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Design and Development of a Solar Energy Operated Maize Sheller

***Balveer Singh*[1]*, Lokesh Kumawat*[2]*, H. Raheman*[1] *and Manish Patel*[3]*

[1]*Agricultural and Food Engineering Department, IIT, Kharagpur (West Bengal), India.*
[2]*Assistant Professor, NIMS Institute of Engineering and Technology (Rajasthan), India.*
[3]*Department of Farm Machinery and Power Engineering,*
College of Agricultural Engineering, JNKVV, Jabalpur (Madhya Pradesh), India.

(Corresponding author: Manish Patel)*
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ABSTRACT: Shelling means removal of maize grains from the portion of the cob that holds them. This separation is done by hand or machine applying shear force. Maize shelling has improved over period of time going from traditional methods to present day mechanized shellers. In traditional method, maize shelling is carried out by hand by pressing the grains with the thumb with an output of about 10-12 kg/h. Engine powered sheller has the short coming of unavailability of fossil fuel in rural areas and increase of pollution, which demands an alternative energy powered sheller. This project work aimed to develop a maize sheller which runs on solar energy with more output capacity, less labor requirement. The major component of the sheller was solar photovoltaic system, shelling unit and blower. The SPV system was consisted of a solar panel, a solar charge controller (MPPT), DC motor, and a motor charge controller. A pair of 325 W solar panel was connected to a solar charge controller to maximize the power which was then transferred to a battery. This power was found sufficient to run the 450 W DC motor through motor charge controller which controlled the speed of motor. The sheller unit (cylinder and blower) was driven by DC motor through chain and sprocket transmission. The developed sheller could work efficiently for 38 min with only discharging the battery. The peripheral speed of cylinder was kept 3.56 m/sec. The moisture content of maize kernels and grain to non-grain ratio were found to be 14.3% and 3.23:1, respectively. The maximum shelling efficiency was obtained 99.6% at a feed rate of 102 kg/h. The corresponding cleaning efficiency, percentage of broken grain and blown grain were obtained 97.8%, 3.9% and 3.6%, respectively. The developed solar operated maize sheller could perform the shelling operation effectively at a solar intensity higher than 600 W/m^2 without any power consumption from battery.

Keywords: Maize sheller, solar energy operated maize sheller, solar photovoltaic system, shelling efficiency, cleaning efficiency, percentage of broken and blown grain.

INTRODUCTION

Maize (*Zea mays*) is one of the important cereals of the world and provides more human food than any other cereal that is high yielding, easy to process and readily digested with low production cost. In India, maize is the third most important food crops after rice and wheat. Maize in India, contributes nearly 9% in the national food basket. Shelling means removal of maize grains from the portion of the cob that holds them. The detachment of maize grain from cob is done by hand or machine by applying shear force. Maize shelling has improved over timeframe going from conventional techniques to present day mechanized shellers. In traditional method, maize shelling is carried out by hand by pressing the grains with the thumb with an output of about 10-12 kg/h. In the conventional technique of maize shelling, fingers or some beating tools were used to remove grain from cobs. The manual method of shelling is tedious, less efficient and consumes a significant time which cause grain losses and involves drudgery. These traditional methods result in serious bruising of human fingers, coupled with low output-rates (Adewale *et al.*, 2000; Kumawat and Raheman 2022). It was stated that the detachment of grains from cobs is depends on the principle of impact or pounding which was given on the cob. Furthermore, the strength of the bond between the grain and the cob depends upon various crop factors; *viz*., kind of crop, variety of crop, maturity phase and moisture content of grain (Dixit *et al.,* 2012). With the help of mechanization with higher increased capacity would allow the farmer to finish the operations timely, thereby it maintains the quality of produce and also reduces grain loss. The IC engine powered or electric motor powered maize shellers are normally large and heavy, require high power input to operate and produce low product quality in terms of percentage seed breakage and purity. The cost of purchasing such shellers are high for the rural farmer and create noise pollution. Today electricity consumption rate is not economical and unavailability or interrupted electricity in rural areas limits the use of motorized maize shellers. Faster depletion of fossil fuel, increase in their price and non-availability of fossil fuel in rural areas are the primary challenges in the mechanization of agriculture in rural areas. Further, mechanization at the cost of environmental pollution is unacceptable. Consequently, to meet the increasing energy demand, the Government of India (GOI) started promoting the use of renewable resources (Anon., 2018; Kumawat and Raheman 2020). Amrutesh *et al.* (2014) developed a solar grass cutter with linear blades by using scotch yoke mechanism. A 350 W 24 V DC motor was used to run the blade. A motor was driven by taking power from 50 W solar photovoltaic systems. Gupta and Raheman (2016) developed a motorized wetland weeder, which was powered by a 100 W solar photovoltaic system. A DC motor of 350 W and 24 V was used to run the weeder. He used four batteries of 12 V and 7 Ah capacity, which could operate the motor for 2.3 hours when charging system was not connected to battery whereas it could run the system 7 hours continuously with simultaneous charging and discharging. The developed weeder was able to cover 30 cm of working width with 4 cm depth of operation. The actual field capacity, weeding efficiency and field efficiency were found to be 0.037 ha/h, 83.11 per cent and 74.2 per cent, respectively with a plant damage was found to be 16 per cent. Sahu and Raheman (2017) developed a solar energy operated paddy thresher, which was powered by a 100 W solar photovoltaic system. A 350 W DC motor was used to run the paddy thresher. The peripheral speed of threshing of the developed thresher was 9.58 m/s and it could able to run continuously for 7 hours. Threshing efficiency and feed rate were found to be 96.23% and 299.33 kg/h with the developed thresher. The cost of threshing of one tonne of paddy grains with the developed solar energy operated paddy thresher was also analyzed and it was calculated about 789.28 rupees as compared to 3153 rupees with pedal operated thresher.

To overcome these problems there is a need for a relatively low cost maize sheller that would significantly cater the farmer's average harvest capacity and which many households can afford and will be affordable to such farmers not only to meet their shelling requirement but also to improve the shelling efficiency and reduce damage of the seed.

MATERIALS AND METHODS

Geographical Location and Climatic Condition. The experiment was conducted at the Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, West Bengal, India. The longitude and latitude of geographical location of the test site was 87°20′E and 22°30′N, respectively from mean sea level. Climatic condition of test was observed to be humid temperate.

Determination of Physical Properties of Maize Kernel. The physical properties of maize kernel are important to design the maize sheller components. The moisture content of crop as well as grain was measured by the procedures given in IS 4333: 2002. The moisture content of the kernel and core were found to the 14.3% and 12.10% on dry basis, respectively.

(a) Size. Size of seed, grain or kernel can be estimated using the equation no. 2.1 (Mohsenin, 1980). A twenty samples of maize (variety Ganga 101) and cores were selected randomly for measurements of length and diameter (Top diameter, middle diameter and tip diameter) of husked maize cobs as shown in Fig. 1; while a sample of one hundred maize kernels were selected randomly for measurements of size of maize kernel as shown in Fig. 2.

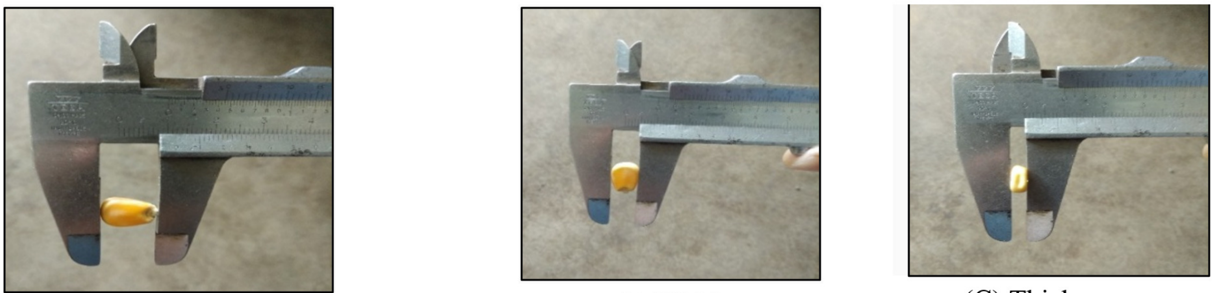
$$D_g = (LWT)^{\frac{1}{3}} \quad (1)$$

Where, D_g = geometric mean diameter, mm

L = length, mm; W = width, mm; T = thickness, mm

(a) Middle diameter (b) Tip diameter (c) Top diameter (d) Length

Fig. 1. Measurements of principal dimensions (mm) of maize cob.



(a) Length (b) Width (C) Thickness

Fig. 2. Measurements of principal dimensions (mm) of maize kernal.

(b) Grain to non-grain (core) ratio. The grain to non-grain ratio was determined by procedure given in IS 7052 (1973). Ten maize cob samples were choose randomly to determine the grain to non-grain ratio and the weight of grain, husk and remaining core were measured for every selected cob by digital weighing balance. The average of the ten selected samples were taken as the grain-core ratio.

CAD model of proposed model. A 3-D CAD model of the proposed solar energy operated maize sheller was made using SolidWorks-2016 to facilitate the development process. An Isometric view with the nomenclature was shown in Fig. 3.

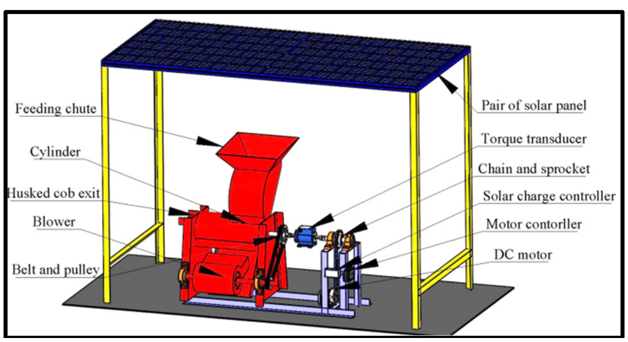


Fig. 3. CAD view of designed model.

Development of maize sheller. The solar energy powered maize sheller was developed at the workshop of Indian Institute of Technology, Kharagpur. The developed sheller mainly consisted of a shelling unit and a blower.

(a) Shelling unit. The main function of shelling unit was to detach the kernel from maize cob. It was consisted of a Spike tooth type cylinder and a semicircular type concave. The length of cylinder was 450 mm and a total 16 pegs were made on the periphery of cylinder to remove maize kernel. A semicircular type conveyor cum sieve was fitted below the cylinder with some clearance. The shape of maize kernel was almost circular, hence circular type holes were made in the concave. The length of concave is same as the length of cylinder. The concave clearance was chosen as 25 mm at front and 20 mm at rear.

(b) Blower. The air velocity required for the blower should be smaller than the terminal velocity of the kernel to separate the fine dust and chaff from the maize seeds. The terminal velocity of the maize kernel is 13.1-14.1 m/s (Sharma, 2007). Hence, the air velocity was kept 4 m/sec for the blower.

Development of the arrangement for power requirement for the developed maize sheller. An arrangement (Fig. 4) was made to determine the power requirement for the sheller (cylinder and blower) and only cylinder without blower, by measuring the torque and rotational speed of cylinder. The power required to run the blower was measured by deducting from the total power required to run the sheller and at the time of measurement of cylinder power, the blower was disconnected from the transmission.

1. Laptop; 2. Battery; 3. DUI; 4. Torque transducer; 5. Belt and pulley transmission system; 6. Feeding chute; 7. Cylinder; 8. Blower; 9. Ac motor

Fig. 4. Arrangements to measure the power requirement for shelling operation.

An arrangement for finding power requirement of maize sheller was made by extending the cylinder shaft from one side and supporting the extended shaft with two pillow bearings. A torque transducer (4) with two side Oldham couplings was mounted between threshing cylinder (7) and power transmission system (5). A 1.5 hp Ac motor (rated rpm 1410) (9) was used to rotate the cylinder and blower (8) with the help of belt and pulley arrangement. The speed of motor was controlled by using a variable frequency varying input frequency and voltage. A speed ratio of transmission system was kept 2.77:1. The torque transducer was connected with Datum universal interface (DUI) (3) through a cable, which was then connected to the laptop (1) for displaying and storing data using a software. The DUI was powered from a 12 V battery (2).

Development of the solar system for the developed sheller. The solar photovoltaic system was mainly consisted of a solar panel, solar charge controller (maximum power point tracker), DC motor, and DC motor controller. A pair of 325 W solar panel was choose to run the 450 W DC motor. The detailed specifications of solar photovoltaic system is given in Table 1.The power transmission system of the developed solar energy operated maize sheller was shown in Fig. 5.

Table 1: Technical specifications of the solar photovoltaic system.

Particulars	Specifications
Solar panel	
Size	1960 mm × 992 mm × 40 mm
Maximum power (P_m), voltage (V_{mp}) and current (I_{mp})	325 W, 37.0 V and 8.78 A
Solar charge controller	
Voltage, current, and efficiency	12V/24V, 20 A, and 99.5 %
Maximum solar panel voltage and power	100 V, 260 W at 12 V, 520 W at 24 V
Motor controller	
Voltage, current, power, and operating temp.	10-50, 960 W at 24 V, 40 A and -20 to 40 °C
DC motor	
Rated power, speed and torque	450 W, 480 rpm, and 76 kg-cm

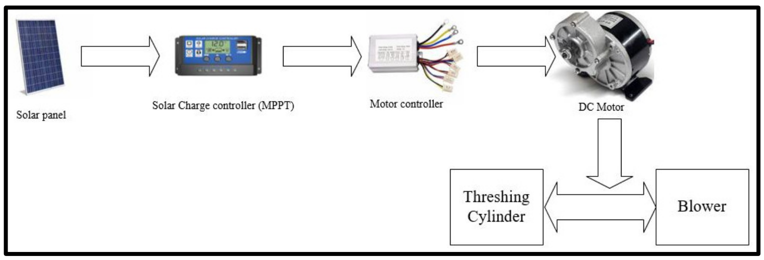


Fig. 5. Block diagram of power transmission system.

Performance evaluation of the developed solar energy operated maize (SEOM) sheller, In India, maize is generally harvested in the month of April- May and September- October in every year. The solar energy available at location of Kharagpur (Latitude 22.310 N and longitude 87.300 E) during this period was found to be in the range of 4.5-5.5 kWh/m^2(NREL, 2014). Hence the peak solar hour for Kharagpur was 4.5-5.5 h @1000 W/m^2/day. The total solar radiation was measured with help of pyranometer as shown in Fig. 6. The shelling operation with SEOM sheller was carried out with 400 rpm speed of threshing cylinder at a feed rate of 105±2 kg/h operated by a single operator.

Fig. 6. Measurement of solar radiation by a pyranometer.

The developed SEOM sheller was tested for its performance such as solar panel conversion efficiency, shelling efficiency, cleaning efficiency, and percentage of broken and blown grains.

All the efficiencies and broken percentage were measured by following the test code from IS 7052 (1973) as follow:

$$A = B+C+D \quad (1)$$

Where, A = total grain input per unit time; B = quantity of (threshed) grain collected from grain outlets per unit time; C = quantity of broken grain from all outlets per unit time; D = quantity of unshelled grain from all outlets per unit time

Percentage of broken and cracked grains

$$\text{Percentage of broken and cracked grain} = \frac{C}{A} \times 100 \quad (2)$$

Percentage of unshelled grains

$$\text{Percentage of unshelled grain} = \frac{D}{A} \times 100 \quad (3)$$

Percentage of blown grains

Percentage of blown grain =

$$\frac{\text{Quantity of clean grain obtained at husk outlet in kg}}{\text{Total grain input in kg}} \times 100 \quad (4)$$

Shelling Efficiency. The shelled grain received from all outlets with respect to total grain input expressed as percentage by mass.

$$\text{Shelling efficiency} = 100 - \text{\% of unshelled grain} \quad (5)$$

Cleaning efficiency

Cleaning efficiency is the clean grain received at main grain outlet with respect to the total grain mixture received at main grain outlet expressed as percentage by mass.

$$\text{Cleaning efficiency} = \frac{M}{F} \times 100 \qquad (6)$$

Where, F (kg)= Total quantity of sample taken at main grain outlet; M (kg)= quantity of clean grain obtained from the sample taken at main grain outlet.

RESULTS AND DISCUSSION

Physical properties of maize cob, core, and maize kernel. The pertinent physical properties of maize cob, core, and kernel is discussed in Table 2. The moisture content of the kernel and core were found to be 14.3% and 12.10% on dry basis, respectively.

Performance of the SEOM sheller. The performance of SEOM sheller was evaluated in the laboratory with Ganga 101 variety of maize. The shelling operation was carried out for one hour on 20th April 2019 at workshop of Agricultural and Food Engineering department, IIT Kharagpur and all the power parameters such as solar panel output, battery power and shelling power requirement of SPV system were recorded at an interval of 5 minutes. During this period the corresponding solar radiation was also measured. All the data with corresponding measured radiation were plotted in a graph shown in Fig. 7. In this graph it can be seen that the average power consumption during shelling operation was in the range of 350 to 400 W. The graph shows that the solar panel of 650 W was able to provide the power requirement for the shelling operation at almost all time and also the surplus power was stored in the battery (shown as positive power for battery power in Fig. 7). During the time 2:15 PM and 3:00 PM the solar panel was not able to provide the power for shelling so the additional power was compensated by the battery (shown as negative power for battery power in Fig. 7).

From the Fig. 7 this can be concluded that the developed SEOM sheller could be operated smoothly without any discharge from battery if the solar radiation is higher than 600 W/m^2. Hence, the sheller could be easily operated for a period of 6 hours without any interruption during the month of April and May from 9:00 AM to 3:00 PM as the solar intensity was matching with the requirement as shown in Fig. 8.

Table 2: Physical properties of maize cob, core, and kernel.

Properties	Mean value			Standard deviation		
	Cores	Cobs	Kernals	Cores	Cobs	Kernals
Top diameter, mm	31.9	51.4	-	±2.43	±2.69	-
Middle diameter, mm	27.95	48.15	-	±2.18	±3.10	-
Tip diameter, mm	19.3	24.5	-	±3.82	±4.87	-
Length, mm	187.9	187.9	10.17	±17.71	±17.71	±1.01
Width, mm	-	-	8.02	-	-	±0.60
Thickness, mm	-	-	3.82	-	-	±0.49
Geometric diameter, mm	-	-	6.76	-	-	±0.40
Grain to non-grain ratio	3.23				±0.29	

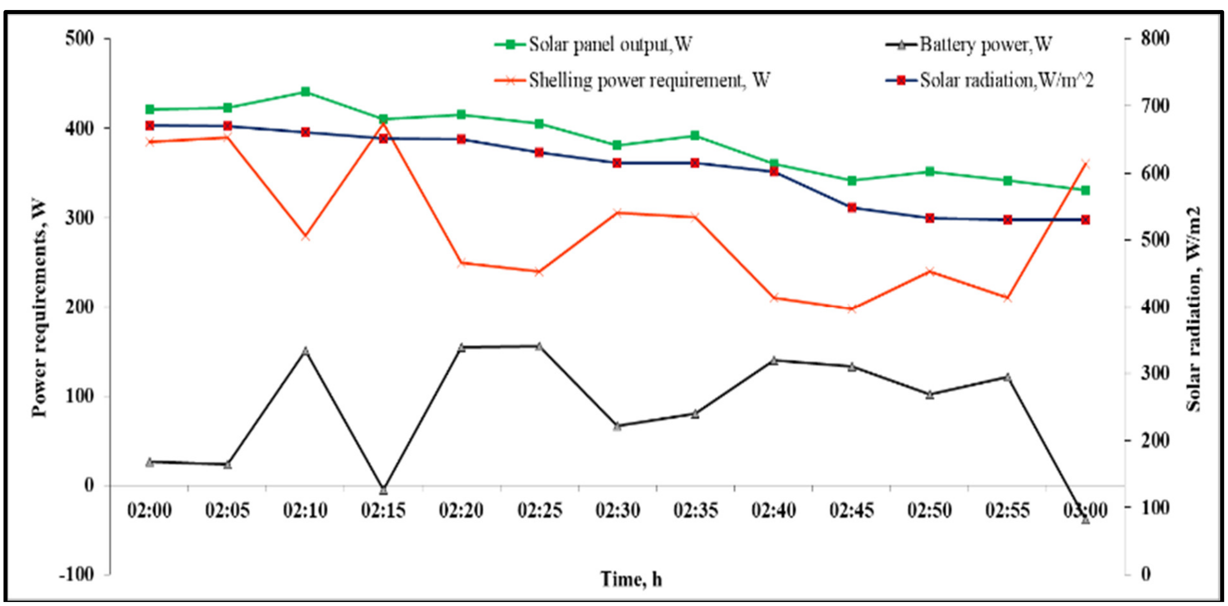


Fig. 7. Performance evaluation of the SPV system developed for the maize sheller.

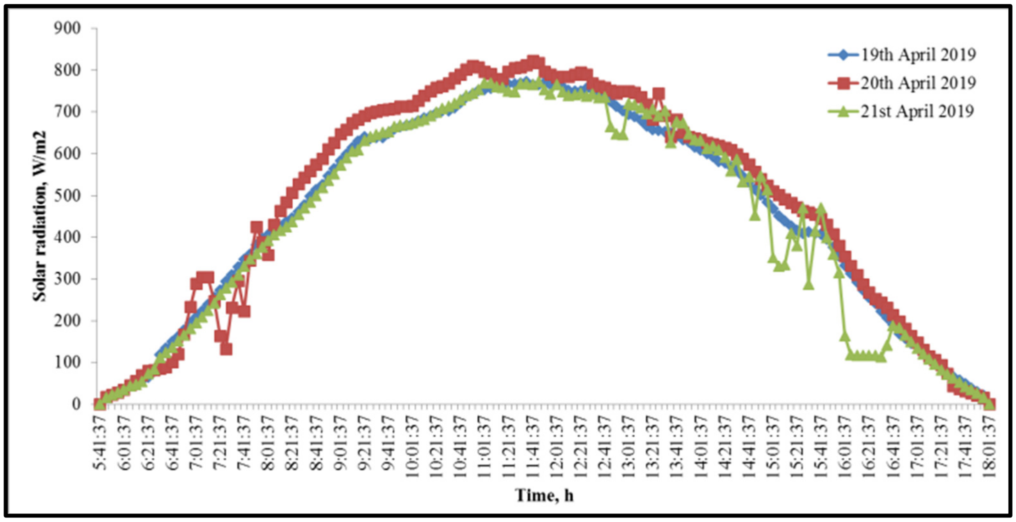


Fig. 8. Solar intensity measured at Agricultural and Food Engineering Department in the month of April 2019.

Testing of solar panel. The current and voltage for different loads were recorded at a radiation of 753.1 W/m^2 and a graph was plotted between voltage and current as shown in Fig. 9. During this test, the local time and the corresponding solar radiation were recorded by using a pyranometer placing on a horizontal surface. The maximum voltage and maximum current were measured from the Fig. 9 and found to be 30 V and 7.15 A, respectively. The area of solar panel was 1.94 m^2 and the solar radiation at the location was 753.1 W/m^2. The conversion efficiency of panel was obtained 14.68%.

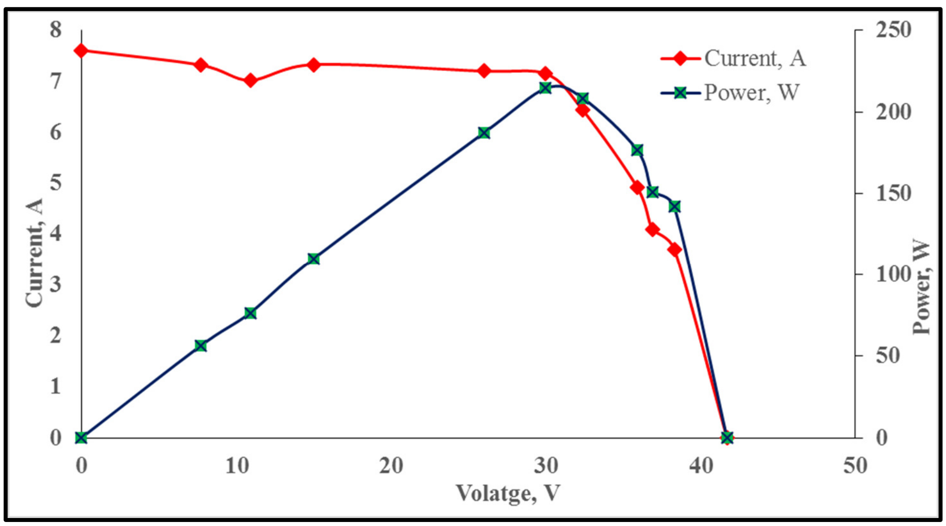


Fig. 9. PV characteristic curve of solar panel during testing.

Power Requirement for threshing cylinder and Blower in Idle condition. During idle condition the maximum power requirement of the sheller was found out by measuring the torque with the help of a torque transducer. Power required by the sheller was measured while blower was connected and disconnected at different cylinder speeds. The results are summarized in Table 3.

Table 3: Power requirement for the shelling unit and blower.

Sr. No.	Cylinder speed(rpm)	Max. power requirement (W)			Max. torque requirement (N-m)		
		Cylinder and blower	Blower disconnected	Blower	Cylinder and blower	Blower disconnected	Blower
1.	350	183	110	73	5	3	2
2.	400	247	168	79	5.89	4	1.9
3.	450	354	248	106	7.52	5.26	2.26
4.	500	523	305	218	10	5.82	4.18

From the Table 3, it can be seen that the power and torque requirement of different components of sheller varies as speed changed during idle running. Total requirement of power and torque for shelling unit were 55-57% and 60-67%, respectively of the total power and torque whereas the power and torque required for blower were 42-50% and 33-40%, respectively of total the power and torque.

Power Requirement for the developed Maize Sheller during Shelling Operation. An experimental investigation was carried out to find the optimum power requirement for shelling the maize. For finding out the optimum power requirement for shelling, the optimum speed at which the shelling operation was performed efficiently and the maximum torque required at this speed was recorded using torque transducer and universal interface. The experiments were conducted at four different peripheral speeds of the shelling unit with manual feeding by an operator. The result of the experiments is shown in Table 4.

From this experiment it was concluded that the maize sheller could be operated efficiently with a cylinder peripheral speed of 3.56 m/s at a feed rate of 102.85 kg/h. At this point of operation, the maximum torque and power requirement were found to be 9.21 N-m and 386 W, respectively. The graph between torque and power is shown in Fig. 10. Hence, for powering the maize sheller, the speed and maximum torque of the suitable DC motor should be 400±10 rpm and 9.21 N-m, respectively.

Testing of the developed SEOM sheller. The shelling operation was carried out for about one hour using a single operator. After the shelling operation, samples were taken for calculating the shelling efficiency, cleaning efficiency, and percentage of broken and blown grain. The developed SEOM sheller was shown in Fig. 11. The summarized result of the performance of the sheller is shown in Table 5. The detailed specifications is shown in Table 6.

Table 4: Power requirement for the developed maize sheller.

Cylinder (rpm)	Peripheral speed (m/sec)	Feed rate (kg/h)	Shelling efficiency (%)	Broken grain (%)	Blown grain (%)	Cleaning efficiency (%)	Max. torque required (N-m)	Max. power required (W)
350	3.11	90	97.78	4.4	2	91.2	8.64	317
400	**3.56**	**102.85**	**98.5**	**4**	**3.5**	**96**	**9.21**	**386**
450	4.0	105.26	98	8	3	96.8	10.39	490
500	4.45	112	99	10	8	98	12	628

Moisture contents: 14.3% (db); Grain to core ratio: 3.23

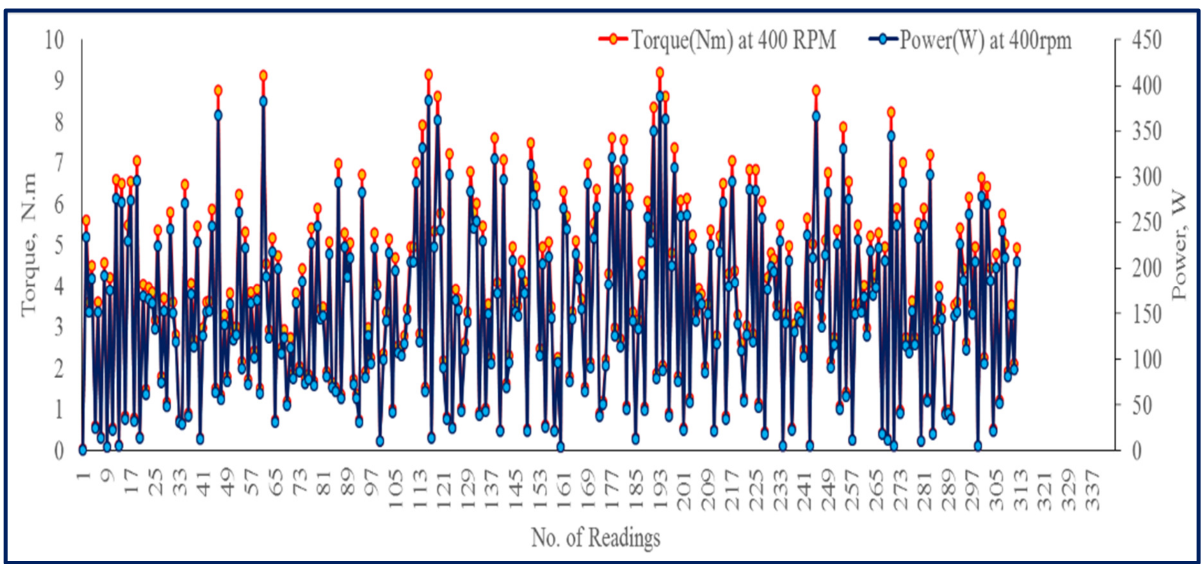


Fig. 10. Torque and power requirement for the shelling operation at 400 rpm.

1. Solar panel 2. Feeding chute 3. Threshing cylinder 4. Blower 5. Torque transducer 6. DC motor

Fig. 11. Solar energy operated maize sheller.

Table 5: Technical Specifications with materials of construction of different components of the developed SEOM sheller.

Components	Dimensions	Materials of construction
A. Feeding hopper		
Top section	400 mm × 400 mm	Mild steel sheet
Bottom section	220 mm × 220 mm	
Height above cylinder cover	280 mm	
B. Cylinder		Mild steel sheet
Diameter including pegs	170 mm	
Diameter without pegs	120 mm	
Length of cylinder	450 mm	
Number of pegs and size	16 (4 row each contains 4 pegs) 25 mm × 25 mm	Mild Steel
Cross section of Peg	25 mm	
Peg height	95 mm	
Peg spacing in row	25 mm	
Diameter of cylinder shaft	470 mm	Mild steel
Length of cylinder shaft	250 mm	
Diameter of driven pulley of Sheller	180 mm	Cast iron
C. Concave		
Length	450 mm	
Peripheral width of concave	180 mm	Mild Steel sheet
Diameter of concave	170 mm	

Table 6: Performance evaluation of the developed SEOM sheller.

Sr. No.	Feed rate (kg/h)	Shelling efficiency (%)	Cleaning efficiency (%)	Broken grain (%)	Blown grain (%)	Average power requirement, (W)
1	102	99.6	97.8	3.9	3.6	356
2	103.5	99.3	97.4	4	3.5	375
3	105.2	99.0	97.3	4.3	3.8	380
4	107.67	98.9	97.0	3.85	4.2	387

From the performance analysis, the shelling efficiency and cleaning efficiency were found to be more than 99% and 97%, respectively, which was satisfying the standard given in the test code IS 7051-1973. The percentage of broken and blown grain were obtained less than 4.3% and 4.2%, respectively, which were somewhat higher than the permissible limits. The variation might be due to change in physical properties of maize variety.

CONCLUSIONS

Finally, the performance of the developed SEOM sheller was evaluated using maize cobs (Ganga 101). It was observed that When the DC motor was running continuously without charging the battery it was able to carry out shelling for a maximum period of 38 min with the shelling efficiency of 99.6%, 99.3%, 99% and 98.9% at a feed rate of 102 kg/h, 103.5 kg/h, 105.2 kg/h and

107.67 kg/h, respectively for maize cob at 14.3% m.c. (db) and grain to non-grain ratio of 3.23:1. The corresponding percentage of broken grain was obtained 3.9%, 4%, 4.3% and 3.85%. The developed SEOM sheller could perform the shelling operation efficiently at a solar intensity higher than 600 W/m^2 without any power consumption from battery. The capacity of developed solar energy operated maize sheller was smaller than engine and electrical powered sheller but it is a renewable energy resource widely available of sunlight with free cost, eco-friendly, clean technology with zero CO_2 emission and reduced the environmental degradation and save the cost of electricity. By on battery power backup, solar energy operated maize sheller can be operated any time in 24 × 7, even in cloudy days or at night and can be used for a longer period of operation of shelling by continuously charged the batteries. Initial installation cost is high but considering it has long advantage with free rechargeable, lower manpower expenses and free from pollution. Hence, it is an efficient and economical substitute of shelling of maize cobs for the small and medium farmers and industries of India.

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Conflict of Interest. None.

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