

Design and fabrication of De-husking machine using Cam follower mechanism for Proso (*cheeno*), Fox-tail (*Kaguno*) millet.

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Abstract – Prose Millet (*Cheeno*) and Foxtail Millet (*Kaguno*) which are commonly cultivated in the mid and high hill of *Karnali* province, Nepal, and has seen a steep decline in production and consumption in recent years. The major problem associated with production of *Cheeno* and *kaguno* is the post-harvest process of removing the protective layer (Husk) from the seed (De-husking). The traditional process of de-husking usually takes 2 hr to de-husk 1.5 per kg of said Millet grain, making them inefficient and also the commercially available millet processors are not suitable for de-husking grains to a consumable capacity. This research consists of a study to replicate and mechanize the manual process of de-husking by the use of Cam and Follower mechanism. The cam is a disc type with a conical metal chunk of a follower, maintaining momentary contact throughout the cam's rotation to replicate the "hit" and "twist" motion of the *Dhuncha*. The machine yielded an average overall efficiency of 61.6% for *Cheeno* and 44.55% for *Kaguno* with time reduction in processing by 69.45% and 63.88% respectively. However, some limitations in functionality followed by low efficiencies and spillage loss warranted the need for further study.

Keywords: Dehusking, Millet, Proso Millet, Foxtail Millet, Cam Follower.

1. Introduction

The geography of Nepal has three distinct segments: the mountains (accounts for 24% of the total area); the hills (56%); and the Terai (20%) with the distinction in climatic conditions FAO (2012). Despite the variation in topography and climate, agriculture remains the top occupation among the people in Nepal. According to MOF (2019/20), 60.5% of total population is dependent on the agriculture for source of income in 2018. Agriculture contributed for 27.7% of national GDP in the same year. The trend of participation in agriculture and its contribution to national GDP is decreasing in nature. The major issue in development of agriculture in Nepal is the absence of integration of suitable technology in the traditional agriculture. There is a huge gap among research and development institutions, leading to ineffective development of technological systems Paudel (2016). In compare to other South Asian countries, the investment on agriculture in Nepal is not satisfactory. There is a serious negligence to the needs of the resource-poor farmer in terms of investment, which is in declining trend Singh (2009). The policies adopted by Nepal regarding agriculture and rural development are indifferent to agricultural mechanization Justice and Biggs 2004. The majority of modern industrial agriculture is concentrated in the Terai plains Justice and Biggs 2015. In other words, Nepal has neglected to

take strong policy to promote mechanization in hillside farming systems in order to avoid potential labor displacement by the application of machines Shrestha (2011).

The negative impact of absence of mechanization has been observed in the cultivation of indigenous plants in hilly regions of Nepal. Small millets have experienced a steep decline in its production and consumption patterns. Several factors like low productivity of crops, need of intensive labor work, the difficulty of post-harvesting process, and absence of attractive returns are responsible to decline in production of small millets IDRC (2014). Moreover, availability of alternatives such as, rice and wheat, has accelerated the shifting of consumption away from the small millets. Foxtail Millet (*Setaria italica* L.) or commonly referred to as *Kaguno* in the high hills and low hills of Jumla and Humla, Karnali Province, Nepal, part of small millet family, is a round-shaped cereal seed, commonly grown in semi-arid lands, such as Asia and central Africa Saleh et al., 2013. Foxtail millet is among the oldest crops cultivated in the current world; the evidence shows the archaeological remains of foxtail millet back from 7400-7935 years in China Austin (2006). The remains were also discovered in Europe that is about 4000 year's old Lu et al., 2009. Currently, 26 countries have foxtail as their cultivated plants which account for second highest production among millet family. The yielding capacity of foxtail millet ranks at fourth among the millet family Bala-Ravi (2004).

Foxtail millet grows well in mountain soil, and is easily comparable to rice and wheat in terms of nutrition, and have long been the staple of highland people in the *Karnali* province of Nepal Mahato (2017). Proso Millet (*Panicum miliaceum* L.) is widely cultivated around south-east Asia as a form of cereal Salini et al., 2010. Proso Millet is commonly referred to as *Cheeno*, which readily grows in the high hills of *Karnali* province, Nepal, and has the potential to replace low yielding crops like wheat and rice in the region as a staple Mahato (2017). The *kaguno* or Foxtail millet cultivated in *Karnali* province is of the red-strain while *Cheeno* appears as the white variety.

One of the major problems associated with Millet cultivation in Nepal is post-harvest processing. The *Cheeno* and *Kaguno* are small grains covered by whitish brown and red shell covers, "husk" which protects the underlying seed and germ. De-husking machines commercially available for large seeds such as Wheat or Rice seeds are unsuitable for these millet varieties as they tend to ruin the integrity of the seeds Gyanwali et al., 2016. There isn't any commercially available De-husking machine dedicated to Fox-tail or Proso Millet in Nepal Gyanwali et al. 2016 had conducted a study on the design and fabrication of Proso millet De-husking machines using a pair of rollers to remove seed husk Gyanwali et al. 2016. With sixty percent efficiency, this solution could certainly act as an alternative.

A field survey conducted by the authors of this paper to Jumla, Karnali, Nepal concluded that locals made use of a makeshift wooden ram (*Dhubche*) equipped with stone prongs at the ramming end to De-husk the millet grains. The locals would initiate a strong ramming action (reciprocating) motion followed by a twist at the end (rotation) to remove the husk from the grains using the frictional force involved in ramming and twisting. While this process is sufficient enough to properly de-husk while maintaining seed integrity, it is an arduous task that requires nearly 2-3 hours of manual work to process 1kg of *Kaguno* or *Cheeno*. While some

solutions Gyanwali et al., 2016 could prove to be efficient and effective in terms of sheer processing time, the ideal solution would be to mechanize the process of "ramming" and "twisting" while maintaining seed integrity and making the machine as little technologically non-invasive (Simple) as possible. Further, the locals wanted a machine that could be mounted on top of an *Okhal* or a *Khal* and this is thus the scope of this paper.



Figure a. Locals using wooden ram (*Dhubche*) to create ram and twist motion while de-husking

The common mechanism which applies both linear and rotational motion is the motion of the screw. The motion of the screw is something that is required to mimic the ram and twist motion required by the de-husking process. However, the simple screw motion doesn't generate the necessary impulse or impact force to de-husk the millets. An average man generates as much as 250 N of force while using a hammer which is analogous to the ramming motion needed for de-husking Science Guys (2000). Therefore, a force range of 100-500 N is required (by impact), which is not possible by using a screw motion.

The cam and follower mechanism are one of the most common and perhaps the most important mechanisms in modern machinery. The "cam" is a rotating element which forms a contact pair with the "follower", which moves and rotates with respect to the contact of the cam Khurmi and Gupta (1976). If a partial contact using a "knife-edge cam" on a heavy conical follower can be maintained during the motion, then the ram force will be sufficient to de-husk the seeds. Further, the partial contact during the total motion also permits twisting motion, since the follower is designed accordingly. Based on the literature survey and background information as stated above, the objective of this work is to design and fabricate the working prototype of Cam Follower Mechanism that can be employed for De-husking process as an alternative of human-powered traditional post-harvesting system.

2. Materials and Methodology

2.1 Materials, Fabrication, and assembly

The core materials used in the prototype consisted mostly of iron and its alloys. For the frame, a standard Mild steel (MS) square section ISO 40×40×5 was used. A standard 1/2 HP A/C motor with a speed of 1490RPM was used to power the mechanism. A 1 HP gearbox of gear ratio 30:1 was used. Brass bushes for respective shaft sizes were fabricated. Motor shaft coupling with the transmission shaft from gearbox was done using a V-belt (B type) (Maharjan, 2014; Budynas et al., 2011) configuration using two pulleys of diameter ratio 2:3, thus giving 75RPM output

speed. The cam and follower were fabricated from a 10mm thick MS sheet. The grinding teeth used in the *Dhubche* was also fabricated from 3 mm MS sheets.

2.2 Design and 3D modeling

The goal was to replicate the mechanism used by the locals in the De-husking and process and automate it so that the resulting machine is simple, efficient, and economic. 3D modeling was carried out using Computer Aided Designing (CAD) software Solid Works 2016 and PTC CREO parametric 6.0. To expedite the fluidity in modeling power units (motors, gearbox), structural units (frame, couplings, shafts), and the core mechanism (cam and followers) were designed separately and assembled using CAD.

2.3 Testing and Analysis

The De-husking time and efficiency were calculated for both *Cheeno & kaguno*. Efficiency was calculated using Equation 1 and the degree of separation was given by equation 2 Gyanwali et al., 2016.

$$\eta_{HUSK} = (M_{DS} + M_H)/M_{TI} \times 100\% \quad (1)$$

Where M_{DS} is the mass of the De-husked seed, M_H is the mass of the husk, and M_{TI} is the total input mass.

$$\eta_{SEP} = M_H/(0.2 \times (M_{DS} + M_H)) \times 100\% \quad (2)$$

Therefore, the overall efficiency is given by the product of De-husking efficiency and the percent degree of separation.

$$\eta_{Overall} = \eta_{HUSK} \times \eta_{SEP} \quad (3)$$

The mass loss fraction is given by the formula,

$$fraction\ lost = Mass\ lost/M_{TI} \times 100\% \quad (4)$$

And, the total time saved is given by, (the units of time are per kilogram mass of the grains).

$$Time\ saved = (T_M - T_m)/T_M \times 100\% \quad (5)$$

Where T_M is the time taken to manually De-husk the seeds, T_m is the time taken by machine to de-husk the grains.

3. Design

3.1 Design of frame and load support

Pressure angle (ϕ) : 30° maximum ³ Peñalozza and Cardona (2006)
 Follower offset : 100mm from the center of the base circle.⁴
 Lift/Stroke : 300mm

- **Path traced by the follower**

Figure 1 represents the displacement curve of the follower i.e. the D-R-R-D motion. The displacement curve is sketched between stroke (in mm) in the ordinate axis and the degree of rotation (rotational displacement of the cam, in degrees) in the abscissa. A to B represents the dwell, where the cam doesn't make any contact with the follower, B to C is the rising stroke where the follower displaces 300mm. At C, the follower instantaneously falls (theoretically) as the cam breaks contact and the rest of the period is dwelling period. One thing to note is that the initial 30° rise stroke is taken so that the cam profile doesn't exactly start from the top of the base circle i.e. point A of figure 2a.⁵

- **Locus of Cam vs Pressure angle**

The cam profile can be seen in Figure 2. The points A, b, c, d, e, f, g, h, i, and B represent the displacement values from figure 1. The maximum pressure angle ϕ is well below 25° which removes the complexity of follower shaft getting stuck on its bearings. In figure 2a, O is the base circle of the cam which has a diameter of 80mm. Each point on the Cam curve represents the displacement in which the cam is capable of lifting the follower too. The follower is offset as considered in the specification. Table 1 collects the information about pressure angle for each of the cam displacement angle in degrees. The pressure angle was extracted geometrically from the referees work (Solid Works 2016).

Table 1 Pressure angle compared to Cam rotation

Position	Cam displacement (θ , Degrees)	Pressure Angle (ϕ , Degrees)	Position	Cam displacement (θ , Degrees)	Pressure Angle (ϕ , Degrees)
A	30°	0°	f	60°	17.25°
b	36°	3.4°	g	66°	20.03°
c	42°	7.07°	h	72°	22.25°
d	48°	12.75°	i	78°	25.02°
e	54°	15.05°	j	84°	27.23°

³ To avoid jamming of follower bearings the 30° limits is not exceeded, to avoid bulky cam higher value of ϕ is taken.

⁴ Follower offset is taken arbitrarily based on feasibility (i.e. not too much as to require more material and not too small to cause contact wear with the follower). This initial assumption sets the ground for the design of the cam profile based on the required follower displacement. Also, follower size plays an important role (more on the follower design section)

⁵ The reason for not letting the cam profile begin from point A is to minimize material usage and maximize strength. The value 30° is taken arbitrarily.

f	60°	17.25°	B	90°	30.25° ⁶
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Using topological optimization, the ideal shape of the cam can be as shown in figure 2a. This design not only removes additional material use but also does it without compromise in mechanical strength. Figure 2b is the final design of the cam.

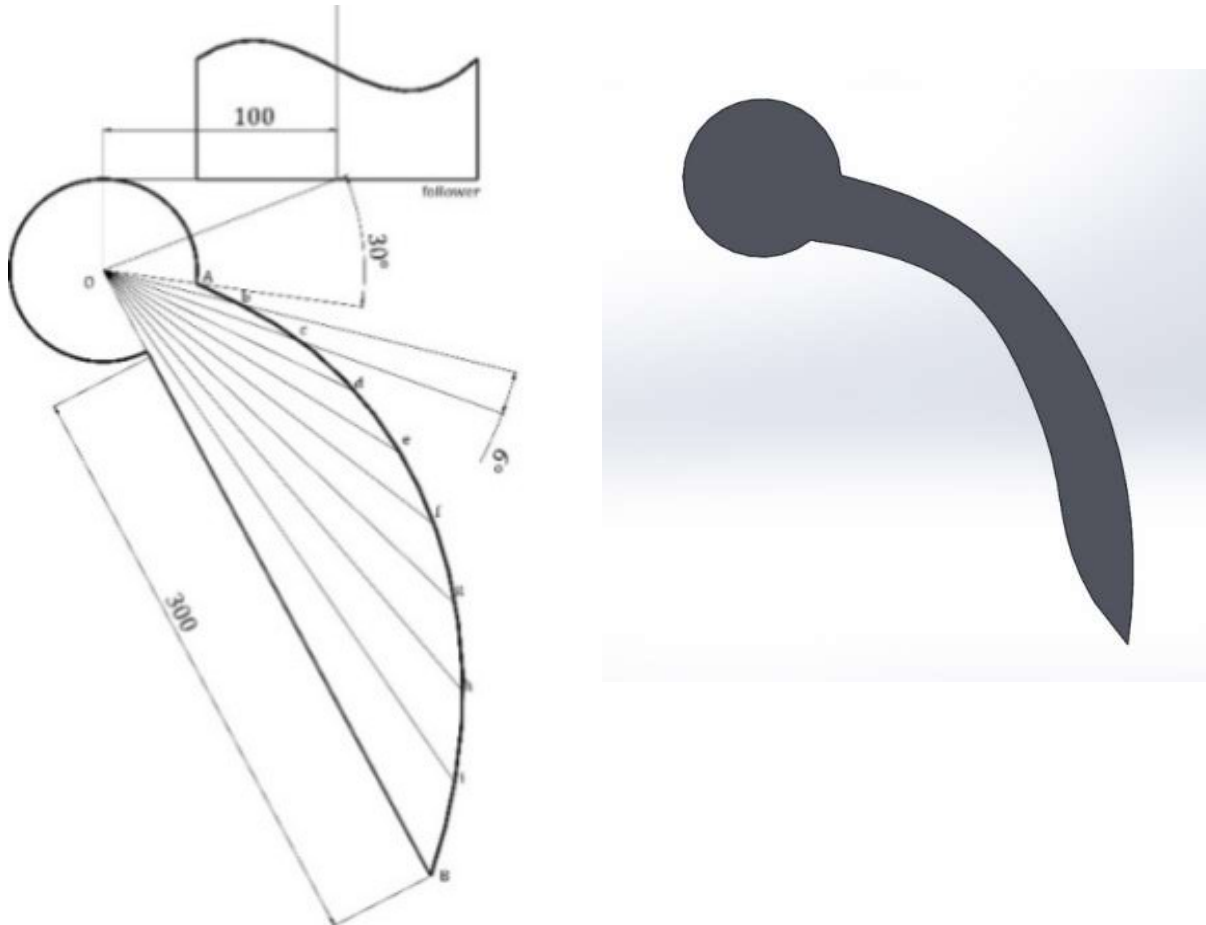


Figure 2a. Cam Profile, b. an optimized version of cam profile using topology optimization

❖ The maximum speed of the cam

The inward stroke or return stroke at C in figure 1 is not instantaneous. When the cam breaks contact with the follower, the follower chunk falls naturally under gravity. Using equations of motions, this time elapsed comes out as 0.247s, with the stroke being 300mm and the acceleration due to gravity (g) as 9.81 m/s^2 . Using a range of values say 0.25 to 0.5s the operating speed range of the cam can be determined. The speed should allow the follower to complete its return stroke during the CD phase of figure 1. i.e. 270° or 4.71 rad should be

⁶ At point B the follower, in operation will have already left the cam, therefore the large pressure angle is not a problem.

completed in 0.5s which accounts for an angular speed of $\omega = 9.42 \text{ rad/s}$ or speed of approx. 90RPM. If 0.25s is used, the angular momentum comes as $\omega_{\text{max}} = 18.84 \text{ rad/s}$, and the speed comes out as 180 RPM. The optimum operating range should be 90-180 RPM with 180 being the limiting speed. A speed higher than 180 RPM wouldn't let the follower chunk complete the return stroke. For speeds below 180 RPM, the follower at return stroke will fall under gravity with no contact between the cam and follower. Hence, the velocity of the follower at the end of the dwell is always the same, which by equations of motions comes out as, $V_{\text{hit}} = 2.42 \text{ m/s}$.

3.3 Follower Design

The follower is offset 100mm from the axis of the base circle of the cam. Follower design is crucial to obtain the “twist” motion that is common in the operation of *Dhuncha*. The follower used in the design of cam is a flat face follower with a cylindrical cross-section.

Figure 3a shows the offset of the cam with respect to the axis of the follower.

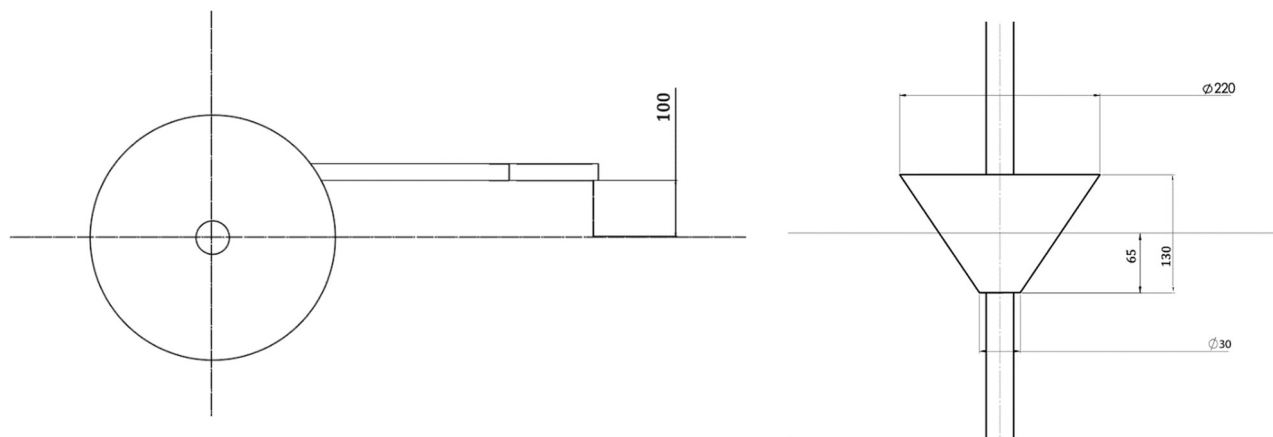


Figure 3a. Cam axis offset with respect to follower axis b. Follower profile

If the Cam axis was coincident with the plane of the follower's central axis, then the follower simply exhibits a reciprocation motion Khurmi and Gupta (1976) from 0-300mm without rotation or "twist". Therefore the cam axis must be offset such that the contact between the cam and follower creates a twist in the follower's shaft. Further, this twist is only possible if the two surfaces meet near tangentially. Therefore, instead of a flat cylindrical follower, the profile must be so that the surface of the cam meets the follower almost tangentially. This is possible with the profile shown in Figure 3b. The follower exhibits a conical profile with the base diameter of 220mm such that the plane where cam meets the follower would have a diameter of 100mm as was estimated in the cam design. Since the value of the twist angle is not as important, the offset distance was taken arbitrarily at 100mm from the central plane of the follower. The follower is mounted on a shaft of 30mm diameter.

From Solid Works 2016, the total volume of the follower profile was $1.56 \times 10^{-3} \text{ m}^3$, if 7850 kg/m^3 is taken as the density of the Mild Steel then the follower amounts to approximately 12 kg.

The total potential energy falling from a height of 300mm, considering acceleration due to gravity (g) as 9.81 m/s^2 will be 35.13 J. The striking force will be equivalent to the weight of the follower and its attachments (shaft, piston) which will be approximately 150N, which is enough to ram the grains with (Science guys, 2000).

❖ Motor Selection and determination of input power

The limiting angular momentum of the cam is $\omega_{\max} = 18.84 \text{ rad/s}$. The force on the follower chunk is equivalent to the weight of the chunk as no other external force acts on it. The weight of the follower is 117N. Therefore, the cam needs to lift 117N during the Rise stroke. The offset distance from the central axis of the cam and the axis of the follower is 100mm as shown in figure 2a. Therefore, the Torque will be 17.7Nm as given by $T = F \cdot r$ (Gyanwali et al., 2016), where F is the weight of the follower, and r is the offset distance.

The power requirement of the motor will be 334 Watts by using $P = T \cdot \omega$ (Wildi & Wildi, 1991) Where, P is the power of the motor. Therefore, a half Horsepower (1/2HP) rated motor was used⁷. A speed reduction gearbox was used to limit the working range to 90-180 RPM



Figure 4 a. 3D model of the Prototype De-husking machine b. fabricated model of a.

❖ Piston Description

The teeth used in the piston were comprised of scrap metal with blunt edges. The teeth were blunt on the side exposed to the grains. The teeth are arranged in such a way that De-husking is carried out by friction against the grain layer and the teeth, and also because of the friction between two adjacent grains, when the teeth displace them. It should also be noted that the relative twisting and rotation in the follower shaft permits the distribution of millet grains. This action spreads the grains evenly and allows De-husking across the sample.

⁷ 1/2HP is only sufficient for the use of a single Cam-Follower setup

4. Results and discussions

For the testing of the efficiency of the machine, 1 kg and 2kg sample of both *Cheeno* and *kaguno* were taken in the *Okhal*. The capacity of *Okhal* was 2.5kg. The samples were weighed using an AC supply electrical 5 kg weighing machine. The husked mass and De-husked seed mass was separated using sieves of no. 100, no.120, and no.140. The efficiency was calculated using equations 1 and 2. The machine was operated at a speed of 120RPM.

Table 2 Efficiency determination of the automatic De-husking mechanism

Sample	Mass of De-husk sample(g)	Mass of husk (g)	Mass Lost(g)	Mass of remaining seeds(g)	Efficiency (η_{husk})(%)	Degree of separation (η_{sep})(%)	Total time elapsed (minutes)
Cheeno(1kg)	586	116	121	117	70.70	82.86	20
Cheeno(2kg)	1235	220	211	244	72.75	87.69	35
Kaguno(1kg)	523	95	120	262	61.8	76.80	25
Kaguno(2kg)	995	167	273	565	58.1	71.85	40

From table 2, it is seen that the efficiency and degree of separation for *Cheeno* (Proso- millet) has increased from 1 to 2kg. This could be attributed to the fact that the compactness of a larger volume of *Cheeno* causes more friction between the large grains which makes de-husking easier. For *kaguno*(fox-tail millet), both the efficiency and separation have decreased with increased mass loss from 1 to 2 kg, which could be because of the small grains and the slippery husk which reduced friction between the grains and caused a larger mass loss.

The average De-husking efficiency for *Cheeno* was 72.725% and *kaguno* was 59.95%, while the degree of separation was 85.275% and 74.325% respectively. Therefore, from equation 3 the overall efficiency was 61.6% for *Cheeno* and 44.55% for *Kaguno*.

Using equation 4, the average percent mass loss for *Cheeno* was 11.06% and that for *Kaguno* was 27.5%.

From table 2 the time elapsed per kg was averaged at 18.33 minutes for *Cheeno* and 21.67 minutes for *Kaguno*. The time required to manually De-husk *Cheeno* and *Kaguno* which is 60 minutes per kg for both. The percent time saved is by equation 5, 69.45% for *Cheeno*, and 63.88% for *Kaguno*.

5. Conclusions

The manual process of de-husking of *Cheeno* (Proso-millet) and *kaguno* (foxtail-millet) can be replicated and mechanized using a partial contact cam-follower mechanism. The prototype Cam-follower mechanism used in the De-husking machine in this study considered a Dwell-Rise-Return-Dwell Disc Cam, which was optimized to contain the least material, such that it resembled an elongated knife-like profile. The follower was a flat disc cylindrical cross-section MS chunk machined to form a Cone, which permitted the twisting motion similar to the manual work. The mechanism yielded an average De-husking efficiency of 71.25% with a degree of

separation of 85.27% with a mass loss of 11.06% and a time reduction of 69.45% for *Cheeno*. For *Kaguno*, it yielded an average De-husking efficiency of 59.95% with a degree of separation of 74.325% with a mass loss of 27.5% and a time reduction of 63.88%. The overall efficiencies were 61.6% for *Cheeno* and 44.55% for *Kaguno*. Due to limitations on machine wear and mechanical reliability followed by low efficiency and time saved, this apparatus is not yet suitable for commercial use. However, using coatings to reduce heat and wear can account for the frictional wear and noise. Using a contained environment for the *Okhal* or *Khal* can reduce spillage. And, using multiple Cam-Follower configuration in a single machine (single input) can substantially decrease the processing time to De-Husk.

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