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Design and Fabrication of a Portable Low-Cost Rice Milling Machine with Automatic Feeding Mechanism

Hasan Farid Khan[a], Mustafa Haider[b*], Shehroze Khan[a], Ali Akbar[a], Rizwan Ahmad[a] & Moazzam Ali[a]

[a]*Department of Mechanical Engineering, The University of Lahore (UOL)*
[b]*Department of Engineering Sciences, NUST PNEC Karachi.*

**Corresponding author: mustafahaider786@gmail.com*

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ABSTRACT

Rice is an important source of food for humans and holds higher importance, it grows on plants in a shell called a hull. To extract, the rice from its shells a rice milling machine is used. These processing machines are costly and not feasible for farmers to buy for their domestic purposes or for small-scale industries. For overcoming this problem an innovative and affordable rice mill is required, for small businesses. Not only the cost but also the machine parameters are much important. This paper is aimed to evaluate the performance of the designed small-sized model of the rice milling machine along with the analysis of the set parameters for the economic rice extraction from the hull without damaging the kernels. In the first step, a conceptual model in CAD was drawn including detailed specifications. In the second step, the design was evaluated and utilized to reproduce/ fabricate each component for a practical machine. Lastly, the machine was evaluated for its performance. Moreover, an automatic feeding system was also introduced as an innovation to reduce feeding labor and increase production. From the results, it was found that the automatic feeding system was reliable, moreover, the 3-horsepower motor was reduced to 2 horsepower for power saving. The cost of the machine was reduced from 80000Pkr to 55000Pkr. However, the rice processing speed was reduced to 100 kg/hour, from 200 kg/hour, which is aimed to be compensated via an automatic feeding mechanism.

Keywords: Automatic feeding, cost reduction, design innovation, milling machine, portable design

INTRODUCTION

Rice (Oryza sativa), is a staple food that is seldom absent from the table, whether for breakfast, lunch, or supper. It is the most extensively eaten grain crop by a substantial portion of the world's human population, particularly in Asia. According to data from the United Nations Ministry of Agriculture, it is the agricultural commodity with the third biggest global output behind sugarcane and maize (2014).

Milling is the process of transforming rice grains into a shape fit for human consumption, and it must be handled with extreme caution to avoid breaking the shell and promote recovery. Brown rice is processed even more to get white rice with a much more pleasing appearance. After collecting and drying, the rice undergoes primary milling, which involves de-husking and the elimination of bran and germ (polishing), before being eaten (Yang et al. 2022), (Xiong et al. 2023), (Wei et al. 2022).

As there is considerable rice production in Pakistan, a lot of processing is required for the conversion of raw rice into its edible form. Even though rice is a semi-aquatic annual plant, it may be a perennial in tropical and subtropical climates. Because of its light and water requirements, it can only grow in the tropics. It's a staple in many nations and a global staple. It's the most extensively eaten cereal grain, particularly in Asia. It's the second-most-produced grain after maize (Bodie et al. 2019).

In this current work following objectives were aimed and achieved, a feasible design of a portable-sized rice milling machine for small industry-level production. CAD designing of each part and the assembly drawing of the complete system after a detailed study (Charles et al. 2004), (Jadhav et al. 2022). In this work not only the machine considerations were analyzed for the design and fabrication considerations but also the machine parameters for efficient process and for minimizing the percentage of the broken kernel were also focused, on by reviewing the available literature (Ruekkasaem et al. 2018), (Mohammad et al. 2022). The machine design constraints were also studied from the previously published work for designing a highly sophisticated design (Jamal, 2021).

The aim of cost-effective machine for the farmers and the small business owners was also a core objective of this current work and this aim was also accomplished by this current design. As there were methodologies described in the previously published work for designing a low-cost agriculture machine (Ogheneochuko 2020).

Recently there are many advancements in the agriculture technologies such as IoT-controlled agriculture machines (B et al. 2021). This not only emphasizes the requirements of newer technologies in underdeveloped countries but also highlights the fact that the farmers should also have better and improved machines for better production of their crops.

For the design, analysis, and fabrication of a newer model of agriculture machine, there is a requirement for performance evaluations and the study of parameter suitability (Folami et al. 2016), (Rice processing 2022), (Rice-mill-machine.com, 2022).

According to the available rice milling machines categories, there are two major divisions, which are fraction-type rice milling machines and grind rice milling machines. In the fraction type, there is a strong friction force that peels off the brown coat from the rice and converts it into white. In the grind rice milling machine, there is an abrasive type of wheel that grinds and removes the outer brown coat from the rice (Performance Evaluation 2017). Moreover, the hybrid types of many machines are also attaining interest due to the higher performance by the application of solar energy (Haider et al. 2021), (Patel et al. 2022).

A lot of rice milling machine manufacturers are available in the market providing their equipment for the rice processing units (Morad et al. 2013).

The available machinery is most likely suitable for many climate conditions of the whole world, however sometimes as there are differences in humidity and temperature conditions, these machines are also evaluated in different regions for their performances (Milling characteristics 2017), (H. Group 2022).

The milling performance of the rice milling machines is also evaluated under different parameters, as the rotating speed of the milling machine changes the quality and quantity of the processed rice also change, and as there is an increase in the RPM of the shaft the temperature also rises and broken kernel ration increases (Rafique et al. 2022).

Rice is best grown in places where labor costs are low and there is a lot of rainfall. Rice may be grown on hills and mountains thanks to water-controlling terraces. Although its parent species are native to Asia and Africa, commerce and export have made it popular worldwide.

Flooding the fields while planting rice seedlings is the customary practice. Rice is harvested, dried, threshed, and milled. Each rice grain has been movable shell (Matz et al. 1970), (Luh et al. 1980), (Koya et al. 1994).

The hull, bran, and other undesired components are removed from the rice. This comprises washing, shelling, bran removal, and sizing. The chaff is also removed by milling rice (Wadsworth et al. 1991).

Conventionally for the removal of chaff, a pestle is utilized. The pestle is used to pound the raw rice, this removes the chaff but also converts the rice grain into a fine powder.

This conventional cleaning of rice results in poor rice production as broken and powdered rice does not sell at a good price. Moreover, this also impacts the local rice requirements instead of producing higher quality rice in a higher quantity to be exported and resulting in considerable income for the country.

To avoid these fore mentioned problems there is an alternative method. The rice winnower is improved by the rice milling machine. That machine is consisting of a hopper, sheller, cleaner, sieve delivery unit, and frame. However, this machine is not such a piece of low-cost equipment that can be purchased by farmers and the owners of small businesses.

It is quite difficult for farmers in rural areas to afford most of the local equipment. To empower the farmers and small businessmen there is a requirement for a low-cost, affordable, and portable rice milling machine.

In the process of rice milling, the shelling is followed by the removal of chaff and even though rice is native to the tropics and at large, it's a standard fare. Making a low-cost rice mill is the primary goal of this research.

For safe storage after harvesting, un-milled grains should be dehydrated to a water content of 12–13 percent wet basis (Kim et al. 2012). Humidity and temperature variations are formed within the dryer during the drying process. However, the tension on the kernel can cause it to fissure (T.J et al. 2005).

During this time, fissured kernels are more likely to crack and lead to a decrease in head rice yield, resulting in cooking quality being poor, and the market value being low (Zhang et al. 2005), (Gorial et al. 1990).

A suitable number of parameters must be considered while designing a suitable rice milling machine. DOE (Design of Experiment) is a research tool for obtaining distinct variables impacting response or results by limiting response variation while keeping response as close as feasible to the design objectives. It has been broadly applied to boost rice crop yield (Thakar et al. 2016).

For example, investigated connected rice plantations to determine the impact of separation between various strains on rice yield and quality.

Bangphan and Bangphan (Bangphan et al. 2012) used a factorial experiment to try to enhance the yield of a brown rice peeling machine.

METHODOLOGY

Rice milling machine production involves many procedures and processes. The machine has various parts that must be assembled correctly to generate a rice mill. For the production of the machine components cutting, drilling, turning, welding, and sheet metal work are the major manufacturing processes.

MATERIALS

Material and procedure must be carefully chosen while designing and fabricating a rice milling machine. This ensures that the finished product works as planned. In selecting a material to meet design and product requirements, numerous factors must be considered so that components and assembly may be made within available resources (Nayan et al. 2021), (Kumar et al. 2022). Table 1 lists the materials used.

TABLE 1. Materials for the components

Sr. No.	Name	Material Used
1	Hopper	Mild steel
2.	Hopper shelling drum	Mild steel
3.	Drum shaft	Mild steel
5.	Transmission belt	Rubber
6	Pulley	Cast Iron
7	Shaft	Mild steel
10	Tube/Hose	Rubber
11	Prime Mover	Electric Motor
12	Body frame assembly	Mild Steel Sheet Metal
13	Blower Assembly	Mild Steel Sheet Metal and ABS for Impeller

DESIGN CONSIDERATION

The following criteria are considered while designing a rice milling machine:

1. The equipment's manufacturing costs must be low.
2. It must be overall cost-effective.
3. It is essential that the equipment be transportable.
4. The expense of maintenance must be reasonable

A brown rice milling machine consists of several mechanical and electrical components which work together to separate the husk and rice. As depicted in Figure 1(a &b), there are 10 main parts in the assembly. The brief details of the parts are referenced in Table 2.

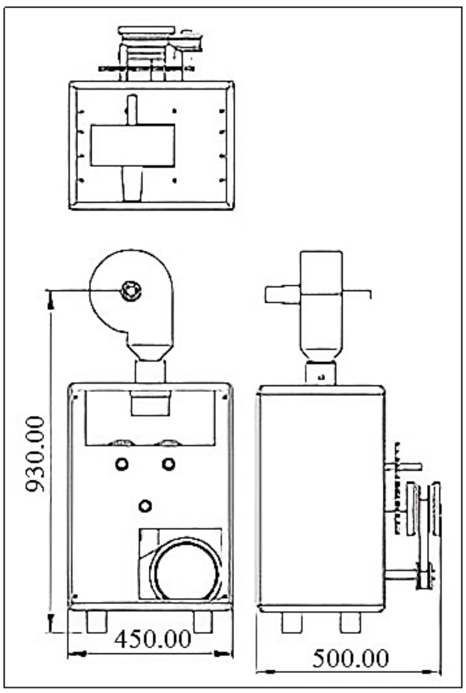

FIGURE 1(a). CAD drawing of rice mill (orthographic) (unit: mm)

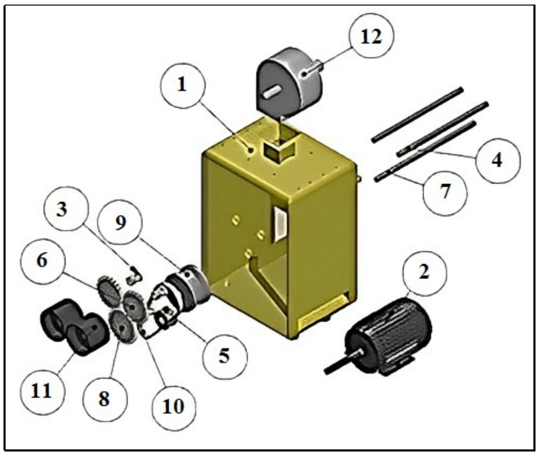

FIGURE 1(b). Labeled parts of rice milling machine.

In the table 2 the description in the terms of name and quantity of each main component of the rice milling machine is mentioned.

TABLE 2. Major components of rice milling machine.

Item No.	Part Name	Qty.
1	Main Frame	1
2	Motor	1
3	Roller Shaft	2
4	Driving Pulley	1
5	Spur Gear	3
6	Roller Driven Pulley	1
7	Driven Pulley	1
8	Pulley Belt	1
9	Roller	2
10	Blower Assembly	1

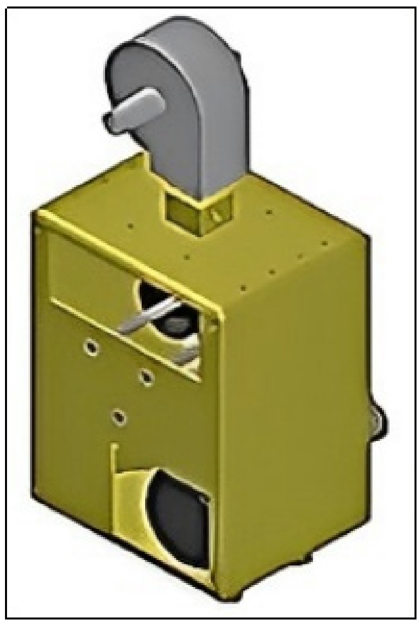

FIGURE 2. Design assembly of rice mill.

DESIGN OF FRAME

The frame is designed to accommodate the rest of the parts in the design such as pulleys, rollers, and gears. The frame was manufactured using mild steel sheet and sheet metal was joined together using rivets. The dimensions and characteristics of the frame are depicted in Figure 3 (a&b).

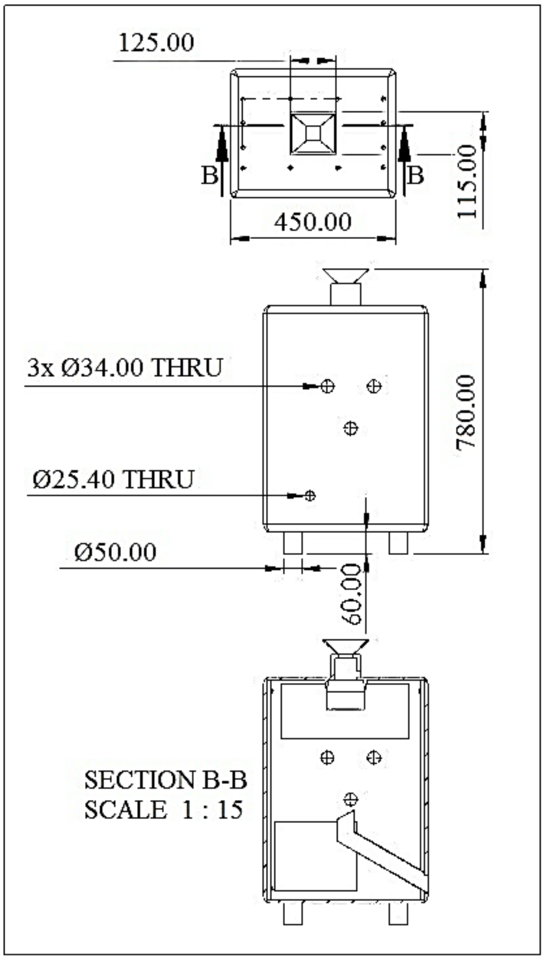

FIGURE 3 (a). Design & dimensions of frame (orthographic) *(unit: mm)*

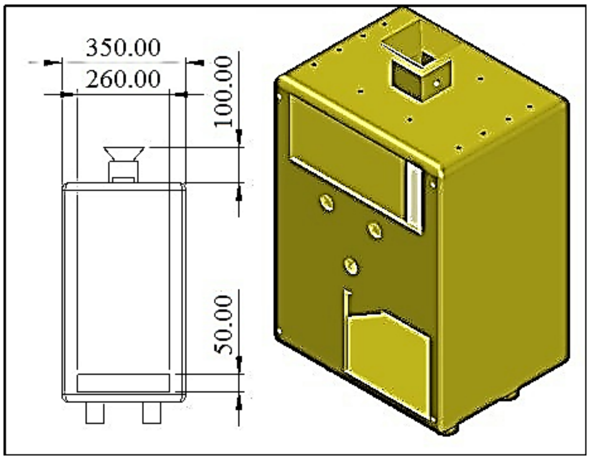

FIGURE 3 (b). Design & dimensions of the frame. *(unit: mm)*

DESIGN OF PULLEYS

The driven and driver pulley has been designed such that they can operate under the full power of 1500W.There is a mechanical advantage of about 2 between the driver and the driven pulley and that means that the torque transmitted by the driven pulley will be twice.

This torque will help in the efficient movement of rollers and rotate the gear- train. MATLAB has used the aid of the designing process of the pulleys. The design of the pulleys is shown in Figure 4 (a &b), there was a ratio of 2:1 between the driver and driven pulleys size in each aspect.

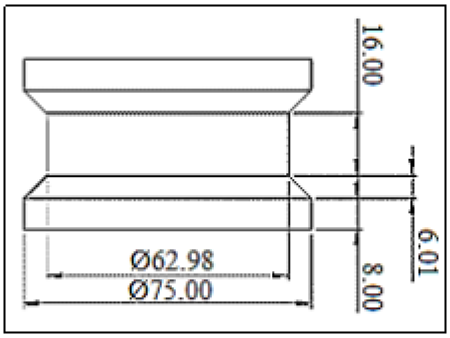

FIGURE 4 (a) Dimensions of driver pulley *(unit: mm)*

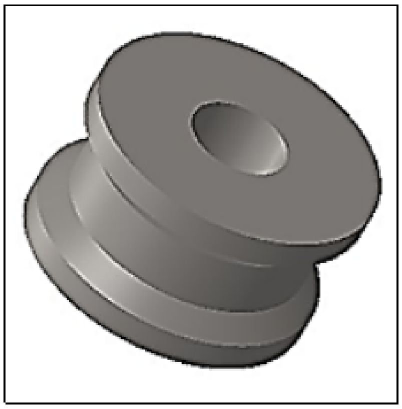

FIGURE 4 (b). Design of pulley

DESIGN OF BELT

A flat belt instead of a v belt was chosen for the drive as the distance between the pulleys is less than 8 meters so the flat belt will suffice for the short distance operation.

Having known the diameters of the driven and driving pulleys and center distance between them, once can determine the length of the belt required from following equation.

$$L = 2C + \frac{\pi}{2}(d + D) + \frac{(d - D)^2}{4C}$$

Here

D: Diameter of large pulley

d: Diameter of small pulley

C: Is the distance between the pulley centers.

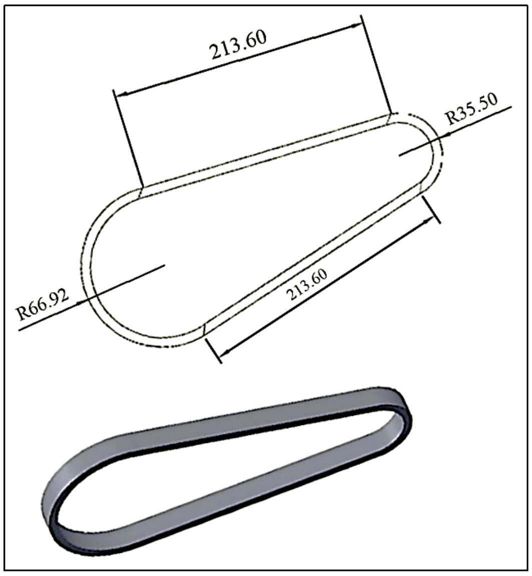

FIGURE 5. Design & dimensions of flat pulley belt, *(unit: mm)*

The choice and type of belt from the manufacturer and the maximum tension it bears are further used in calculations to calculate the pulley RPMs.

The design of the pulley belt has been shown in Figure 5. The design calculations from MATLAB showed that 735mm of belt length is required for our design.

DESIGN OF GEARS

A spur gear train has been used to drive the rollers and to also change the direction of each roller. The sizes of each gear have been made the same because mechanical advantage has already been achieved by using the pulleys and further increase in size will decrease rpm which will slow the rice milling process.

Figure 6 shows the design of the spur gear and the table 3 shows the parameters of the gears.

TABLE 3. Gear parameters

Sr. No.	Parameter	Output
1	Number of Teeth	26
2	Module	5
3	Pressure Angle	20°
4	Outer Diameter	140 mm
5	Pitch Diameter	130 mm
6	Root Diameter	117.5 mm
7	Addendum	5 mm
8	Dedendum	6.25 mm
9	Working Depth	10 mm
10	Whole Depth	11.25 mm
11	Circular Pitch	15.708 mm

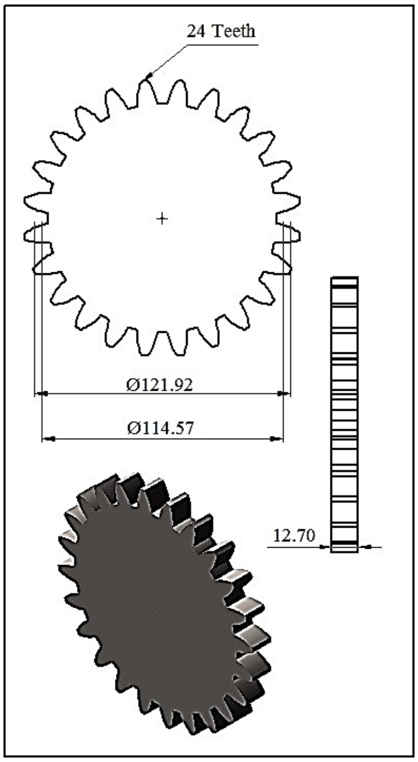

FIGURE 6. Design & dimensions of spur gear, *(unit: mm).*

DESIGN OF ROLLER

Rollers are the main part of the rice milling machine and they are used to separate the hull from the brown rice. The gap between the rollers, friction between the rice and roller, and torque with which it is driven are all important parameters to consider (Milling characteristics 2017).

Figure 7 (a &b) illustrate some of the main dimensions of the roller and MATLAB was also utilized for the calculations of forces on the roller. From the calculations, the final results are:

TABLE 4. Roller parameters

Sr. No.	Parameter	Value
1	$\tau R, \boldsymbol{Driven}$	119×10^3 N.mm
2	$\boldsymbol{NR}$	3742 N
3	$\boldsymbol{FR}$	1871.2 N

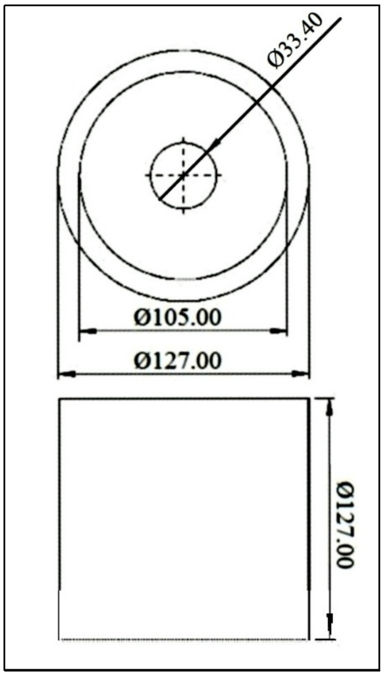

FIGURE 7(a). Design & dimensions of roller, *(unit: mm)*

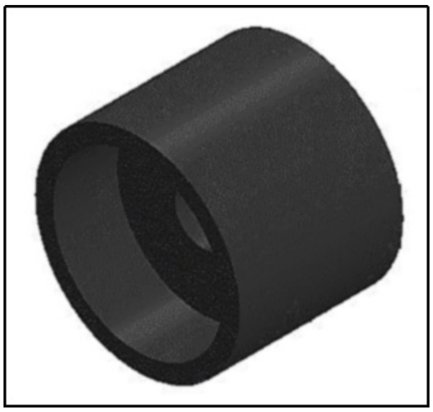

FIGURE 7(b). Design of roller

FEA ANALYSIS OF ROLLER

The forces calculated from MATLAB are utilized in the FEA model of the roller to investigate the stresses on the roller.

As seen in Figure 8(a), the stresses on the roller are not that significant as compared to the yield strength of the rubber roller and hence we have sufficient factor of safety. However, after a longer run it has been observed that there is a continuous wear on the upper surface of the roller. This is due to the frictional effect resulting in the surface degradation of the rubber roller. As any harder material of roller can lead to the breakage of the rice grains, rubber is usually selected for roller material for husk removal or rice.

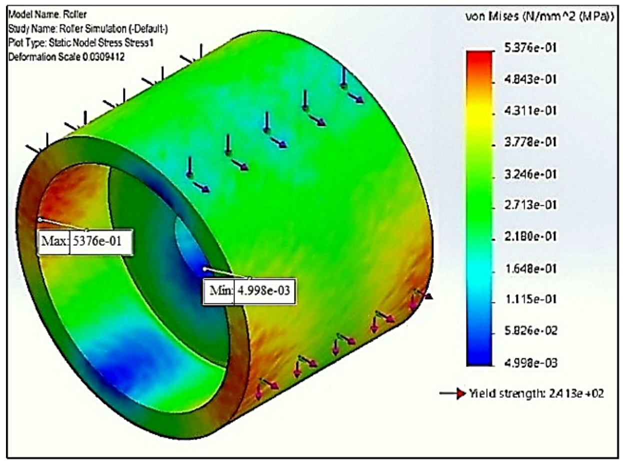

FIGURE 8(a). FEA analysis of roller

DESIGN OF ROLLER SHAFT

The roller shaft must bear torsional as well as bending loads due to the weights of the pulley and roller, so a reliable design of the shaft is needed for high-stress life (Milling characteristics 2017) and to avoid the failure of the shaft as well.

The FEA model was created to investigate the stresses on the shaft as depicted in Figure 8(b). The maximum stress on the shaft is way below its yield strength and according to von mises criteria, the shaft is safe to use with high-stress life.

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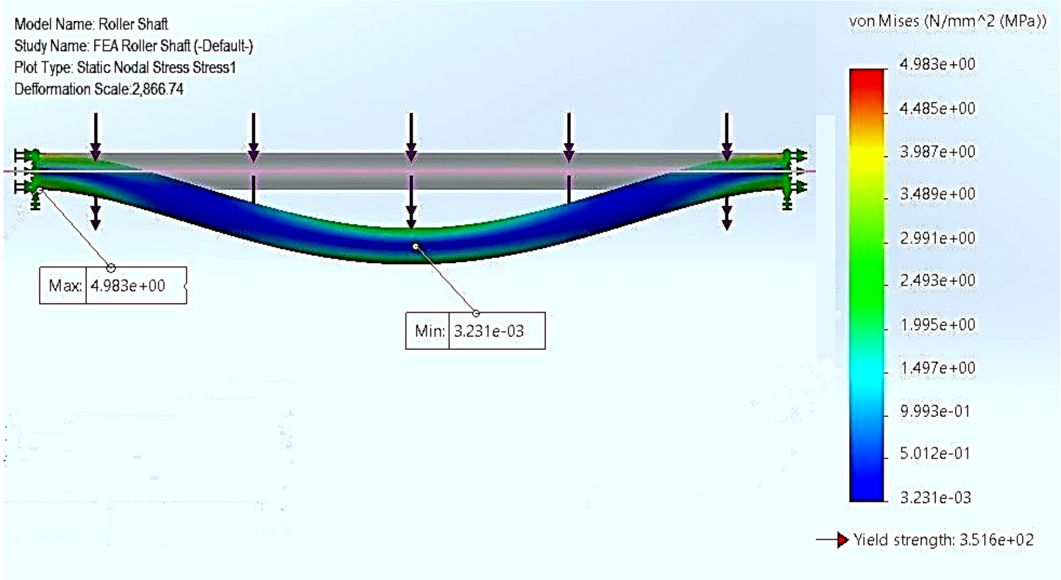

FIGURE 8(b). FEA analysis of shaft (A load of 150N distributed has been used for the analysis of the shaft).

The FEA analysis of roller and roller shaft was performed however the for the gear drive it was not considered essential. As from many observations, it was found that after longer service time the wear on the gears of rice milling machines is not considerable, so the FEA analysis of gear drive was not performed in this work.

DESIGN OF BLOWER

It is possible to use a Rice Hull Blower to dispense rice husks into containers by feeding them via a flexible hose from a hopper. An operator loads the hopper with the material. A rotating airlock is a next stop on the material's journey.

Large steel impellers are soldered to the shaft of this rotating airlock. The veins on the exterior of the casing provide a tight seal. While rotating, a pressured air stream picks up any material that falls into a void between the shaft's veins.

The substance is transported to its destination by way of the hose and an air jet. Devices called diffusers, which are just enlarged pipes, are located at the end of the line.

Instead of acting as a jet and forcing material out of the container, the longer pipe slows down the airflow, allowing the rice hulls to drop out of the end (Performance Evaluation 2017).

The design of the assembly is shown in Figure 9(a, b & c). The blower fan consists of 18 rectangular blade which creates a vacuum inside the blower casing and a pressure differential (Performance Evaluation 2017) so that the rice can pass inside the casing to the rollers through the frame opening. Typical dimensions of the blower fan are shown in Figure 9(a, b & c).

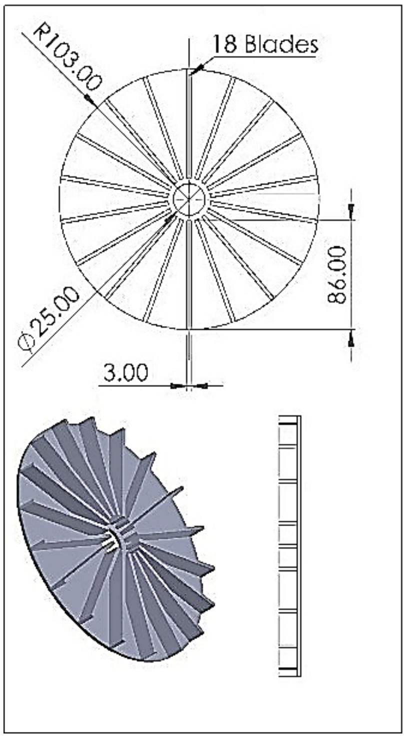

FIGURE 9 (a). Design &dimension blower fan, *(unit: mm)*

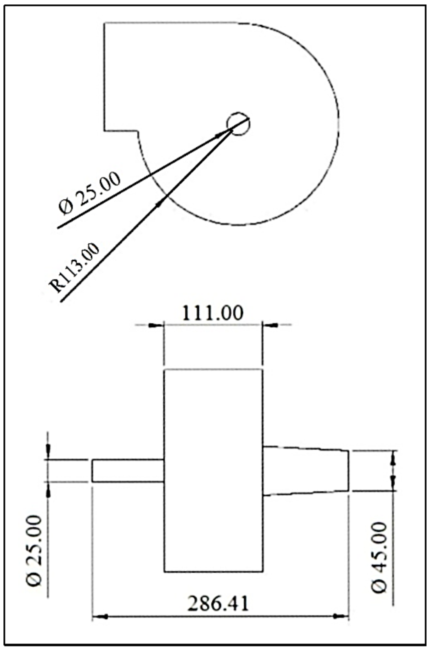

FIGURE 9 (c). Blower fan casing drawing *(unit: mm)*

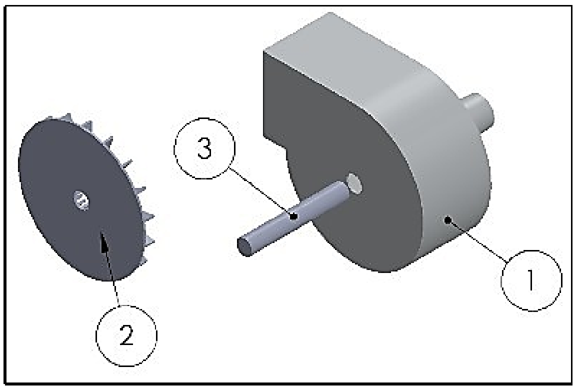

FIGURE 9 (c). Blower fan assembly schematic

SELECTION OF BEARINGS

Ball bearings are also used extensively to support the rollers and the roller shafts inside the frame and the choice of bearing extensively depends on the dimensions of the inner and outer ring. SKF bearings are widely available, and one can choose from their catalog the size of the bearing that is suitable. According to our requirements, W 63804-2RS1 SKF deep groove ball bearing has been used in the assembly.

RESULTS AND DISCUSSION

To achieve the maximum efficiency and production rate in a rice milling machine, the feed rate, rpm of the roller, and gap between the rollers are the most important parameters.

If the gap between the rollers is large, then a large amount of rice will pass through the rollers un-milled as insufficient normal and friction forces will be generated to remove the husk layer and moreover, if the rpm of the roller is too high, then there is a high probability that the milled rice would contain many broken kernels.

Finally, the feed rate should be optimized so that the rollers can mill every rice gain. Certainly, there are other parameters such as maximum power of the motor, but it doesn't directly affect the performance of the machine, but it limits the rpm and torque of the overall machine.

The driver motor for running the rice milling was also reduced to 2 horse power instead of 3 horse power. The reason of this alteration was to reduce the power consumption and also as this machine was aimed to process brown rice rather highly polished white rice. For processing highly polished white rice the number of rollers is more and require much more power for operation. Furthermore, this current rice milling was also aimed to run on solar power in future so a lesser power requirement should be suitable. As in Asia a lot of solar power is available and many works are reported of partial and complete small-scale machines running on solar energy (Haider et al. 2021), (Patel et al. 2022). The targeted market for this current model is Asia, as here brown rice is becoming more appealing. Specifications of the motor installed, are mentioned in Table 5.

TABLE 5. Motor Specifications

Sr. No.	Parameter	Value
1	Power	2HP
2	RPM (max)	1450
3	Weight (kg)	43
4	Voltage (input)	220-230
5	Product Code	NM 05

Similarly, the type of belt used doesn't affect the performance of the machine directly, but it is best practice to use a flat type of belt for low distances below 2 meters and V-belts for over 6 meters (Charles et al. 2004) because otherwise, the wear of the belt would be great, and it must be changed frequently.

Interestingly, the suction blower installed resulted in a higher feed rate and a lower percentage of broken kernels in the milled rice which increased the overall effectiveness of the rice milling machine. The impeller of the blower assembly was 3-D printed for lightweight construction to create a proper vacuum and to decrease the starting lag.

After the design process, different sheet metal and manufacturing techniques (Rice-mill-machine.com 2022) had been used to manufacture the machine as depicted in Figure 10. The machine contains a suction blower which is a new addition and helps in the intake of rice. This blower is usually not installed in the machine with the same specifications. The total cost of the machine is also lower compared to its counterparts in the market.

The complete breakdown is given in Table 5. To evaluate the costs and performance of the rice milling machine on different parameters (Folami et al. 2016), they were compared to currently available rice milling machines and the comparison can be seen in the Table 6.

TABLE 6. Cost of different components

Sr. No.	Part Name	Cost (Pkr)
1	Hopper	2000
2	Electric Motor and Pulleys	17000
3	Frame	5000
4	Main Chamber and Roller	8000
5	Suction Pump	10000
6	Roller Shaft (material)	1000
7	Roller Shaft (Labor)	1500
8	Miscellaneous	2500
9	Cost of Blower/Aspirator	8000
Total		55000

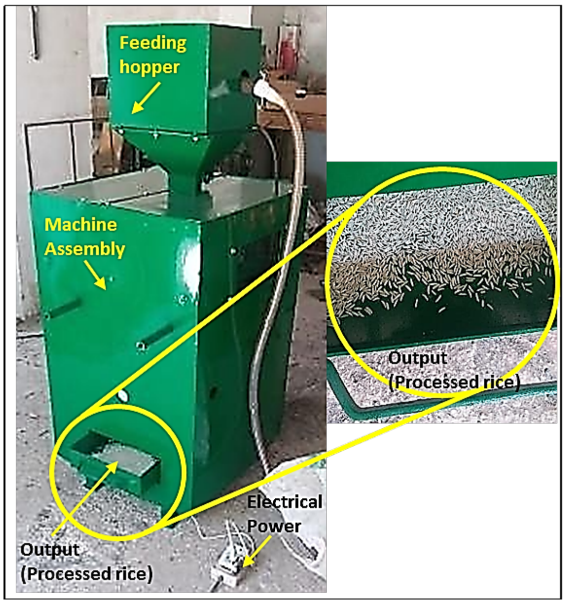

FIGURE 10. Manufactured Rice Milling Machine

Rice milling machine after its fabrication was evaluated for the performance and productivity. It was found that in the comparison of 3 horse power motor driven machines it was producing lesser processed rice, but in the long run the automatic feeding system was resulting in a continuous production. Moreover, this automatic feeding resulted in the manual labor reduction, with uninterrupted production rate.

Due to the single unit production of this model/prototype its cost was around 55000 Pkr, and as per estimation of mass production its cost would be reduced to 40000-45000 Pkr. As the aim of this milling machine was not only to provide a sustainable solution to small-sized requirements but also to ensure the local manufacturing of small and medium machinery for utilization and export.

TABLE 7. Comparison of different rice milling machines

Sr. No.	Specification	Current Model	Vinspire Agrotech	Vinglob Greentech	Rising Indsutries
1	Power HP	2	3	3	3
2	Production kg/hr.	100	200	150	200
3	Construction Material	Mild Steel	Mild Steel	Mild Steel	Mild Steel
4	Operation Mode	Auto	Semi-Auto	Auto	Auto
5	Cost Pkr	55,000	90,000	75,000	70,000

CONCLUSION

From the above discussion and analysis, the following conclusions are drawn.

1. A low-cost and light weighted rice mill design was aimed to analyze for cost-effectiveness and as a practical solution for small business holders and farmers.
2. For lower power consumption the motor of 2 HP was utilized instead of 3 HP, with the aim of running the machine on solar (PV) power.
3. An automatic feeding mechanism was introduced to enhance production and reduce manual feeding labor.
4. The objective of cost reduction, without compromising performance was satisfactorily obtained.

The machine parameters were also analyzed for performance improvements as this machine is utilized for brown rice which is healthier as compared to other rice, however, needs more processing and from analysis, it was found that,

1. The gap between the rollers had a major effect on the ratio of un-milled and milled rice at the exit of the machine.
2. The rpm of the roller was the main deterrent for the production rate of the milled rice and for the percentage of broken kernels.
3. Power from the main motors limited the rpm and torque being transferred to the other assemblies.
4. Flat type belt is a recommended choice for a rice milling machine.
5. Use of a suction blower increases the feed and production rate of the milled rice.
6. Light-weight impeller material of the blower decreases the starting lag of the impeller.

As the aim of this work was to empower the farmers that they should be able to process their own produced rice and sell it directly to the market, or to utilize it for their own needs. As the initial cost of this one machine is around 55000 Pakistani rupees, it is very much hopeful that the mass production of this machine shall further reduce the cost. Moreover, as Pakistan is a country with a sufficient amount of solar energy, this machine also has an adaptability to work via utilizing solar energy.

For future recommendations, it is advised that this unit should be run on solar (PV module) power, and its performance evaluation should be done for finding any potential hurdle that might be faced.

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DECLARATION OF COMPETING INTEREST

None

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