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Research Paper

Development and performance evaluation of low-cost cylinder type maize sheller for small farmers of Jammu and Kashmir

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ABSTRACT

A study was conducted to utilize physical attributes and engineering parameters of local maize varieties (white, yellow and multi-coloured) to develop a power operated maize sheller for small farmers of Jammu and Kashmir. The moisture content measured was within 13-14% limit for all the three varieties. Tri-axial dimensions in terms of length, diameter of maize cobs, eccentricity index, sphericity of maize grains and engineering parameters of bulk density of cobs, angle of repose of maize cobs and grains were used to select the design values of functional components of maize sheller. The maize sheller comprised of feeding hopper, cylindrical drum, beaters, sieving unit, outlet for maize cobs and grains. The performance of the maize sheller was evaluated in terms of variety, RPM and type of beater. The optimization of the response parameters using Design expert 10.0 revealed that RPM of 720, closed chain type beater resulted in 96.01% shelling efficiency, 24.23 kg h^{-1} shelling capacity, 3.08% unshelled grain percentage, 1.67% mechanical damage percentage, 98.91% cleaning efficiency, labour requirement of 2.83 man-minutes kg^{-1} and 95% germination percentage for yellow maize variety. The economic analysis revealed that operating cost was 78.74 Rs. h^{-1} with break-event point of 9052.0 Kg, benefit-cost ratio of 1.30:1 and 585.2 hours payback period. The unit cost of maize shelling was calculated as Rs. 3.42 per kg. The maize sheller can be useful to cater to the needs of small and marginal farmers and provide entrepreneurship opportunities to the rural youth of Jammu and Kashmir.

Key words: Jammu and Kashmir, local varieties, low-cost, maize sheller, motorized

The thrust on the agricultural system to feed 9.6 billion people by 2050 has resulted in the manifold increase in production level of staple cereals – Rice, Wheat and Maize (Gerland *et al*., 2014). At global level, maize (*Zea mays L.*), wheat (*TriticumAestivaum*) and rice (*OryzaSativa*) is cultivated extensively over an area of 216Mha, 197 Mha and 165 Mha (Erenstein *et al*., 2022) producing 757 Mt, 1137 Mt and 757 Mt, respectively (FAOStat, 2021). Maize crop is primarily used as feed (56%) (Erenstein,2010) and food (13%) with 20% share in food calories (Shiferaw *et al*., 2011) amounting to 18.5 kg/capita/person (FAOStat, 2021). China and India are the main producers of maize crop, totalling 36% of the global production (UN-DESA, 2019). India produces 26 Mt of maize from 9.2 Mha land and the demand is expected to increase to 45 Mt by 2022 (FICCI, 2018). Maize crop is perceived as an essential ingredient to help the developing nations to achieve sustainable development goals (Franzo *et al*., 2021). From Indian perspective, the burgeoning population has resulted in reduction in per capita land holdings from 1.08 ha in 2015-16 from 1.15 ha in 2011-12 (Anonymous, 2016). Moreover, the expansion of non-farm activities and lack of technological alternatives is compelling the rural youth to migrate to urban areas resulting in seasonal labour shortage (Zhang *et al*., 2014). In order to arrest this process, efforts should be directed to design and develop small efficient tools and implements (World Bank, 2007) for small fields to ensure the sustainability of agricultural activities and reduction in drudgery and cost.

Jammu and Kashmir produces 591242.16 MT of maize crop from 254190.0 hectares (Anonymous, 2021). The individual contribution of Kashmir valley is 182729.16 MT from 56520 ha while Jammu contributes 408513 MT from 197670 ha land (Anonymous, 2021). However, In Kashmir valley, the problem is more severe owing to undulating topography, drastic reduction in per capita land holding to 0.59 (Greater Kashmir,2020) and heavy reliance on manual power. Maize processing is laborious and involves harvesting, drying, dehusking, shelling, storing and milling (Okure and Ssekanyo, 2017) with post-harvest losses as high as 30% (Seatini, 2014). Shelling of the maize cobs is challenging and labour-intensive operation (Okule and Sekanyo, 2017). It is believed that the use of appropriate machinery increases the income of small landholding farmers, total production efficiency and peak-labour constraints (Mottaleb *et al*., 2016; Biggs *et al*., 2011). The small custom based machines can solve the problems of small landholdings with low resource potential (Krupnik *et al*., 2013). In most of the developed countries, maize combines (Wang *et al*., 2012) and engine operated maize shellers are commonly used for separation of grains from maize cobs (Nsubuga *et al*., 2021). These heavy machines are costly, time consuming and demands huge energy to move from one place to another (Nsubuga *et al.,* 2021).

In Jammu and Kashmir, the shelling of the maize cobs is usually carried out manually or hand operated maize shellers. Hand operated maize shellers have limited capacity and are mostly used for seed purpose (Kumar and Begum, 2021). A low-cost manual lever operated maize sheller with 91.37% shelling efficiency and 5.33% unshelled percentage can serve as panacea for small farmers (Bashir *et al*., 2022). However, the manual operations are hard, laborious, time consuming and full of drudgery (Muzamil *et al*., 2018). The performance of the existing maize shellers has failed to cure the anomalies in the shelling operation owing to lack of concern for crop characteristics and machine parameters (Ojomo and Alemu, 2012). The capacity of these manual (hand and lever) operated shellers is limited. The power operated maize shellers with cylinder-concave mechanism, involves selection of appropriate clearance to achieve higher efficiency. They are costly and damage percentage is also higher than recommended damage percentage of less than 2% for maize shelling (EAC, 2017). Therefore, it was envisaged to fabricate and evaluate cylinder type rotary beater based maize sheller to achieve the objective of maize shelling.

Unit operations in Maize processing: The processing of maize involves harvesting at the field level, separation of maize cobs and plants, dehusking and shelling operation, storing and milling, Fig. 1. The plants are usually harvested by harvesters or maize combines. The maize combines possess a feeding mechanism, threshing unit, separation and cleaning unit to complete the operation in one-go. The maize cobs are subjected to dehusking operation in which the upper layer is removed to expose the grains. The shelling process involves the separation of maize cobs and grains. In Jammu and Kashmir, maize shelling is carried out by either manually or with the help of shellers (manual and power operated). Power operated shellers are based on cylinder-concave mechanism that allows the maize cobs to pass through the clearance provided between the revolving cylinder and stationary concave. This results in damage and low viability of the seeds to germinate.

Fig. 1: Unit operations in maize processing

MATERIALS AND METHODS

Market Survey: The market survey was carried out to select the local varieties that occupies maximum share in Jammu and Kashmir. After thorough analysis and survey, three varieties were selected on the basis of availability and consumption.

Collection and preparation of maize varieties: The local maize varieties (white, yellow and multi-coloured) were procured from different districts of Jammu and Kashmir, Fig. 2.

Engineering properties of maize cobs and grains: The engineering properties of the maize cobs and grains were measured in terms of moisture content, length of cobs and maize grains, diameter of maize cobs, sphericity (Chhabra and Kaur, 2017) of maize grains, bulk density of maize cobs and angle of repose (Wani *et al*., 2017) of maize cobs and grains (Mullen, 2016). The physical characteristics and engineering parameters are essential to design and develop efficient agricultural machines (Muzamil *et al*., 2021).

1. **Moisture content**: The moisture content of maize grains was measured by gravimetric method (Mohiuddin *et al*., 2022).
2. **Tri-axial dimensions:** The tri-axial dimensions of maize cobs and grains were measured using digital Vernier Calliper (Malla *et al*., 2022) with an accuracy of 0.01 mm, Fig. 2. A total of 50 cobs and grains were used for each replicate.
3. **Bulk density**: It is the total mass of the sample to the total volume the sample. A known mass of maize cobs was placed in cuboidal section. It was mixed thoroughly to arrange the maize cobs systematically. The dimensions of the cuboidal section were measured to determine the volume. The ratio of the mass of the sample to the volume of the cuboidal section was used to determine bulk density of maize cobs. It was used to decide the diameter and capacity of the cylindrical drum.

$$Bulk\ density = \frac{Mass\ of\ the\ sample}{Volume\ of\ the\ box} -------------(1)$$

4. **Angle of Repose**: It is the steepest angle of descent or dip relative to horizontal plane to which a material can be piled without slumping. It was measured by angle of repose apparatus (Mohiuddin *et al*., 2022).

Fig. 2: Measurement of tri-axial dimensions of maize varieties with digital Vernier Calliper

Selection of design values for maize sheller: The physical characteristics and engineering parameters were used to conceptualize and select the design values of individual components of maize sheller, Table 1. The functional components were sketched using Pro-E software, Fig. 3.

Table 1: Design values of functional components of cylinder type maize sheller

Components	Parameters	Design values	Reference
Feeding hopper	• Bulk density (333.7-359.2 kg m^{-3}) • Angle of repose of cobs (23.2° -24.1°)	V=0.019 m^3	Aremu *et al.*,2015
Cylindrical drum	• Bulk density • Angle of repose • Tri axial dimension of • Maize cob Length x diameter = (119.6-138.6 x 34.28-38.69mm)	ϕ 300 mm L = 700 mm V=0.05 m^3	Malla *et al.*, 2022
Sieve size	• Tri-axial dimensions of maize grain ❖ Length (9.69-10.61 mm) ❖ Angle of repose of grains (25.3 - 26.2°)	15 mm	Nsubuga *et al.*, 2021

Development of maize sheller: The maize sheller comprised of a feeding hopper, cylinder, beaters, outlet for maize cobs and grains, sieving unit and 0.5 hp electric motor as power source. The feeding hopper was trapezoidal in shape with 300 mm upper opening, 320 mm height and 150 mm converging chute to feed the cobs to the rotating beaters, Fig. 3. The diameter (ϕ) of the cylindrical drum was 298 mm, sufficient to accommodate 3 kg maize cobs at one time. The shaft diameter (ϕ) was 35 mm and length 1016 mm with beaters mounted on its surface. Three types of beaters were used for maize shelling *viz.* closed chain, open chain and rope, Fig. 4. The inner surface of the cylindrical drum was corrugated to rip off the maize grains from maize cobs. The shaft was powered by 0.5 hp electric motor mounted on the mainframe at the lower side to maintain the stability. V-belt was used to transfer the motion of motor to the shaft. The rotation of the shaft generated impact force and centrifugal force, pushing the maize cobs towards the corrugated outer side. The convergence of impact, centrifugal and frictional force resulted in the shelling of maize cobs. A number of holes were made in the cylindrical drum to provide a space to the maize grains towards the cleaning sieve. The sieve was placed at the lower end of the cylindrical drum. The length of the cleaning sieve was 400 mm with 15 mm diameter holes. The outlet for the maize cobs was in the form of a 160 mm diameter (ϕ) chute. The overall dimensions of the maize sheller were 1530 mm x 950 mm x 835 mm. Four wheels were also provided for maneuverability in the field.

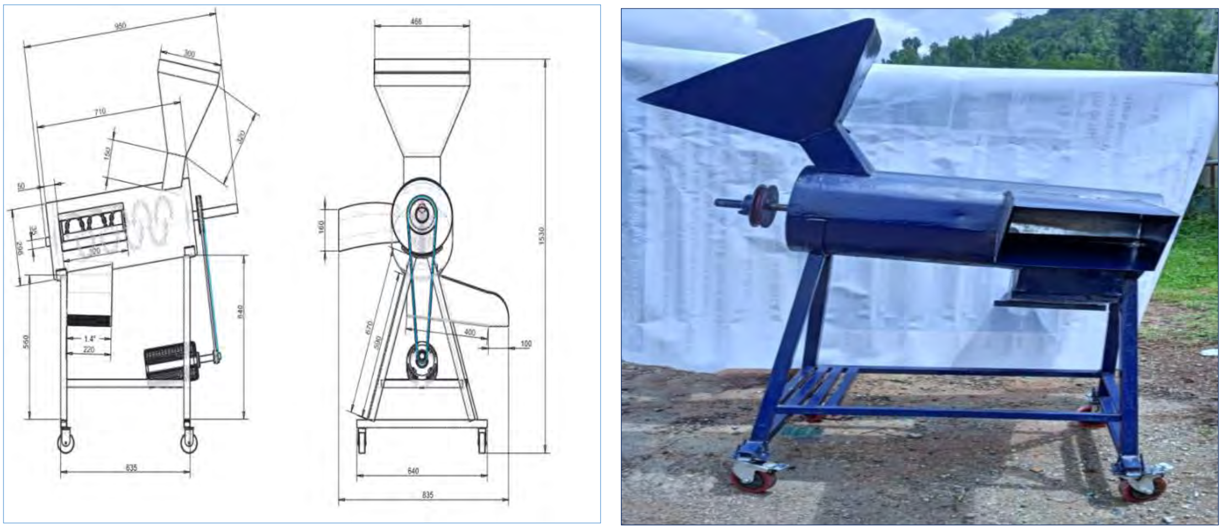
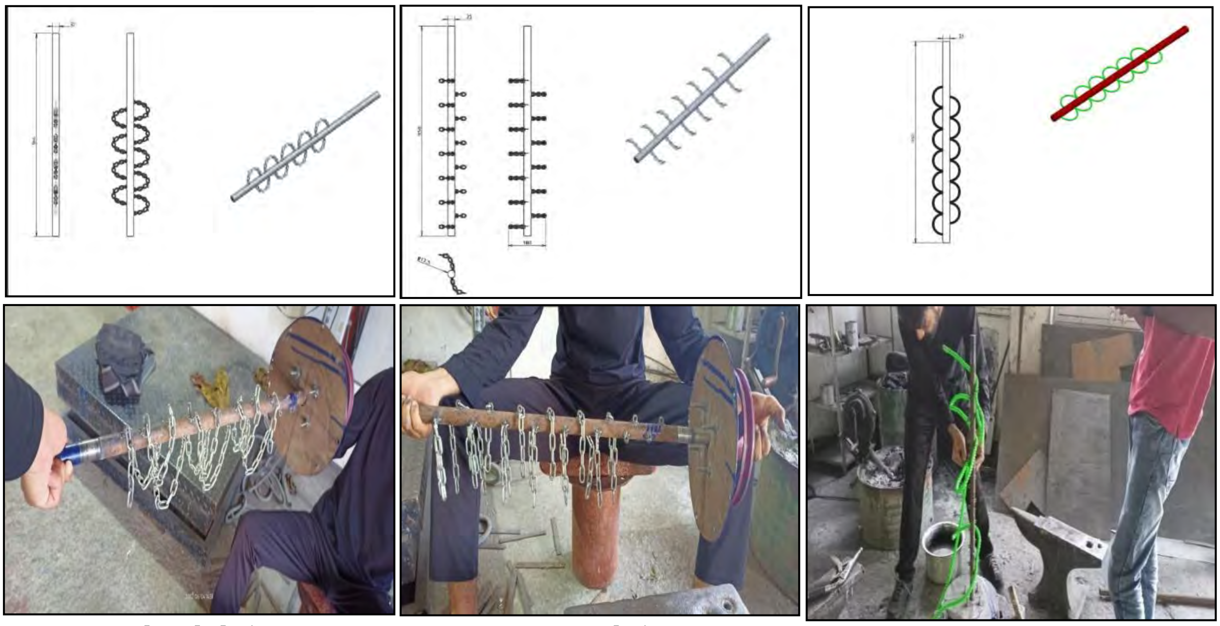


Fig. 3: Conceptual design using Pro-E software and fabricated prototype of maize sheller



Closed chain Open chain Rope

Fig. 4: Types of beaters used in maize sheller

Plan of experiment: The maize sheller was evaluated as per plan of experiment, Table 2. The crop parameter of variety (White, Yellow and Multicolored), machine parameter of RPM (344, 530, 720 rpm) and type of beater (Open chain, closed chain and rope) was selected to assess the impact of response parameters in terms of shelling efficiency, shelling capacity, unshelled grain percentage damage percentage, cleaning efficiency, labour requirement and germination percentage.

Table2: Plan of experiment for the evaluation of cylinder type maize sheller

Parameter	Variables	Levels	Response
Crop	Variety	3 (White, Yellow and Multi-coloured)	• Shelling efficiency • Shelling capacity, kg h^{-1} • Unshelled grain percentage • Damage percentage • Cleaning efficiency • Labour requirement, man-min. per kg • Germination percentage
Machine	RPM	3 (344, 500, 720 rpm)	
	Type of beater	3 (Open chain, closed chain and rope)	

Statistical analysis: The analysis of the data obtained from the experimental trials was carried out in SPSS and design expert 10.0 software. The main objective was to check the impact of independent parameters on response parameters and their interaction effect at 5% level of significance ($p<0.05$).

Performance evaluation parameters: The performance of the cylinder type maize sheller was measured using the standard procedures (Naveenkumar, 2011) in terms of shelling efficiency, shelling capacity (Nsubuga *et al.*, 2021), damage percentage, Unshelled grain percentage, cleaning efficiency, labour requirement and germination percentage. The economic assessment was calculated in terms of operating cost (fixed cost and variable cost), break-even point, benefit cost ratio, payback period and unit cost of maize shelling.

1. Shelling efficiency: It refers to the shelling of the maize cobs with reference to the input fed to the sheller. It was measured by the weight of shelled grains (kg) obtained from all outlets to the total weight of grain input (kg).

$$Shelling\ efficiency = \frac{Weight\ of\ shelled\ grains}{Total\ weight\ of\ the\ sample} x\ 100 \text{ -------------------------- } (2)$$

2. Shelling capacity: It was measured by the weight of shelled grains (kg) to the total time taken (h) in the shelling process. The hopper of the maize sheller was designed to cater to 3 kg maize cobs (V=0.019 m^3) at one time (Table 1).

$$Shelling\ capacity = \frac{Weight\ of\ shelled\ grains}{Total\ time\ taken} x\ 100 \text{ ------------------------------ } (3)$$

3. Unshelled grain percentage: It was calculated from the ratio of weight of unshelled grains to the total weight of the grains.

$$Unshelled\ grain\ percentage = \frac{Weight\ of\ unshelled\ grains}{Total\ weight\ of\ the\ grains} x\ 100 \text{ -------------- } (4)$$

4. Mechanical damage: It refers to the quantity of broken/damaged grains from all outlets per unit time to the total weight of grain input per unit time.

$$Mechanical\ damage = \frac{Weight\ of\ cracked\ and\ broken\ grains}{Total\ weight\ of\ grains} x\ 100 \text{ -------------- } (5)$$

5. Cleaning efficiency: It governs the efficiency of the cleaning sieves. It was measured by the weight of clean grains from main grain outlet to the total weight of shelled grains and weight of residue.

$$Cleaning\ efficiency = \frac{Weight\ of\ clean\ grains\ from\ main\ grain\ outlet}{Total\ weight\ of\ shelled\ grains + Wt.of\ residue} x\ 100 \text{ ----- } (6)$$

6. Labour requirement: It was calculated from the inverse of shelling capacity in man-minutes per kg.

7. Germination percentage: Germination test was conducted to check the vigour of the shelled maize grains. Twenty randomly selected shelled grains were selected from each sample and germinated in the Seed Germinator, located at Basic Engineering and Applied Science lab of COAE&T at SKUAST-K. The Seed Germinator was operated at 28^0C for 4 days.

RESULTS AND DISCUSSION

Tri-axial dimensions of maize cobs and grains: The tri-axial dimensions of maize cobs and grains were measured and used to select the design parameters of maize sheller. The length and diameter of 138.6±14.78mm, 34.28±2.55mm of white, 119.68±13.55mm, 36.51±3.02mm of yellow and 120.84±15.86mm, 38.69±3.5mm of multi-coloured variety was used to select hopper dimensions, diameter of the cylindrical drum and dimensions of outlet for maize cobs, Table 3. On the other hand, the tri-axial dimensions and sphericity of maize grains (0.77±0.06 white, 0.76±0.06 yellow and 0.81±0.07 multi-coloured) were employed to decide the diameter of hole in the cylindrical drum and size of sieve.

Engineering properties of maize cobs and grains: The engineering properties were used in terms of moisture content, angle of repose of cobs, angle of repose of grains, and bulk density, Table 4. The moisture content was 14.82 ± 0.46 %of white, 13.86 ±0.63 % yellow and 13.8 ±0.46 % of multi-coloured maize variety. The angle of repose of 23.2±0.58° of white cobs, 23.6±0.47° yellow cobs and 24.1±0.51° multi-coloured cobs was used to design the feeding hopper and decide the inclination of cylindrical drum. The angle of repose 26.2±0.28° of white grains, 25.3±0.27° yellow and 25.7±0.25° multi-coloured grains was used for deciding the angle of inclination of cylindrical drum and sieve.

Table 3: Physical attributes of maize cobs and grains relevant to the design of maize sheller

	Variety	Length, mm	Diameter, mm	Width, mm	Thickness, mm	Sphericity
Maize cobs	White	138.6±14.78	34.28±2.55			
	Yellow	119.68±13.55	36.51±3.02			
	Multi-coloured	120.84±15.86	38.69±3.5			
Maize grains	White	10.53±0.83		9.31±0.75	5.63±1.03	0.77±0.06
	Yellow	10.61±1.22		9.11±0.99	5.53±0.73	0.76±0.06
	Multi-coloured	9.69±0.90		8.93±0.80	5.62±1.27	0.81±0.07

Table 4: Engineering properties of maize cobs and grains relevant to the design of maize sheller

	Variety	Moisture content, %	Angle of repose of cobs, degree	Angle of repose of grains, degree	Bulk density, kg m^{-3}
Maize cobs	White		23.2±0.58		333.79
	Yellow		23.6±0.47		353.07
	Multi-coloured		24.1±0.51		359.28
Maize grains	White	14.82±0.46		26.2±0.28	
	Yellow	13.86±0.63		25.3±0.27	
	Multi-coloured	13.8±0.46		25.7±0.25	

Variation in shelling capacity and shelling efficiency: The shelling efficiency increased from 30.17 – 95.78% with an increase in RPM (Chaudhary, 2016) from 344 to 720 rpm for different types of beaters and maize varieties. At 720 RPM, the shelling efficiency increased from 63.98 – 95.78%, maximum shelling efficiency was associated with closed chain and yellow maize variety, Fig. 5. The high speed pulled the maize grains from the maize cobs and resulted in shelling efficiency of 98.51% at 886 rpm and moisture content of 13 % (Pavasiya *et al*., 2018). However, the shelling efficiency was lower than the recommended shelling efficiency of 98.0 % as recommended by Oriaku *et al*., 2014. When the rpm was reduced to 530, maximum shelling efficiency was obtained from open chain type beater and white variety of maize. It can be attributed to the fact that the open chain induces more impact on the surface of maize cobs, resulting in separation of grains and cobs. A similar trend was observed at 344 rpm and 530 rpm. The open chain resulted in more shelling efficiency than closed chain and rope. In general, lower shelling efficiency was obtained with rope type of beaters. The flexibility of the rope prevented to generate impact force that would be sufficient to shell the maize cobs. The analysis revealed that speed, rpm and maize variety was significantly ($p<0.05$) influencing the shelling efficiency.

The shelling capacity at 720 rpm varied from 13.66 to 24.52 kg h^{-1} with different beaters and maize variety. The maximum shelling capacity of 24.52 kg h^{-1} was associated with open chain beater and white maize variety, Fig. 5. When the rpm was reduced to 530, shelling capacity of 25.0 kg h^{-1} was obtained with closed chain beater and white variety. It was observed that shelling efficiency with open chain and closed chain was comparable at 530 rpm and 720 rpm; however, the values were lower with rope type of beater. A similar trend was observed at 344 rpm with maximum shelling capacity of 13.68 kg h^{-1} with closed chain beater and white maize variety.

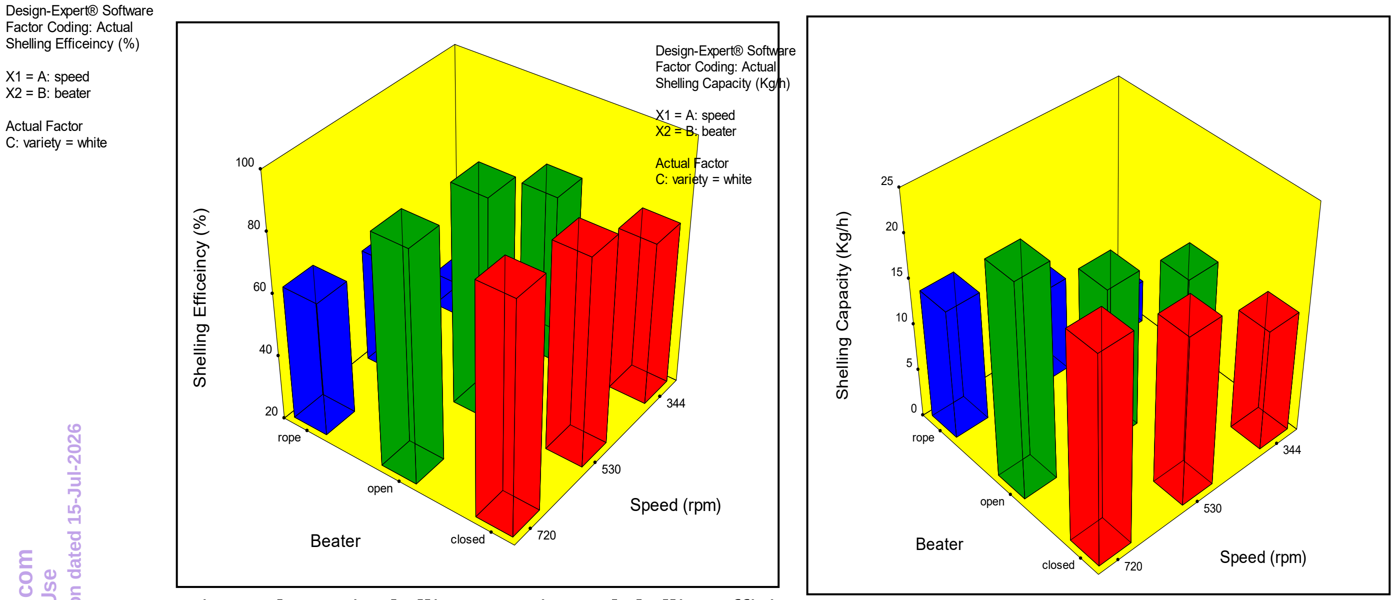


Fig.5: Change in shelling capacity and shelling efficiency

Change in unshelled grain percentage: The unshelled grain percentage was highest with rope type beater and low rpm.The unshelled grain percentage varied from 1.90 – 29.40 % at 720 rpm and different types of beaters. At 720 rpm, the lowest unshelling grain percentage was obtained in comparison to 530 rpm and 344 rpm, Fig. 6. It was observed that increasing the speed generated sufficient impact force to separate the grains from maize cobs. The rope type beater failed to provide the force and resulted in higher un-shelling grain percentage. The lowest un-shelling grain percentage of 1.90% was obtained at 720 rpm with closed chain type beater and white variety of maize. Statistically, the independent parameters were significantly ($p<0.05$) influencing the response parameters.

Change in cleaning efficiency: The cleaning efficiency is the representative of the efficiency of sieving unit. It was observed that the cleaning efficiency ≥95% in all the treatment combinations, Table 5. The maximum cleaning efficiency of 99.22% was observed at 344 rpm, open chain type beater and multicolour maize variety. This may be attributed to the fact that lower speed provided more time of the impurities to settle (Aremu *et al.*, 2015; Ilori *et al.*, 2013).

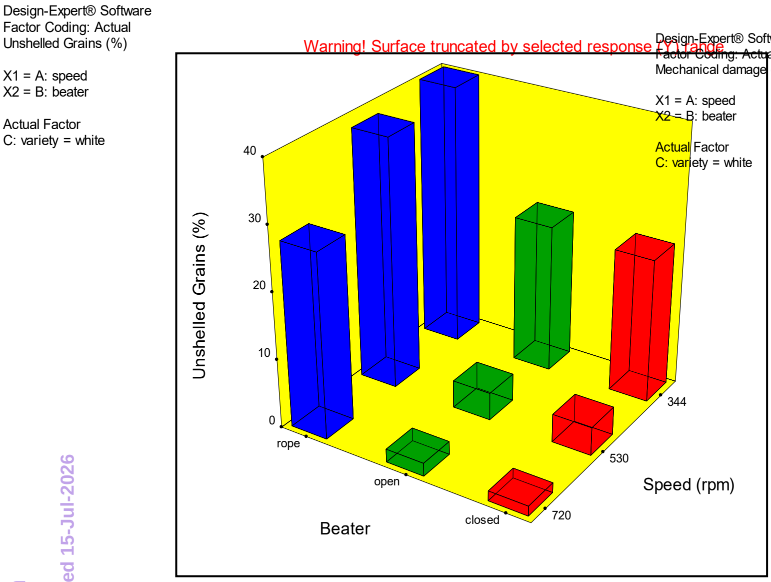
Change in labour requirement: In general, the labour requirement was lower with open chain and closed chain type beaters and higher rpm across all the treatment combinations. The minimum labour requirement of 2.70 man-minutes per kg was associated with 720 rpm, closed type chain and white variety, Table 5. Highest labour requirement of 13.76 man-minutes per kg was observed with 344 rpm, rope type beater and yellow maize variety. The analysis at ($p<0.05$) was significantly influencing the labour requirement of the maize sheller.

Variation in mechanical damage and germination percentage: The mechanical damage ranged from 0.13 – 1.67 %, which was lower than recommended 2% (EAC, 2017; Seatini, 2014) and germination percentage from 85-100% across all treatment combinations, Fig. 7. The screen size of 15 mm provided optimum gap for the impurities to settle down and grains to roll towards the collecting tray. The smaller hole size of 12 mm restricted the movement of grains and increased the mechanical damage (Nsubuga *et al.*, 2021). It was observed that the mechanical damage was less with low rpm and rope type beater. At 720 rpm, the mechanical damage of 1.67%, germination percentage of 95% was observed with closed chain and white variety, Table 5. When the speed was reduced to 530 rpm, the mechanical damage was 1.04%, germination percentage of 95% for white variety. When the speed was further reduced to 344 rpm, the mechanical damage was observed to be lower and germination percentage was higher. The reason can be the relation between the rpm and impact force, responsible for inducing more damage and lowering the germination potential of maize grains.

Table 5: Effect of crop and machine parameters on cleaning efficiency

R	ToB	V	CE	LR	GP	R	ToB	V	CE	LR	GP	R	ToB	V	CE	LR	GP
720	Closed chain	White	98.99	2.7	95%	530	Closed chain	White	98.90	3.1	95%	344	Closed chain	White	99.12	4.3	90%
720	Closed chain	Multi-coloured	99.07	2.4	90%	530	Closed chain	Multi-coloured	99.11	3.3	95%	344	Closed chain	Multi-coloured	98.49	4.6	95%
720	Closed chain	Yellow	98.91	2.5	95%	530	Closed chain	Yellow	99.03	3.3	90%	344	Closed chain	Yellow	99.17	4.4	95%
720	Open chain	White	99.09	2.4	95%	530	Open chain	White	98.99	3.5	95%	344	Open chain	White	98.83	4.6	95%
720	Open chain	Multi-coloured	98.90	2.5	90%	530	Open chain	Multi-coloured	98.91	3.3	90%	344	Open chain	Multi-coloured	99.22	4.7	90%
720	Open chain	Yellow	99.14	2.5	95%	530	Open chain	Yellow	98.95	3.6	85%	344	Open chain	Yellow	98.77	4.4	95%
720	Rope	White	98.99	4.1	100%	530	Rope	White	98.72	5.6	95%	344	Rope	White	98.96	12.8	90%
720	Rope	Multi-coloured	99.02	4.3	95%	530	Rope	Multi-coloured	98.84	6.2	90%	344	Rope	Multi-coloured	99.02	13.2	95%
720	Rope	Yellow	98.99	4.1	90%	530	Rope	Yellow	98.92	5.8	90%	344	Rope	Yellow	98.99	13.7	90%

(R: RPM; ToB: Type of beater; V = Variety; CE: Cleaning efficiency; LR: Labour requirement, man-min. per kg; GP: Germination percentage



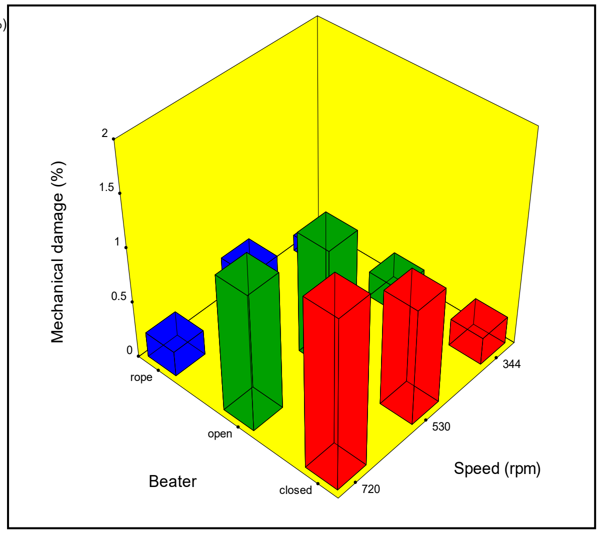


Fig. 6: Change in un-shelling grain percentage with speed and type of beater

Fig.7: Variation in mechanical damage with type of beater and rpm

Optimisation of working parameters of maize sheller: The optimization of the working parameters of maize sheller was carried out through Design Expert 10.0. It was observed that 720 rpm with closed chain type beater resulted in shelling efficiency of 96.01%, shelling capacity of 24.23 kg h^{-1}, mechanical damage of 1.67%, unshelled grain percentage of 3.08%, cleaning efficiency of 98.91%, labour requirement of 2.81 man-min. per kg and germination percentage of 95% with overall desirability of 0.86, Table 6.

Table 6: Optimization of operational parameters of maize sheller

RPM	Type of beater	Variety	SE	SC	UG	MD	CE	LR	GP	Desirability
720	Closed	Yellow	96.01	24.23	3.08	1.67	98.91	2.81	95	0.86
720	Open	multi	94.40	23.74	1.20	29.469	98.9	2.68	90	0.85
720	Open	white	94.62	23.64	1.29	29.25	99.09	5.57	95	0.83

SE: Shelling efficiency; SC: Shelling capacity, kg h^{-1}; MD: Mechanical damage, %; UG: Unshelled grain percentage; CE: Cleaning efficiency; LR: Labour requirement, man-min. per kg; GP = Germination percentage

Cost analysis: The cost analysis is an important factor that governs the adoption rate of the machinery among the farmers. The cost analysis revealed that the operating cost of the machine was Rs. 78.74 per hour, break event point of 9052 kg, benefit cost ratio of 1.30: and payback period of 585.2 hours, Table 7. The unit cost of maize shelling was calculated as Rs. 3.42 per kg. The cost of the developed prototype of maize sheller was Rs. 13,560.

Table 7: Appraisal of cost attributes of maize sheller

Parameter	Value	Importance
Operating cost, Rs h^{-1} (fixed cost + variable cost)	78.74	It is used to assess the running cost of the maize sheller per unit time.
Break event point, kg	9052	It defines the limit above which the operation of the maize sheller will be profitable.
Benefit cost ratio	1.30:1	It is the benefit accrued from each rupee invested.
Payback period, hours	585.2	It is the time limit during which the money invested will be recovered.
Unit cost of maize shelling, Rs. kg^{-1}	3.42	It helps to decide the rate in custom hiring model.

CONCLUSION

The average length (mm) of white, multi-coloured and yellow cobs was 138.60±14.78, 120.84±15.86, and 119.68±13.55 respectively. The average diameter (mm) of white, multi-coloured and yellow cobs was 34.28±2.55, 38.69±3.50 and 36.51±3.02respectively. The average sphericity of maize grains varied from 0.76 to 0.81. The physical parameters of moisture content (13.8%-14.82%), bulk density (333.79 kg/m^3 - 359.28 kg/m^3) and angle of repose of cobs (23.2^o - 24.1^o) and grains (25.3 - 26.2^O) were used to decide the design parameters of functional components of maize sheller. The cylindrical type maize sheller comprised of feeding hopper, shelling drum, beaters, outlet and sieving system. It was observed that maximum shelling efficiency of 96.01%, shelling capacity of 24.23 kg h^{-1}, mechanical damage of 1.67%, unshelled grain percentage of 3.08%, cleaning efficiency of 98.91%, labour requirement of 2.81 man-min. per kg and germination percentage of 95% with yellow maize variety. The economic analysis revealed that operating cost was 78.74 Rs. h^{-1}with 9052.0 Kg break-even point, 585.2 hours payback period and 1.30:1 benefit- cost ratio. The unit cost of maize shelling was calculated as Rs. 3.42 per kg. The maize sheller can reduce the drudgery and provide entrepreneurship opportunities to the rural youth of Jammu and Kashmir.

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REFERENCES

Anonymous, 2021. Agriculture production and farmers welfare department, J&K, UT.

Anonymous. 2016. Agricultural Census Agriculture census division, Department of Agriculture, Co-operation and farmer's welfare, Ministry of Agriculture and farmers welfare, Government of India.

Aremu, D. O., Adewumi, I. O. and A. J. Ijadunola. 2015. Design, fabrication and performance evaluation of a motorized maize shelling machine. *Journal of Biology, Agriculture and Healthcare*, **5**: 154-164.

Bashir, B., Dixit, J. and Faisal, S. 2022. Design and development of lever operated maize cob sheller for marginal and small farmers. *SKUAST Journal of research*, **24**: 149-159.

Biggs, S., Justice, S. and Lewis, D. 2011. Patterns of rural mechanization, energy and employment in South Asia: reopening the debate in economic and political weekly, **46**: 78-82.

Chaudhary, S. 2016. Development and performance evaluation of modified maize dehusker cum sheller. Ph.D diss., Sam Higginbottom Institute of Agriculture, Technology and Sciences

Chhabra, N. and Kaur. A. 2017. Studies on physical and engineering characteristics of maize, pearl millet and soybean. *Journal of Pharmacognosy and Phytochemistry*, **6**: 1-5.

EAC.2017. East African Community Maize Specifications 'Use Standards, Know your Quality, Improve your Livelihood' Characteristics Description, 8.

Erenstein, O. 2010. The evolving maize sector in Asia: Challenges and opportunities. *Journal of New Seeds*, **11**: 1–15. *(doi. org/10.1080/15228860903517770)*.

Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K. and Prasanna, B. M. 2022. Global maize production, consumption and trade: trends and R&D implications. *Food Security*. (doi.org/10.1007/s12571-022-01288-7).

FAOStat.2021. FAO Stat. FAO, Rome. http://www.fao.org/faostat.

FICCI (Federation of Indian Chambers and Commerce of Industry). 2018. Maize vision 2022.

Gerland, P., Raftery, A.E., Sevcíkova, H., Li, N., Gu, D., Spoorenberg, T., Alkema, L., Fosdick, B.K., Chunn, J., Lalic, N., Bay, G., Buettner, T., Heilig, G.K. and Wilmoth, J. 2014. World Population stabilization unlikely this century. *Science,* **346**: 234-237.

Greater Kashmir, 2020 (*https://www.greaterkashmir.com/kashmir/kashmirs-agriculture-land-shrinks-to-389000-hectares*)

Ilori, T. A., Raji, A. O. and Kilanko, O. 2013. Modelling some ergonomic parameters with machine parameter using hand powered maize sheller. *Journal of Engineering and Technology Research*, **5**: 52-57.

Krupnik, T. J., Valle, S. S., McDonald, A. J., Justice, S., Hossain, I. and Gathala, M. K. 2013. Made in Bangladesh: Scale-appropriate machinery for agricultural resource conservation. International Maize and Wheat Improvement Centre (CIMMYT), Mexico, D. F.

Kumar, A. and Begum, S. H. 2021. Design, development and performance evaluation of a hand operated maize sheller. *International Journal of Agricultural Engineering*, **9**: 113-117.

Malla, U. M., Khan, A. R., Muzamil, M., Mohiuddin, M., Rashid, S., Banday, R.Z. and Kumar, R. 2022. Development and evaluation of four-row seeder for vegetable crops in the temperate region of Jammu and Kashmir. *SKUAST Journal of Research,* **24**: 71-79. (*doi.org/10.5958/2349-297X.2022.00016.2*).

Mohiuddin, M., Muzamil, Dixit, J., Faisal, S. and Khan, I. 2022. Engineering Properties of Chilli Fruit Relevant to the Design and Evaluation of Chilli Seed Extractor for Hilly Region of Kashmir Valley. *Journal of Institution of Engineers, India Ser. A,* **103**: 433-443. (doi.org/10.1007/s40030-022-00617-5).

Mottaleb, K. A., Krupnik, T. J. and Erenstein, O. 2016. Factors associated with small-scale agricultural machinery adoption in Bangladesh: Census findings. *Journal of Rural studies,* **46**:155-168.

Mullen, R. 2016. Agricultural Statistics, Why Replication and Randomization are Important. Available at: https://fabe.osu.edu/sites/fabe/files/imce/images/Precision_Ag/ Agricultural Statistics%2C Why Replication and Randomization Are Important.pdf.

Muzamil, M., Mani, I, Kumar, A. and Shukla, L. 2021. An engineering intervention to prevent paddy straw burning through in situ microbial degradation. *Journal of Institution of Engineers, India Ser. A,* **102:** 11–17. (*doi.org/10.1007/s40030-020-00490-0*).

Muzamil, M., Wani, J., Mustafa, A., Mohiuddin, M, Mir, A, Faisal, S. and Nirbhavane, S. 2018. A low cost divergent type apple grader for Kashmiri apples. *International Journal of Current Microbiology and Applies Sciences*, **7**: 3561-3569

Naveenkumar, D. B. 2011. Modification and evaluation of power operated maize (Zea mays L.) sheller. M.S. thesis, Post harvest process and food engineering department, University of Agricultural Sciences, Bangalore.

Nsubuga, D., Kabenge, I., Zziwa, A., Kiggundu, N., Wanyama, J. and Banadda, N. 2021. Improving maize shelling operation using motorized mobile shellers: A step towards reducing post harvest losses in low developing countries. *Intechopen* (*doi:10.5772/intechopen.101039*).

Ojomo, A. O., and M. O. Alemu.2012. Response surface methodology approach to optimising performance parameters of a locally fabricated maize shelling machine. *Journal of Science and Multidisciplinary Research*, **4**: 70-79.

Okule, D. and Sekanyo, S. 2017. User perception towards a motorized thresher (Kungula) in Uganda: A need finding survey. *African Journal of Agricultural Research*, **12**:997-1004.

Oriaku, E. C., Agulanna, C. N., Nwannewuihe, H. U., Onwukwe, M. C. and Adiele, I. D. 2014. Design and performance evaluation of a corn de-cobbing and separating machine. *American Journal of Engineering Research*, **3**: 127-136.

Pavasiya, U. N., Patel, H., Patel, K., Mandar, M. M. and Sutariya, H. R. 2018. Design & fabrication of a motorized maize shelling machine. *Journal of Material Science and Mechanical Engineering*, **5**: 5-12.

Seatini. 2014. The Status of Implementation of the East African Standard for Maize Grains and Development of a Standard for Sesame Seed in Uganda. Available at: (*http://www.seatiniuganda.org/ publications/research/81-*) baseline-study-the-status-of-implementation-on-the-eastafrican-standard-for-maize-grains-and-development-of-astandard-for-sesame-in-uganda-1/file.html.

Shiferaw, B., Prasanna, B., Hellin, J., &Banziger, M. 2011. Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. *Food Security*, **3**: 307–327. (*doi.org/10.1007/s12571-011-0140-5*).

UN-DESA.2019. World population prospects 2019. UN Department for Economic and Social Afairs, New York. https://population.

Wang, K., Xie, R., Min, B., Hou, P., Xue, J. and Li, S. 2012. Review of combine harvester losses for maize and influencing factors. *International Journal of Agricultural and Biological Engineering*, **14**: 1-10.

Wani, I. A., Sogi, D. S., Wani, A. A. and Gill, B. S. 2017. Physical and cooking characteristics of some Indian kidney bean (*Phaseolus vulgaris L.) cultivars. Journal of the Saudi Society of Agricultural Sciences*, **16**: 7-15.

World Bank, 2007. Agriculture for development, World Development Report. The international bank for reconstruction and development/The World Bank, Washington DC.

Zhang, X., Rashid, S., Ahmad, K. and Ahmed, A. 2014. Escalation of real wages in Bangladesh: is it the beginning of structural transformation? *World Dev*. **64**: 273-285.