models are suitable for small farm holdings. The design of Farida (SBC), Rahman (SBC) and Uttaran (SBC) models is same, except the size. The technical performances of Farida (SBC) and Rahman (SBC) models are slightly better than the Uttaran (SBC) model. This is because of the workmanship and adjustment made by the operator during operation. The technical performances of these sheller models are satisfactory. Based on the shelling capacity and economic returns these models are suitable for large farm holdings and custom-hire service. Farida (SBC), Rahman (SBC) and Uttaran (SBC) models have higher shelling capacity and have higher benefit-cost ratios, Gross Margins (GM) and Net Margins (NM). Partial Budget (PB) analyses indicate net gain in favour of these models over low capacity models and appear as most beneficial for custom-hire service. Economic analysis suggest that hand sheller could be beneficial for very small farm holdings, Binimoy (SP) and Sarker (SP) models for small farm holdings and Farida (SBC), Rahman (SBC) and Uttaran (SBC) models for medium to large farm holdings and custom-hire service.[50]

Different types of hand operated maize shellers viz., hand held tubular maize sheller, wooden maize sheller, rotary disc type and bench mounted tubular maize sheller and they compared their performance with manual method of maize shelling. In terms of kernel output, operational cost and performance index bench mounted tubular and rotary disc type maize sheller well performed. [58]

A shelling machine consisting of shelling unit, reduction unit i.e. worm and worm gear type and single-phase one hp electric motor. The developed power operated maize sheller was tested at load for short duration's operations as well as in laboratory. The analysis of data collected during the short duration tests revealed that the shelling capacity of the machine was 100.25 kg/h with shelling efficiency of 99.95%.

The performance of a tractor powered maize sheller, shelling with tractor wheels, the traditional shelling techniques were evaluated in terms of shelling efficiency, grain damage and grain output. The test result reported that shelling of maize with tractor wheels acquired the highest percentage of grain damage. The tractor powered maize sheller has maximum grain output of about 80 kg/ha was obtained as compared to 30.90 kg/ha by shelling with tractor wheels and 13.19 kg/ha with the traditional shelling techniques and it shows that shelling with tractor wheels had the lowermost shelling efficiency of about 73.76% when compared with the other shelling methods. [54]

*Table 1: Performance of different threshers.*

| Sr. No. | Equipment | Power source | Type of threshing element | Dehusking & Shelling efficiency,% | Output capacity, kg/h | References |
|---|---|---|---|---|---|---|
| 1 | Maize dehusker cum sheller | 2.23kW motor | Parallel-staggered-parallel lugs | 94.59-97.13 | 600 | 83 |
| 2 | Maize dehusker-cum-sheller | 12 hp power tiller | Peg type | 72 & 85 | 400-510 | 18 |
| 3 | Hand operated maize dehusker-sheller | 2 women | Solid lugs, rasp bar, spike tooth, square solid lugs | 100 & 98.8 | 60 | 20 |
| 4 | Maize dehusker-sheller | 2.23kW motor | Peg type | 99-99.7 & 97.5-98.4 | 10-40 | 17 |
| 5 | Rotary maize sheller | 7.5kW motor | Shelling plate | 98.52-99.3 | 250.50-384.66 | 48 |
| 6 | Manually powered continuous flow maize sheller | Human power | Rotating disk, 2 concave stationary compartments, spikes | 67 | 6.82 for 99 Seconds | 53 |
| 7 | Hand operated maize desheller | Human power | - | 99.95 | 24 | 78 |
| 8 | Maize threshing machine | 5 hp motor | Threshing bars | 99.2 | 200 | 25 |
| 9 | Corn shelling & threshing machine | 2 hp motor | - | 90 & 90 | 300 | 19 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 10 | Local maize sheller | 3.72kW motor | Rasp-bar | 90.6-99.2 | 325.2-327.7 | 55 |
| 11 | Maize sheller | 2.23kW motor | - | 91.29 | 55 | 46 |

## VI. SOLAR PHOTOVOLTAIC SYSTEM AND ITS UTILIZATION

### 6.1 Paddy winnower

The solar photovoltaic operated paddy winnower. It was observed at the feed rate 120 Kgh$^{-1}$ overall output capacity at 30 cm distance was found to be maximum (119.77 kg h$^{-1}$), as compared to output capacity at 20 cm (119.30 kg h$^{-1}$) and 10 cm (118.74 kg h$^{-1}$) respectively. The weighted average cleaning efficiency at 30 cm distance (93.00%) was found to be maximum as compared to cleaning efficiency at 20 cm (89.13%) and 10 cm (62.24 %), respectively. The average cleaning efficiency of SPV operated paddy winnower was more than 90% with low operating cost of 0.25 Rs kg$^{-1}$. The developed SPV operated paddy winnower provided the solution for on farm paddy winnowing without dependency on natural wind velocity and secure electricity supply. [73]

Development of the solar power operated paddy winnower. Performance was carried out at three feed rates for PLR 1100 type paddy variety 171.43 kg.h$^{-1}$, 200 kg.h$^{-1}$ and 240 kg.h$^{-1}$ and for RGL 2537 type paddy variety 200 kg.h$^{-1}$, 240 kg.h$^{-1}$, and 267 kg.h$^{-1}$ respectively. The paddy winnower was mounted with 0.25 hp DC motor and connected to a 150 watt photovoltaic solar panel. The highest cleaning efficiency of about 94% was achieved for feed rate 171.43 kg/h at main outlet. The highest output capacity of 223.47 kg/h was achieved at feed rate of 267 kg/h. It was observed the cleaning efficiency of both the paddy varieties was decreased on increasing the feed rate. [74]

### 6.2 Solar water pump

Photovoltaic solar water pumps are available to pump from anywhere in the range of up to 200m head and with outputs of up to 250m³/day. In general photovoltaic pumps are economic compared to diesel pumps up to approximately 3kWp for village water supply and to around 1kWp for irrigation. Solar Photovoltaic (SPV) sets represent an environment-friendly, low-maintenance and cost effective alternative to irrigation pump sets which run on grid electricity or diesel. It is estimated that India's potential for Solar PV water pumping for irrigation to is 9 to 70 million solar PV pump sets, i.e. at least 255 billion lit/year of diesel savings. [75]

Different types of solar energy systems like as solar photovoltaic and solar thermal for pumping water, drying crops, cooling the storages and producing heating/cooling greenhouses. It was been proven that photovoltaic systems and thermal system would be the suitable options in agricultural application and especially for the distant rural area. [76]

### 6.3 Tracking system

The automatic solar tracker system which ensures 25 to 30% of more energy conversion than the existing static solar module system. Although ASTS is a prototype towards a real system, but still its software and hardware can be used to drive a real and very huge solar panel. A small portable battery can drive its control circuitry. Therefore by just replacing the sensing instrument, its algorithm and control system can be used in RADAR and moveable dish antennas. [77]

It deals with the efficiency of solar cell with and without tracking system. It also includes a proposed plan of simple dual axis tracking device which is based on servo motors which are in turn interfaced using arduino microcontroller kit. The instructions to the servo motor comes from highly efficient light dependent resistors which are responsible for moment of PV panels towards maximum light intensity. The use of stepper motors in solar trackers enables accurate tracking of the sun and light dependent resistor are used to determine the solar light intensity. Solar tracking system based on microcontroller and also describes about the simple and attractive features of tracking system. This solar tracker operation costs and maintenance cost are comparatively low. [62]

Solar tracking system is a power generating method from sunlight. This method of power generation is simple and is taken from natural resource. This needs only maximum sunlight to generate power. It helps for power generation by setting the equipment to get maximum sunlight automatically. This system is tracking for maximum intensity of light. When there is decrease in intensity of light, this system automatically changes its direction to get maximum intensity of light. Solar tracking system I reached up to the movement of stepper motor. Movement of motor by signal from light sensing circuit when the intensity of light is maximum is done. [67]

## 7. Cost economics of operation

Different machines used for dehusking and shelling of maize was evaluated of their economic and technical feasibility and for optimizing their operating parameters. [82]

The development of the following equipment related to dehusking and dehusking-shelling [57]

1. Hand operated maize dehusker
2. Pedal operated maize dehusker
3. Pedal operated maize dehusker-cum-sheller
4. Pedal operated maize dehusker-sheller
5. Power operated maize dehusker
6. Power operated maize dehusker-sheller

On the basis of performance of each machine different combinations for maize dehusking and shelling were suggested for the small and marginal farm holdings. It was found that the pedal operated maize dehusker sheller (single cylinder) was best suited having total area of 10 hectare and production of less than 300 quintal of maize cobs that is for small and marginal farmers. The power operated machines were found to suitable for large farmers having total area of more than 30 ha and annual production more than 1000 quintal.

7.1 Fixed cost

The total production cost of MDS was ₹ 34,500. The dehusking and shelling hiring price were 5/qt based on machine feed rate of 600 kg/h with 250 annual working hours (8-year life time) and considering annual cost of operation (Fixed + running = ₹ 7762.5 + ₹ 12 118.7). The payback period (Investment/net annual return = ₹ 34500/ ₹ 46064) was found to be 0.74 year. The benefit cost ratio (Discounted return/ discounted cost = ₹441,597/₹ 196512) was found to be 2.24. [83]

The cost of use of machine calculated with power tiller as prime mover has been found to be Rs. 371/hr or Rs. 68.70 / q, whereas, in traditional method, it was 375.00 Rs. /q. There is net saving of Rs. 306/q with respect to manual threshing. [18]

Cost of fabricating (manufacturing) the final prototype came to Rs.14, 500/ (290 $). The cost of getting one kg maize grain with hand operated maize dehusker sheller came to Rs.1.15 Fixed cost of maize dehusking shelling per kg maize grain with hand operated maize dehusker – sheller consist of depreciation cost using straight line method, interest on investment, insurance and shelter cost of machine is ₹1,305, ₹997.5, ₹290 respectively. Hence total fixed cost Rs. /annum ₹ 2,592.5. [20]

The virtual prototype modelling and analysis of low cost hand operated maize desheller. The analysis of data collected during the short duration test revealed that the machine is stable and strong and its speed of operation 60 rpm was quite satisfactory. The shelling capacity of the machine was 24 kg/h with shelling efficiency of 99.95 % and cleaning efficiency of 99.37%. The breakage percentage was 0.406 which is well within the prescribed limit for such machines. The labour requirement wasreducedby89.60%using this machine [78]

The result of comparison of power operated maize sheller with manual shelling of indicated that for 25% internal rate of return (IRR), power operated maize sheller appearance like a wise investment of 5-8 acres. They stated that, it makes economic sense to operate shellers at higher capacities and along with the high capital cost to save large numbers of labour to farmers and maize sellers hence power operated maize sheller can able to overcome the shortage of expensive labour during peak harvesting season and it saves the cost. [79]

A tubular maize sheller was tested on farm women and the results revealed that the shelling efficiency of tubular maize sheller as compared to hand shelling was 26 kg/ha. Hence about 43% saving in cost of workers per unit of output is done in comparison to the hand shelling. [23]

Three levels of grain moisture content and cylinder speed, three types of local maize shellers and the results indicated that the optimum moisture content of maize for shelling, using sheller types SLM, KWT and TMO, was 32.5, 35.0 and 35.0% (w. b.), respectively. The minimum total costs of shelling and drying were Rs. 3,573/t, Rs. 3,176/ t and Rs. 3,315/t while the optimum grain mechanical damage was 18.4, 17.8 and 21.1%, respectively. [81]

7.2Variable cost

Variable cost of maize dehusking shelling per kg maize grain with hand operated maize dehusker –sheller consist of repair and maintenance costs, (Rs. / annum 30 % of cost of maize dehusker sheller), Workers charge ( Rs. / annum No. × h × charge) is ₹ 4,350.0, ₹ 6,800.0. Hence total variable cost (TVC) / annum, Rs. 11,150.0 [20].

## VII. CONCLUSION

Maize is most important cereal crop in the world agricultural economy. Dehusking and shelling of maize are the major operations of maize after the harvesting. Traditionally dehusking and shelling is done by manually with help of sickle or by beating of stick. These requires more labors and also these are time consuming operations. After that engine, motor, tractor, power tiller operated maize dehusker cum shelling machines are come out. These are machineries are unsuitable where electricity is major problem, also easily unviability of fuel in rural areas. Tractor operated maize dehusker cum shellers are unaffordable for marginal farmers. Solar operated maize dehusker cum sheller is more significant where electricity is major problem in a rural areas. Using of Solar power gives the benefit to the environment as renewable energy, it saves fuel cost.

Design and development of solar powered maize dehusker cum sheller is more reliable for marginal and small farmers. Engineering properties of maize plays a key role while designing of maize dehusker cum sheller. Performance of machine depends upon a design of cylinder, concave clearance, and speed of cylinder, feed rate, and moisture content of maize. An axial flow spike tooth type machine gives a better performance in terms of dehusking, shelling, cleaning efficiency.

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