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# Ergonomics Assessment and Performance Evaluation of Hand-Cranked Improved Chakki

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## ABSTRACT

Hand Cranked Improved Chakki was evaluated at Dr. Rajendra Prasad Central Agricultural University, Pusa by rural men and women for products like *dal* and sattu from common pulses like green gram and Bengal gram. Machine performance indicators were output capacity, dehulling efficiency, milling efficiency, product recovery, and operational cost. The machine recorded the highest *dal* recovery (36.29 kg/h) at 5 mm clearance between upper and lower stones for green gram. The highest product recovery of Bengal gram was 40.53-44.40 kg/h for *dal* at 7.0 mm stone clearance and 3.27-3.56 kg/h for *sattu* at 1.5 mm clearance. Highest dehulling efficiency was 96.75 and 97.25 percent whereas highest dal recovery was 84 and 78 percent for Green gram and Bengal gram respectively. The machine registered 93.7 percent milling efficiency for the preparation of *sattu*. The cost of production was Rs20.49/kg for *sattu*, Rs1.98/kg for Green gram *dal* and Rs1.62/kg for Bengal gram *dal*. A common trend of increase in heartbeat, oxygen, and energy consumption rate was noticed with an increase in the age of the subjects irrespective of their gender. *Dal* preparation by machine was reported to be a comfortable task with the lowest work-rest time ratio varying between 5:1 and 3:1 for different subjects. For preparation of dal, Hand cranked improved chakki can very easily be adopted for cottage industry.

***Keywords:*** *Hand Cranked Improved Chakki, Stone Clearance, Dehusking Efficiency, Milling Efficiency and Cost of operation, Oxygen and Energy Consumption Rate, Product recovery, Ergonomics evaluation.*

## INTRODUCTION

Population in India is increasing rapidly and united families are disintegrating into nuclear families. In the post-green revolution era, the focus shifted from the cultivation of pulses and other crops to the cereal crops. Therefore, cultivation of pulse in disintegrated fashion in small area does not attract the large industries to develop small machines to cope with the requirement of pulse growing small farmers.

Pulses are a good source of protein being rich in lysine and therefore, often regarded as poor man's meat [1]**.** Additionally, pulses provide energy, essential minerals, vitamins and several compounds beneficial for good health [2]. The availability of pulses is reducing in India on account of losses during harvest and post-harvest operations ranging between 6.36 and 8.41 percent [3]. However, the conversion of pulses into *dal* is the third largest food processing industry in the country after rice and wheat milling industries[4]. De-hulling is an important aspect of pulse processing and the yield of de-hulled seeds is an important quality characteristic [5]. The main objective of pulse milling is to remove the hull completely from seeds with minimum percentage of the powder and breakage[6]. De-hulling process in pulses has invited the development of many machines through trial-and-error procedures. Obviously, the performance evaluation of the machine should include all possible factors contributing to the performance. De-hulling efficiencies of different pulses vary between 40-50 percent without any pretreatment [7]. Majority of pulse milling is done at the domestic, cottage, and small to medium-scale industries. Losses during milling at domestic and cottage levels are about 10-15 percent [8]. The traditional chakki available in villages had its own demerits like tedious operation, low capacity, besides high percentage of broken grains. The higher physical energy and postural requirements in the operation of traditional chakki may lead to clinical and anatomical disorders which may affect the operator's health [9]. The present study has been conducted to evaluate Hand Cranked Improved Chakki for dal milling which is of high relevance in the context of promotion of dal production at the household level in states like Bihar, predominated by small farms and farmers in reference to minimum loss and associated drudgery in operation.

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## MATERIAL AND METHODS

Hand cranked improved chakki was developed with facilities to provide rotation to the upper stone out of a pair of stones used in

the machine through lever and bevel gear arrangements. The machine consists of a frame, product collector, hopper, pair of stones, bevel gear arrangement, lever etc. to facilitate the operator for the operation of the machine in sitting or standing posture. The machine was tested for milling of dal from green gram and Bengal gram grains, besides preparation of sattu from Bengal gram. The machine was operated by male and female operators aged from 25 to 40 years with the rotational speed of the stone between 60 to 70 RPM (round per minute). Ergonomic studies were conducted followed by the response of the operator on a 10 points scale about the comfort level in the operation of the machine. The requisite parameters such as oxygen and energy consumption rate, heartbeat, body mass index, and work rest-time ratio were noted to draw the necessary conclusion. The standard methodologies were adopted and the performance of the machine was reported in terms of de-hulling efficiency, milling efficiency, machinery cost per kg of product etc. by using the following formulas:

***Performance Evaluation of Machine***

- ***De-hulling efficiency: The de-hulling efficiency for preparation of dal from Green gram and Bengal gram grains was determined by using the formula:***

$$\text{De-hulling efficiency (\%)} = \frac{\text{Weight of sample} - (\text{Weight of whole grain} + \text{Weight of splitted grain})}{\text{Weight of sample}} \times 100$$

- ***Milling efficiency: Milling efficiency of the machine for sattu preparation from Bengal gram grain was worked out by using the formula:***

$$\text{Milling efficiency} = \frac{\text{Degree of dehusking} \times \text{Quality index}}{100}$$

*Where, Degree of dehusking and quality index may further be calculated by using the formula:*

$$\text{Degree of dehusking (\%)} = \frac{\text{Total input weight} - \text{Weight of whole un-dehusked grain}}{\text{Weight of whole undehusked grain}} \times 100$$

$$\text{Quality index} = \frac{\text{Dehusked split and full grain}}{\text{Dehusked split and full grain} + \text{Broken weight} + \text{Power weight}} \times 100$$

- ***Un-dehusked grain: The percentage of un-dehusked grain had been calculated by the formula;***

$$\text{Un-dehusked grain (\%)} = \frac{\text{Weight of unhusk after milling}}{\text{Weight of whole grains after milling}} \times 100$$

- ***Dal recovery: The dal recovery was calculated by the formula***

$$\text{Dal recovery (\%)} = \frac{\text{Weight of dal after milling}}{\text{Weight of whole grains after milling}} \times 100$$

- ***Broken: The broken percentage had been calculated by the formula***

$$\text{Broken (\%)} = \frac{\text{Weight of broken after milling}}{\text{Weight of whole grains after milling}} \times 100$$

- ***Dal output capacity:***

$$\text{Dal output capacity (\%)} = \frac{\text{Dal received at the end of process}}{\text{Time}}$$

- ***Body mass index (BMI):***

$$\text{Body mass index (BMI)} = \frac{\text{Weight (kg)}}{[\text{Height (m)}]^2}$$

- ***Oxygen consumption rate:***

$$\text{Oxygen consumption rate} = \text{Heartbeat } 0.0114 \times \text{Heartbeat rate} - 0.68$$

- ***Energy consumption rate:***

$$\text{Energy consumption rate} = 20.86 \times \text{Oxygen consumption rate}$$

***Cost Economics***

The cost of use of the machine on an hourly basis was determined by using a straight line method of computation of depreciation cost and by considering the purchase price of Rs16,800/-, life of the machine 3 years, annual use of 200 hours, rate of interest 10% and repair & maintenance cost at 6% annual basis. The labor cost opted at the available market rate had been considered. The hourly product output was divided by the hourly cost of the machine to determine the cost of the product at per Kg of production.

***Ergonomics Assessment***

Selection of subject: The subject/ operator from different sex (male and female) and age group i.e. 25-30, 31-35, 36-40 were selected randomly from the labor pool of the University by taking care that the subject was physically fit and not suffering from any illness and willingness to participate in undertaking the experiment with a condition that their name and address will not be disclosed.

***Measurement of body comfort level****:* Assessment of body comfort level at 10 point scale was decided on the basis of interviews from subjects. The score 1 – 3 was allotted upon the expression of the operator about the task being a difficult one. When the operators had expressed the work as moderately difficult, the score was allotted between 4 and 5. For a statement of the operator about the operation being comfortable, a 6 – 8 score was allotted and lastly, for a highly comfortable operation, the allotted score was 9 – 10.

***Measurement of work-rest time ratio****:* Each subject/ machine operator was allowed to operate the machine in four slots, each of 15 minutes duration for every operation. After 15 minutes of operation and before starting the next slot operation, the operator was allowed to take rest and rest time was noted by Stop-watch. This process was repeated for every operator and for every operation such as the de-hulling of green gram dal, de-hulling of Bengal gram dal, and milling of Bengal gram into *sattu.* The average of rest time expressed in minutes for every slot of machine operation in a particular job/ operation of dal milling/ sattu making was noted and was further expressed as the work-rest time ratio for the operator in every operation of dal milling and *sattu* preparation.

## RESULTS AND DISCUSSION

The production efficiency of dal from Green gram and Bengal gram has been presented in Table 1-2 whereas that of *sattu* has been given in Table 3. For the preparation of dal from Greengram, the machine has been adjusted at 5.00 mm clearance between both grinding stones and testing has been done at 60, 65, and 70 RPM(Table 1). The feed rate (kg/h) was recorded as 43.16, 43.39, and 44.26 at 60, 65, and 70 RPM respectively. The product recovery by weight was found to be highest (36.29 kg/h) at 70 RPM. But the percentage recovery of product (dal) was found to be highest (83.99%) at 60 RPM. Even the dehulling efficiency was highest (97.25%) at 60 RPM with a minimum percentage of broken grains (0.99%). The highest percentage of broken grains (1.99%) was observed at 70 RPM with minimum dehulling efficiency (96.00%) and product recovery (82.00%).

In case of the preparation of dal from Bengalgram, the clearance between both grinding stones of the machine has been kept at 7.00 mm because of the larger size of the grain. The testing has been done at 60, 65, and 70 RPM (Table 2). The feed rate (kg/h) was observed as 52.63, 55.57, and 56.93 at 60, 65, and 70 RPM respectively. The highest recovery (by weight) of the product (dal) was 44.40 kg/h at 70 RPM. The percentage recovery of product (dal) also was found to be highest (77.99%) at 70 RPM. But the dehulling efficiency was highest (96.75%) at 60 RPM with a minimum percentage of broken grains (1.67%). The highest percentage of broken grains (2.85%) was observed at 70 RPM with minimum dehulling efficiency (96.00%).

For the preparation of sattu from Bengal gram, the clearance between grinding stones has been adjusted at 1.5 mm for fine grinding (Table 3). The machine has been operated at 60, 65 and 70 RPM. The feed rate (kg/h) was recorded as 3.50, 3.80 and 3.77 at 60, 65, and 70 RPM respectively. The highest recovery (by weight) of *sattu* was 3.56 kg/h at 65 RPM. The percentage recovery of *sattu* was the same (93.7%) irrespective of RPM. But the percentage of un-split sole grain (0.25%) and un-milled broken grains (0.75%) was highest at 70 RPM.

The cost of production based on the product recovery and machinery cost has been presented in Table 4. The total machinery cost including fixed cost and operational cost has come to Rs 71.71 per hour. Based on the machinery cost and product recovery, the cost of production for dal from Green gram was recorded as Rs 1.98 per kg whereas the cost of production in case of Bengal gram dal was recorded as Rs1.62 per kg. The preparation of *sattu* requires fine grinding. Therefore the product recovery for sattu was less resulting in a higher cost of production (Rs 20.49 kg/hr).

The ergonomic evaluation for the preparation of dal and sattu has been presented in Table 5. The subjects selected were having BMI between 18.30 to 23.20 kg/m$^2$. The status of heart rate, oxygen consumption rate, energy consumption rate, body discomfort level, and rest time required after 15 minutes of operation have been recorded. The average heart-beat per minute was recorded between 60 to 79 at rest whereas the heartbeat varies between 65 to 90 per minute after the operation of the machine for preparation of dal from Green gram and Bengal gram. The heartbeat was recorded between 78 to 105 for preparation of *sattu* which was higher due to the requirement of more effort for milling of *sattu*. The average oxygen consumption rate at the highest heartbeat was recorded between 0.16 litre per minute to 0.35 litre per minute during the preparation of dal from Green gram. The oxygen consumption rate was recorded as very high (0.21 liter per minute to 0.52 liter per minute) in the case of preparation of *sattu.* Likewise, the energy consumption rate was also higher in the case of *sattu* (4.38 kJ/minute to 10.85 kJ/minute) as compared to that required for the preparation of dal from green gram (3.34 kJ/minute to 7.30 kJ/minute) and dal from Bengal gram (2.71 kJ/minute to 6.47 kJ/minute). Only two persons out of six gave a score of 5 (moderately difficult) in the case of green gram dal preparation whereas only one person out of six gave a score of 5 (moderately difficult) in case of Bengal gram dal preparation. Surprisingly, all were male who gave a score for 'moderately difficult'. But in case of *sattu* preparation, all respondents irrespective of gender reported the operation as 'moderately difficult'. But in all cases, the operators find themselves fit for operation of the machine again after 5 minutes. In case of dal preparation, only 2-3 minutes were required to make the operator ready to go for the next operation.

## CONCLUSION

The performance of Hand-cranked Improved Chakki was very good for the preparation of dal. The machine can be operated between 60-70 RPM but the clearance between grinding stones has to be adjusted depending upon the nature of products and type of raw materials. The dal recovery was highest with high dehulling efficiency in the case of Green gram at 60 RPM with 5.00 mm clearance between grinding stones whereas it was highest in case of Bengal gram at 70 RPM with 7.00 mm grinding stone clearance. Dehulling efficiency was 96.0-96.75 percent for Bengal gram and 96.0-97.25% for Green gram whereas dal recovery was 82-84 percent and 77-78 percent for Green gram and Bengal gram respectively. The machine had registered 93.7 percent milling efficiency for preparation of sattu. The cost of production was Rs. 20.49/kg for *sattu*, Rs 1.98/kg for Green gram *dal* and Rs 1.62/kg for Bengal gram *dal*. A common trend of increase in heartbeat, oxygen, and energy consumption rate was noticed with the increase in age of the subjects irrespective of their gender. *Dal* preparation by machine was reported to be a comfortable task in comparison to *sattu* preparation with the lowest work-rest time ratio varying between 5:1 and 3:1 for different subjects.

***Table 1. Production of dal (Green gram) at the variable rotational speed of improved chakki***

| S. No. | RPM of chakki | Clearance between stones mm | Feed rate kg/h | Product recovery by weight kg/h | Product (Dal) recovery % | De-hulling efficiency % | Un-split grain % | Broken grain % |
|---|---|---|---|---|---|---|---|---|
| 1. | 60 | 5.0 | 43.16 | 36.25 | 83.99 | 97.25 | 2.75 | 0.99 |
| 2. | 65 | 5.0 | 43.39 | 35.91 | 82.78 | 96.83 | 3.17 | 1.51 |
| 3. | 70 | 5.0 | 44.26 | 36.29 | 82.00 | 96.00 | 4.00 | 1.99 |

***Table 2. Production of dal (Bengal gram) at the variable rotational speed of improved chakki***

| S. No. | RPM of chakki | Clearance between stones mm | Feed rate kg/ h | Product recovery by weight kg/h | Product (Dal) recovery % | De-hulling efficiency, % | Un-split grain % | Broken grain % |
|---|---|---|---|---|---|---|---|---|
| 1. | 60 | 7.0 | 52.63 | 40.53 | 77.01 | 96.75 | 3.25 | 1.67 |
| 2. | 65 | 7.0 | 55.57 | 42.93 | 77.27 | 96.13 | 3.87 | 2.33 |
| 3. | 70 | 7.0 | 56.93 | 44.40 | 77.99 | 96.00 | 4.00 | 2.85 |

***Table 3. Production of sattu (Bengal gram) at the variable rotational speed of improved chakki***

| S. No. | RPM of chakki | Clearance between stones mm | Feed rate kg/ h | Sattu recovery by weight kg/h | Average Milling efficiency % | Un-split sole grain % | Un-milled broken grain % |
|---|---|---|---|---|---|---|---|
| 1. | 60 | 1.5 | 3.50 | 3.27 | 93.7 | 0.10 | 0.25 |
| 2. | 65 | 1.5 | 3.80 | 3.56 | 93.7 | 0.19 | 0.50 |
| 3. | 70 | 1.5 | 3.77 | 3.53 | 93.7 | 0.25 | 0.75 |

***Table 4. Machinery cost per kg production of Green gram, Bengal gram and Sattu***

| S. No. | Particulars | Machinery Cost, Rs/h | | | Product recovery kg/h | Machinery Cost/ kg of product Rs/kg |
|---|---|---|---|---|---|---|
| | | Fixed Cost | Operational Cost | Total Cost | | |
| 1. | Hand-cranked improved chakki | 26.67 | 45.04 | 71.71 | - | - |
| 2. | Green gram dal | | | | 36.29 | 1.98 |
| 3. | Bengal gram dal | | | | 44.40 | 1.62 |
| 4. | Sattu | | | | 3.56 | 20.14 |

***Table 5. Ergonomic evaluation of operator in production of dal and sattu for a slot of 15 minutes continuous operational time for four cycles.***

| S. No. | Name of Product | Subject's number and gender | BMI | Average Heartbeat per minute | | Av. Oxygen consumption rate at highest heartbeat litre/minute | Av. Energy consumption rate at highest heartbeat kJ/minute | Body discomfort level at 1-10 scale | Av. Work rest time ratio, minute |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Before machine operation | After machine operation | | | | |
| 1. | Green gram dal | Subject – 1 (F) (25-30 yrs) | 18.30 | 63 | 76 | 0.19 | 3.96 | 6 | 15:2 |
| | | Subject – 2 (F) (31-35 yrs) | 20.70 | 68 | 81 | 0.24 | 5.01 | 8 | 15:3 |
| | | Subject – 3 (F) (36-40yrs) | 19.01 | 72 | 85 | 0.29 | 6.05 | 8 | 15:3 |
| | | Subject – 4 (M) (25-30 yrs) | 19.50 | 67 | 74 | 0.16 | 3.34 | 7 | 15:2 |
| | | Subject – 5 (M) (31-35 yrs) | 21.70 | 74 | 82 | 0.25 | 5.22 | 5 | 15:2 |
| | | Subject – 6(M) (36-40yrs) | 23.20 | 79 | 90 | 0.35 | 7.30 | 5 | 15:3 |
| 2. | Bengal Gram | Subject – 1 (F) (25-30 yrs) | 18.30 | 61 | 72 | 0.14 | 2.92 | 8 | 15:2 |
| | | Subject – 2 (F) (31-35 yrs) | 20.70 | 65 | 74 | 0.16 | 3.34 | 6 | 15:3 |
| | | Subject – 3 (F) (36-40 yrs) | 19.01 | 72 | 87 | 0.31 | 6.47 | 6 | 15:3 |
| | | Subject – 4 (M) (25-30 yrs) | 19.50 | 60 | 65 | 0.06 | 1.25 | 7 | 15:1 |
| | | Subject – 5 (M) (31-35 yrs) | 21.70 | 63 | 71 | 0.13 | 2.71 | 6 | 15:2 |
| | | Subject – 6(M) (36-40 yrs) | 23.20 | 66 | 77 | 0.20 | 4.17 | 5 | 15:3 |
| 3. | Sattu | Subject – 1 (F) (25-30 yrs) | 18.30 | 62 | 83 | 0.27 | 5.63 | 5 | 15:3 |
| | | Subject – 2 (F) (31-35 yrs) | 20.70 | 65 | 96 | 0.41 | 8.55 | 4 | 15:5 |
| | | Subject – 3 (F) (36-40 yrs) | 19.01 | 64 | 105 | 0.52 | 10.85 | 4 | 15:5 |
| | | Subject – 4 (M) (25-30 yrs) | 19.50 | 69 | 78 | 0.21 | 4.38 | 5 | 15:4 |
| | | Subject – 5 (M) (31-35 yrs) | 21.70 | 63 | 93 | 0.38 | 7.93 | 5 | 15:4 |
| | | Subject – 6(M) (36-40 yrs) | 23.20 | 71 | 98 | 0.44 | 9.18 | 4 | 15:5 |

* Comfort level:1 – 3 difficult, 4 – 5 moderately difficult, 6 – 8 moderately comfortable, 9 – 10 highly comfortable.

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