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AMC-made Impeller-type Buckwheat Dehuller and Optimization of Impeller Speed

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ABSTRACT

The outer hull or husk of buckwheat (Fagopyrum esculentum Moench.*) kernel comprises about 20-30% of the weight of the buckwheat grain. Since it is inedible it should be removed before processing into flour. While imported and expensive dehulling machines are available in Bhutan, to reduce cost and gain wider adoption by farmers and perform the operation efficiently, the Agriculture Machinery Centre (AMC) has developed a buckwheat dehuller based on the impact and shear principle for efficient dehulling of whole buckwheat with most of the machine's body parts available locally. The present study was carried out to test the machine and to evaluate the best operating impeller speed for efficient dehulling of buckwheat. The machine was tested at five different levels of impeller speed: 1,700, 1,800, 1,900, 2,000 and 2,100 revolutions per minute (rpm). Process performance of dehulling efficiency (DE), and broken percentage (B%) were measured at each rpm. There was a significant difference in DE and (B%) across the five different speeds. The best DE of 88.94 % was observed at 2,100 rpm. However, there was also a high correlation between dehulling efficiency and the proportion of broken kernels, with the highest broken percentage of 43.96% observed at 2,100 rpm.*

Keywords: *Buckwheat: Dehulling efficiency; Dehuller machine*

1. Introduction

Buckwheat (*Fagopyrum esculentum* Moench.) is a pseudocereal, having gluten-free grains characterized by an excellent nutrient profile (Solanki, Mridula, Kudos, & Gupta, 2018). Buckwheat belongs to the Polygonaceae family and is taxonomically distant from the Gramineae family to which most cereals such as rice, wheat and maize belong. However, buckwheat seed has chemical and utilization characteristics like most cereal grains and thus is usually classified as a cereal (Ikeda, 2002).

There are several varieties of buckwheat species (Nagatomo, 1984; Ohnishi, 1991 as cited in Ikeda-K, 2002). The commonly cultivated species for human consumption are common buckwheat (*Fagopyrum esculentum* Moench.) also known as sweet buckwheat and Tartary or

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bitter buckwheat (*E tataricum* Gaertner). Buckwheat is a very versatile crop that can grow on most infertile land where most crops often fail. It is suitable for ecological growing, without the use of artificial fertilizers or pesticides (Krkošková & Mrazova, 2005). It is a rich source of starch and contains many valuable compounds, such as proteins, antioxidative substances, trace elements and dietary fibre (Bonafaccia, Marocchini, & Kreft, 2003; Kreft, Knapp, & Kreft, 1999). Due to the well-balanced amino acid composition buckwheat proteins have a high biological value, although their digestibility is relatively low (Yeshajahu & George, 1972). Buckwheat protein extracts may have a strong healing effect on some chronic diseases, such as diabetes, hypertension, hypercholesterolemia, and many other cardiovascular diseases (Li & Zhang, 2001). Besides high-quality proteins, buckwheat seed contains several components with healing benefits: flavonoids and flavones, phytosterols, fagopyrins and thiamin-binding proteins (Krkošková & Mrázová, 2005).

Agriculture Statistics (2019) (RSD, 2020) show that buckwheat is grown in all 20 dzongkhags of Bhutan. Amongst them, higher quantities are produced by farmers of Samdrupjongkhar, Bumthang, Haa, Trongsa, Dagana, Wangdue, Chhukha and Samtse dzongkhags. The total production was 2,350.43 Mt with an average yield of 459.389 kg/acre in the year 2019 (RSD, 2020). As per the buckwheat value chain analysis carried out by the Department of Agriculture Marketing and Cooperatives (DAMC), 44.9% of the households cultivate both bitter and sweet buckwheat; another 22.2% cultivate only bitter buckwheat and 32.9% grow sweet buckwheat (DAMC, 2019). In terms of agricultural assets owned by the buckwheat producing households, as high as 42.1% of households did not own any of the main agricultural equipment/machinery. Both males and females equally take part in buckwheat farming. While ploughing is led by males, land preparation, sowing, harvesting, and threshing is done by both males and females. It is mostly the males who engage in grinding using watermills and women who use stone grinders (DAMC, 2019). Thus the adoption of a cheap and efficient dehulling machine may lead to less drudgery, especially for women.

In Bhutan, buckwheat is mainly grown for its grains. The grains are used in the form of processed products, mainly flour. Buckwheat *Choydam* (hard dough), *Puda* (noodles), *Kontong* (cooked small balls), *Teyzey* (pancake), *Khuli* (cooked, soft Roti type), *Keptang* (unleavened circular bread) and *La zey* (flour baked with distilled alcohol); *Drengo* (flour paste); *Tshangjay* (flour paste with fermented wine); and *Hentey* (dumplings) are items that are usually prepared from buckwheat flour (Norbu & Roder, 2001). Buckwheat is also used to make *Ara* (distilled local liquor) / *Bangchang* (fermented wine). Sweet buckwheat hulls are also used to make pillows and mattresses.

Buckwheat is regaining popularity because of growing demand in the market fueled by a newfound awareness of its nutritional value (Yonten, 2018). People are realizing the nutritional value of buckwheat and the traditional food cultures of the past. Buckwheat is also identified as one of the three organic products under the National Organic Flagship Program (NOFP) in the country.

The common sweet buckwheat bears triangular seeds with a black hull that covers the light green to white kernel inside. The outer hull or husk is mainly composed of cellulose and it comprises about 20-30% of the weight of the buckwheat grain depending on the variety. Since it is inedible and cannot be digested by the human digestive system the hull is removed from the buckwheat kernel before further processing into flour (Solanki et al., 2018). The hull has a smaller density than water and this allows easier removal of the hull from the kernel. The hardness of the hull depends on the species of buckwheat (Krkošková & Mrazova, 2005). Traditionally, buckwheat grains are directly milled using a water mill, traditional stone grinder or any other crude method. After milling, the segregation of the husk from the flour is done using traditional sieving methods. This is highly inefficient in terms of the product quality as a huge portion of inseparable crushed husks remains in the flour.

While performing preliminary trials employing various grain dehulling methods used for paddy in the country, it was observed that the dehulling based on the principle of impact and shear (impeller type huller) gave better performance for these grains as compared to dehulling of grains using rubber roll sheller. The latter resulted in a high proportion of broken grains. Given this, a buckwheat dehuller machine based on the impact and shear principle was developed at the AMC (Figure 1). The present study was carried out to evaluate the machine's performance by comparing dehulling operations at five different speeds measured in revolutions per minute

Figure 1. AMC made buckwheat dehuller

(rpm).

2. Materials and method

2.1 Description of the machine components

The buckwheat dehulling machine consists of three major components: frame, dehulling unit and aspiration unit. The machine has two frames, the first and the main one supports the entire dehulling unit and the second frame holds the aspiration unit. The dehulling unit is the main component of the machine responsible for removing the husk from the buckwheat groats. This unit comprises 12 blades impeller and a stationary concave casing design based on centrifugal and Coriolis forces, whereby the buckwheat grains are thrown against the liner part of the impeller housing. This unit is driven by a 1 horsepower (hp) single phase motor in conjunction with pulley drive to maintain desirable speeds. The aspiration unit is designed to separate the husk and other lighter fractions from the mixture of groats, husk and unhusked grains produced from the dehulling operation. It comprises a 0.56 hp blower attached to the separating duct.

2.2 Working of the machine

The buckwheat grains are fed through the hopper into the dehulling unit where the buckwheat grains are dehulled, and the mixture of groats, husk and unhusked grains then passes through the aspirator attached to the machine. The aspirator separates the husk from the mixture and blows them out of the husk outlet, while the mixture of groats and unhusked grains is obtained at an outlet below the machine.

2.3 Dehulling principle

The dehulling takes place based on the impact and shear principle. The grains are fed into the centre of the rotor, through the rotating impeller where they are subjected to centrifugal force and thrown towards the rubber-lined casing. The shelling takes place here due to the high-force impact that hits the grains because of the frictional force between impeller blades and the grains (Figure 2). This causes the hulls to break loose from the groats, eventually releasing the groats free.

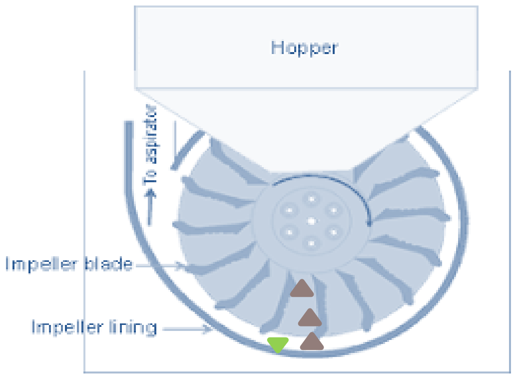

Figure 2. Schematic drawing of impact and shear principle in dehulling machine

2.4 Design consideration

The materials used for the fabrication of the machine were of adequate strength and stability. Most of the components were purchased from the local hardware stores. Consideration was given to keep the cost of the components reasonably low and yet, readily available. This will allow easy duplication by in-country manufacturers and at the same time satisfy all strength requirements.

2.5 Design support frame

The machine has two frames, the first main frame supports the entire dehulling unit and the second frame supports the aspiration unit. A frame of 550 x 265 x 530 mm size was fabricated to support the entire weight of the dehulling unit. The base of the frame was made of a C-channel of 100 x 50 x 6 mm size and an angle bar of 40 x 40 x 6 mm size to give the required rigidity. A second frame of 955 x 243 x 500 mm size that supports the aspirating unit was designed using 25 x 25 x 3 mm size angle bar.

2.6 Design of dehulling unit

The dehulling unit comprises 12 impeller blades radially arranged on an impeller hub, a liner and a casing. The impeller blades were made up of mild steel sheets of 3 mm thickness (Figure 3).

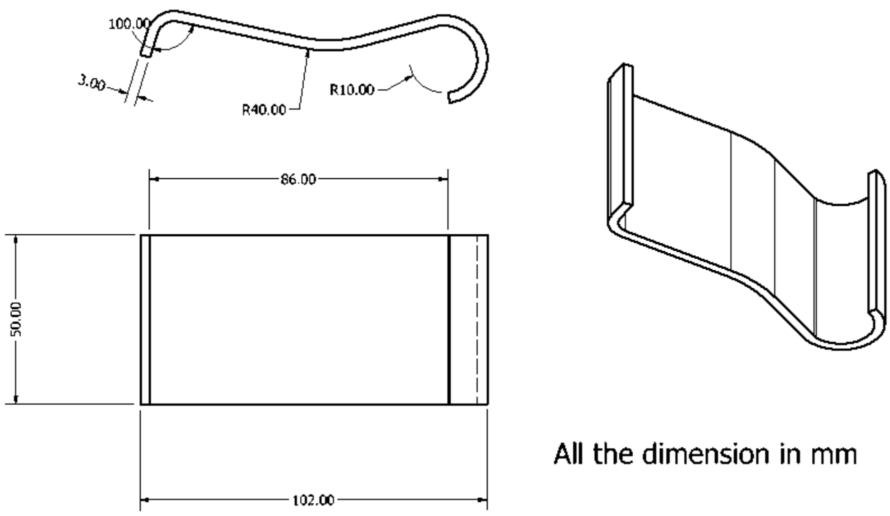

Figure 3. Impeller blades

The impeller hub (Figure 4) consists of a simple 3 mm mild steel hub with a diameter of 308 mm to accommodate twelve blades at an angular spacing of 30 degrees. It was made into two symmetrical halves for easy placement of blades in between. The thickness of each half was 3 mm; one half of the hub is slotted with a hole of a diameter of 91 mm for the entry of grains and another half with 20 mm hole for the shaft.

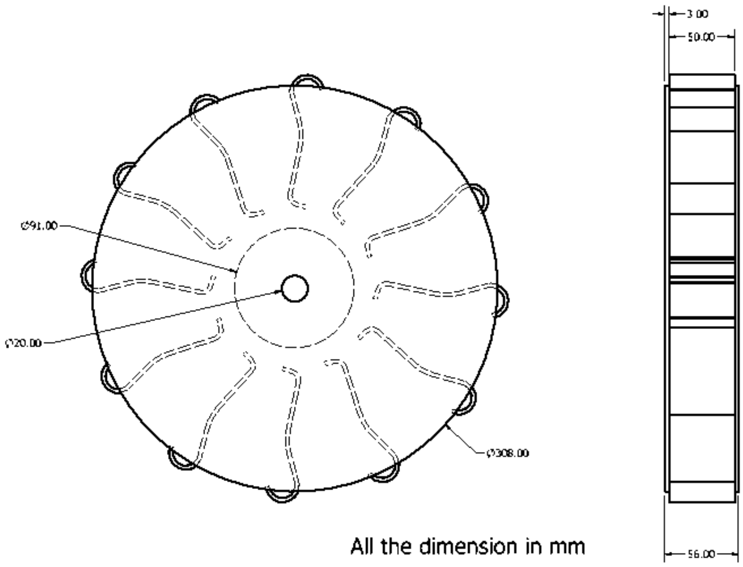

Figure 4. Impeller hub

The liner used was a locally available polyester rice mill nylon belt. It was placed over the entire inner circumference of the casing. The casing and the outlet chute were fabricated with a mild steel sheet of size 2 mm.

The hopper is a frustum of a pyramid (pyramid portion with its upper head cut off by a plane parallel to its base). It is the medium through which grains are introduced to the dehulling unit. It is made of 2 mm thick mild steel. The volumetric capacity of the hopper is 7,930 cm^3.

2.7 Design of aspiration unit

The aspiration unit (Figure 5) is designed to separate the husk and other lighter fractions from the mixture of groats, husk and unhusked grains produced from the dehulling operation. The unit comprises a centrifugal air blower of 0.56 hp with 2800 rated rpm attached to the separating duct. The blower used has an independent power connection. The separating ducts used were made of locally available polyvinyl chloride pipes of size three inches.

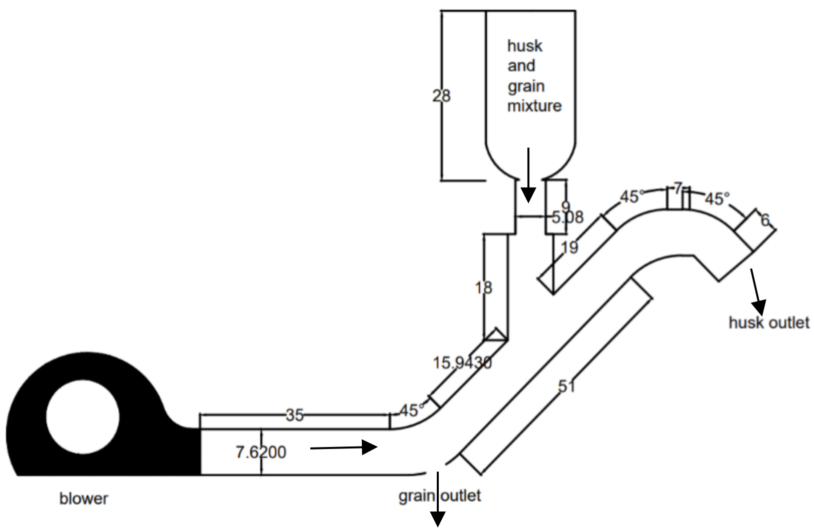

Figure 5. Aspirator duct (all dimension in cm)

2.8 Sample preparation

Common sweet buckwheat grains (*Fagopyrum esculentum*) were obtained from the National Seed Centre, Paro. The dehulling test was conducted at AMC, Paro. Grains were cleaned using a manual mechanical winnower to remove foreign matters, and broken and immature grains. The grains were then dried to an average moisture content of 8.56±0.15%. The moisture content of the grains was measured using universal grain moisture meter (INDOSAW).

2.9 Dehulling test and measurements

The buckwheat samples of dried buckwheat at 8.56±0.15% moisture content were dehulled to evaluate the performance of the AMC designed impeller dehulling machine at five different levels of speed (1,700, 1,800, 1,900, 2,000 & 2,100) rpm. The mass of grain and husk obtained at the outlet were classified as whole groats, un-hulled grains, broken grains and husk.

The experiment was carried out following a completely randomized design (CRD) with a single factor (speed) at 5 levels with three replicates each.

Dehulling efficiency (DE) was measured as follows:

$DE = \frac{\mathrm{Mt} - \mathrm{Mn}}{\mathrm{Mt}} * 100$………………………… (Solanki et al., 2018)

Where:
Mn is a mass of grain left unhusked after the dehulling operation
Mt is the total mass of grain fed into the hopper

Broken percentage (B%) was measured as follows:

$B\% = \frac{\text{Ml}}{\text{Mt}} * 100$ …………………… (Singh, Saha, & Mishra, 2010)

Where:
Ml is the broken kernels loss in the form of powder and broken grain after dehulling
Mt is the total mass of grain fed into the hopper

2.10 Statistical analysis

Pearson's correlation, simple linear regression and one-way ANOVA were performed to explore relationships between impeller speed (rpm), dehulling efficiency (%) and broken percentage (%). Bartlett's test for equal variances was performed to check the data for equality of variances assumption before running ANOVA. Tukey's test was used to test for significance among treatment means.

3. Results and Discussion

Dehulling efficiency increased linearly with an increase in the speed of the impeller (Figure 6). Simple linear regression of DE and speed (rpm) was found highly significant (P<0.000). The average dehulling efficiency of the machine was 83.26±4.80% which is considered acceptable. In a study by Solanki et al., (2018) who used roller type dehusker set at 800 rpm, only 66.61% of DE was achieved.

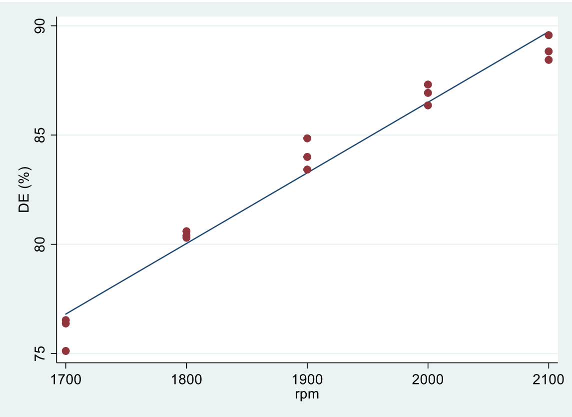

Figure 6. Scatter and line plot of DE% and impeller speed (rpm)

DE was significantly different between all the five levels of speed (Table 1). The highest dehulling efficiency was observed at 2,100 rpm (88.95%) and the lowest at 1,700 rpm (72.69%).

Similarly, the broken percentage was also found to increase linearly with increasing impeller speeds (Figure 7) although there was no significant difference between the rpms 1,700 and 1,800; 1,900 and 2,000; and 2,000 and 2,100 (Table 1). The absence of significant difference between the aforementioned pairs, despite the means being different from each other as in the case of dehulling efficiency, could be due to the higher variation in the broken proportion data for rpms of 1,800 and 2,000.

Table 1. Mean dehulling efficiency and broken percentage across the five different speeds

Speed level (rpm)	Dehulling efficiency (%)	Broken (%)
1700	76.01 ± 0.77^{e}	29.54 ± 0.54^{c}
1800	80.43 ± 0.15^{d}	32.94 ± 2.86^{c}
1900	84.09 ± 0.72^{c}	38.36 ± 1.46^{b}
2000	86.87 ± 0.48^{b}	39.40 ± 2.37^{ab}
2100	88.95 ± 0.57^{a}	43.97 ± 0.72^{a}

Mean values within the columns with different superscripts are significantly different between speeds levels at P < 0.05 by Tukey's test (mean ± standard deviation, n=3)

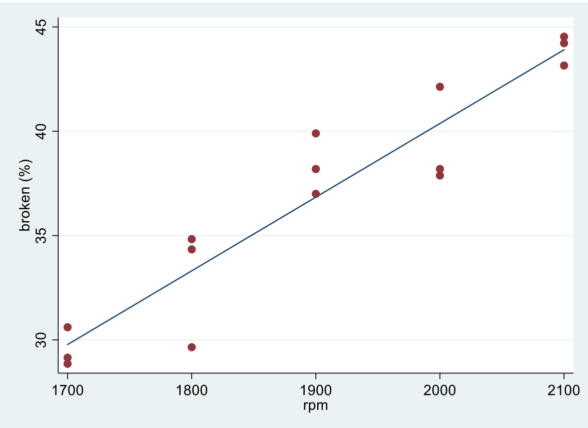

Figure 7. Scatter and line plot of broken % and impeller speed (rpm)

What could be the reason for observing a higher proportion of brokens as the impeller speed increased? Just as the higher roller speed induces rapid separation of the hull from the kernels, a similar frictional force may be induced on the body of the kernels, especially if they are quite fragile or soft. Similar observations were also made by Solanki et al. (2018), Jain (1980), Joshi (1993) and Guptaa and Das (1999) in dehulling of buckwheat, paddy, pumpkin seed and sunflower seed, respectively.

The results show a very high correlation between the machine's dehulling efficiency and the proportion of broken grains, with a Pearson's correlation coefficient of 0.95 and a highly significant P-value (P<0.000). Is this a paradox then? In the case of buckwheat, people often grind it further into flour and then consume it in the form of various products mentioned earlier. Hence, it may be argued that the presence of broken grains is of no concern as they will be ground further along with the unbroken grains into flour at the end of the day. Thus, it can be safely reasoned that the machine can be operated at 2,100 rpm to obtain the highest dehulling efficiency without worrying about broken grains proportion.

4. Conclusion

While it was already proven through informal tests conducted at the Agriculture Machinery Centre that the locally fabricated huller machine was effective at dehulling buckwheat grains, this study substantiates this further with the empirical evidence generated. The results indicate that the best dehulling performance for this machine could be obtained if the system is operated at a roller speed of 2,100 rpm at 8.56% moisture content. Under these conditions, the values of dehulling efficiency were as high as 88.95%. However, the percentage of the broken grain was also observed to be the highest at this speed. On the other hand, since buckwheat kernels are anyway crushed further and consumed as flour, it is of no concern.

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