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Novel Solar Powered Winnowing Machine Design

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Abstract

India, a country with the second most fertile land and a diverse range of agro-climatic regions, is one of the world's largest producers of wheat, rice, pulses, and many other products. However, India's well-doing agricultural sector has started to shrink and is infested with massive inefficiencies. To this end, the paper proposes a novel design of a winnowing device that works on solar power that would inevitably increase the efficacy of the winnowing process. This device would make winnowing a lot faster with an efficiency of at least 95% while requiring minimal investment and also falling in line with the move to renewable power. Rural India faces a paucity of electricity while also being gifted with a hefty quantity of sunlight spread over long periods. Owing to this factor, the proposed machine works entirely on solar power and is self-sustainable, tackling the problem of less electricity available by using an abundant resource available to man. Winnowing in India is mainly labour-intensive, and the machines used also require significant investments, making it impossible for struggling farmers to buy it. However, the study aims to solve this issue and provide a solar-powered, self-sustainable, low-cost machine to make situations more hopeful for the farmers in India.

Keywords: Winnowing; Farming; Chaff; Grain; Solar Energy; Cost-Effective;

1. Introduction

India is a country with 60.4% [1] of its total land (159.7 million hectares [2]) being fertile land and an average of 7 hours and 20 minutes of sunlight each day [3]. These factors make India suitable to carry forward various types of farming at a large scale. However, despite all these natural conditions favouring India's primary sector, it is plagued with colossal inefficiencies discussed below. While the number of people involved in the agricultural sector in India is decreasing, for many crops like paddy and wheat, farming is still

Figure 1: Winnowing

predominantly labour-intensive due to a lack of efficient, affordable, and readily available machinery [4, 5, 6], particularly in rural areas, the hotspot of farming in India [7]. India majorly produces rice, wheat, millets, pulses, and vegetables [6], and a majority of these crops require a process called winnowing that farmers must do before it is ready to be sold. Winnowing is a process wherein the husk of the crop is separated from the grain. Traditionally, as seen in Figure 1, winnowing was done by sieving the grain from a height with the wind blowing in a particular direction to separate the chaff and the seed based on density, leading the chaff to blow away and create a pile further away from the farmer in comparison to the seeds. This process is very dependent on the natural wind and thus is very unreliable. However, to this day, a method very similar to this is used. Another problem with this method is that it is highly labour-intensive and thus time-consuming and inefficient. This, therefore, reduces the amount of crops the farmers can grow because due to this slow process, excess crops may start rotting before being wholly processed. Apart from this, this method requires plenty of space and is heavily climate dependent. Artificial wind can be created using high power fans; however, if sufficient room is not provided, the chaff and grain may not separate [8]. Along with this, if the weather is damp or dusty, then this process may become useless as it would make the crops prone to rotting faster or make them dusty and unhealthy to consume.

Due to these reasons, people have tried creating machines with which this process could be made easier. However, all these machines created are costly and are not favoured by the farmers of India.

2. The Existing Model

Winnowing machines in use today are very bulky, have huge electricity costs, and cause a lot of wastage. Most of them take input from the top wherein the farmer dump all the stalks of the crop and receive output from two ducts,

There are several issues with this machine, and hence is not preferred by Indian farmers. First and foremost, these machines require a lot of power to work. Machines available today require 1 to 5 kilowatt of electricity an hour to work as they are built on electric motor engines [11]. This is not very reasonable for the majority of farmers working in rural India as to date, getting sufficient and uncut power for all the necessary home appliances in these areas itself is a struggle [12], and burdening their system further with such power-hungry machines might compromise the safe working of all other appliances used at their homes.

Figure 2: The Existing Model

Apart from this, the machines are also very costly, with the commonly available machines amounting up to an average of 70,000 rupees ($940) [11]. This is a very high initial investment considering the fact that the average income of farmers in India is just Rs 4000 ($53.61) a month [13]. Buying this machine would cause them to spend at least 17 months' worth of their income. This is completely unreasonable as apart from this initial establishment cost, the cost of electricity and maintenance would make these machines a financial burden on the farmer rather than a valuable asset.

Furthermore, another drawback of this currently existing system is its inefficiency. While the fan would manage to separate the husk and the seed, due to a long, narrow, and common path was taken by both, the possibility of some portions of the husk mixing with grains and forming a heterogeneous mixture is highly possible. This would require the farmer to repeatedly winnow the produce to achieve a certain standard of separation. Due to this common duct where the husk is free to fly around randomly with the help of the high wind speed without necessarily being expelled, the husk may enter the duct for the grains and make the process a lot more cumbersome.

The repair costs for this machine would also be very high since they tend to have many moving parts and complex electronic wirings. In rural India, this kind of repair generally means frequent trips to the nearest city, causing the already high repair fees to be further bumped up.

An alternate design style for the winnowing machine is one wherein a rotating drum [9] is used. In this, the drum containing the chaff and the seed is continuously rotated, thereby keeping the chaff and seeds in a circular motion, leading them to experience a centripetal force. The drum has holes on its surface that allow air to circulate within the drum, allowing the air to pick low-density particles and blow out while also exposing an outlet for the other heavier, unwanted elements to leave the mixture [14].

While this is a different kind of mechanism, the power consumption, initial investment cost, and repair cost are very high. Apart from this, such a machine also increases the risk of damaging the seeds when spun at high speed, and the seeds may hit the drum's wall at high velocity and thus break. This would cause the product's value to fall and thus serve as a disadvantage to the farmers. Apart from this, these machines are not very readily available in India, further adding to the economic burden on the poor farmers of rural India, making it unusable.

Due to this wide variety of factors, farmers with already weak economic conditions are further burdened, making it a wrong choice for the farmer to invest in, creating a need for a cheaper, easier to use, and efficient model.

3. The Presented Model

The model that is being proposed is much better suited to meet the farmer's needs at a lower initial and power cost without compromising on the efficiency of the sorting. This machine is a lot more compact and runs using solar energy and basic computer cooling fans. As shown in Figure 3, this device has one funnelled input port and two output ports: one for the seeds and one for the

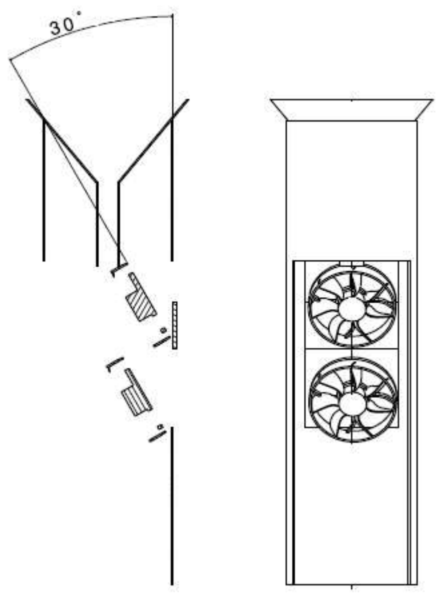

Figure 3: Visualization of the model

husk. Other features of the machine also include two fans at different levels and a lightweight casing to make it easily portable. All of these features help the machine make less mess and be more efficient and easy to use.

The machine takes an input consisting of the chaff and the grain from the conical hopper on the top. Once released, the mixture falls down a vertical PVC pipe wherein multiple fans blow wind at a certain angle to blow the chaff away. Right opposite these fans is an opening that has been optimized in size to provide a direct passage of flow for the separated chaff.

As stated before and seen in the diagram above, there are two such fans, making the whole process more efficient as any chaff that might have gone past the first fan would then be blown away by the second. While the chaff is getting separated, the grains would vertically fall down the central duct without disturbance as their density would cause them to be unaffected by the wind. In the end, two piles would be created wherein one has only grains while the other would have chaff. Buckets can be attached to the end of this machine to make the process tidier and help collect the two products.

All the fans would be connected to 1 solar panel, which would have to be kept in the sun during the day, as shown in Figure 4. The power requirement of each of these fans is just 3.36W, making using one solar panel to recharge a battery of decent size to power the entire system sufficient (calculations in next section).

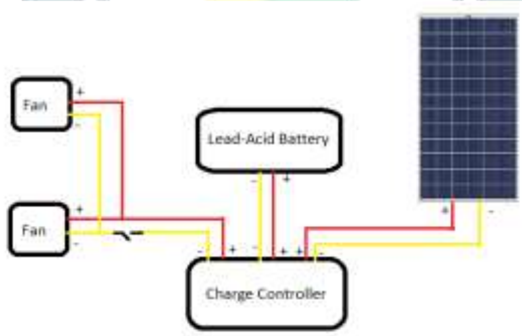

Figure 4: Electric Circuit Diagram

Due to all these different machine features, farmers would have no electricity bills, making it very affordable. The solar panels would also be small in size and manageable, reducing the amount spent on repairs. This device would also reach efficiency levels similar to the existing model today and help provide the farmers with a much better and feasible option.

Scale: All dimensions shown in the diagrams in the following sections have the unit of $\times 10^{-3} m$

3.1: Hopper

The hopper is made using a plastic funnel with a 0.025 m opening at the bottom to allow the mixture to flow through at a controlled rate to make it manageable for the machine. Dimensions for the hopper can be seen in Figure 5 below.

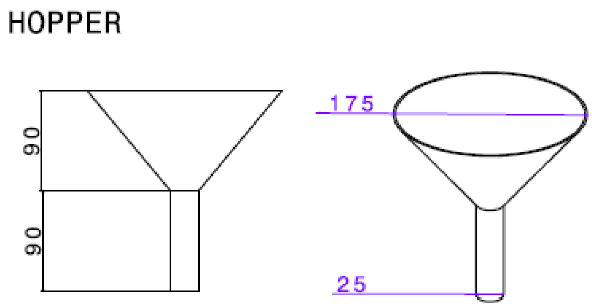

Figure 5: Hopper

3.2: Fans:

The fans have a dimension of 0.09 m x 0.09 m (as seen in Figure 6), 0.28 A current consumption, and wind speed generation of 3.71 m/s. They have been arranged at 30 degrees from the vertical (shown in Figure 3) to ensure the best results (see calculations in the next section).

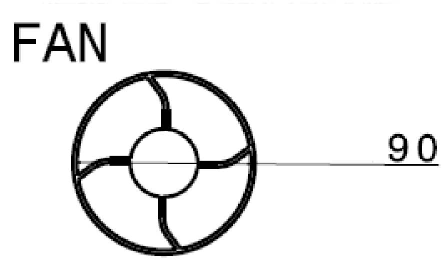

Figure 6: Fan

3.3: PVC Pipe:

The PVC pipe is 0.14 m wide to provide enough room for the husk to blow away while also preventing the rice grain from falling out and 0.5 m long to accommodate the two fans comfortably. The pipe also has an opening opposite to the side of the fans, which is 0.35 m long and 0.115 mm wide to provide enough room for all the husk to be blown out. These dimensions of the hole were determined experimentally to optimize the system and can be seen in Figure 7.

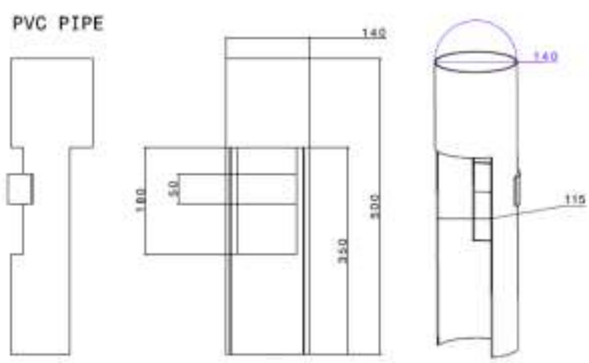

Figure 7: PVC Pipe Layout

3.4: Solar Panel:

The solar panel being used is a 12 V Solar panel with a power of 20 W and a short circuit current of 1.5 A (component sizing in next section). The size of the panel is 0.49 m x 0.35 m x 0.035 m.

3.5: Charge Controller:

The charge controller has a 12 V and 6 A rating. This module takes electricity from the panel without overcharging the battery and preventing the backward flow of electricity.

3.6: Sealed Lead Acid Battery:

The battery is a 12 V, 7.2Ah Sealed Lead Acid battery which is going to be charged by the panel. The sealed lead-acid battery is used because of its much cheaper prices than the Lithium-Ion batteries and fewer servicing requirements than the flooded lead-acid battery, helping make the model cheap. (component sizing in next section).

4. Calculations and Component Sizing:

The following is the discussion and calculations that have been done while developing the model:

4.1: Fan:

First, it was fundamental to decide upon the fan that would be used since it was responsible for separating the chaff and grains. The two choices available were either using a high-powered motor and an additional fan attachment or a computer cooling fan. The CPU cooling fan was then finalized to be the one used since it would be more cost-effective and easier for farmers to the source. The CPU cooling fans were also chosen because motor fan attachments of the required size were extremely difficult to find in the market. Post this, a medium-sized fan with a radius of 0.045m and an air displacement of 50 Cubic Feet per Minute (CFM) was finalized since it was the best fan in its size with good quality and reasonable price. Using the following calculations, the wind speed generated by the fan was found out:

CFM of fan= 50

Radius of fan= 0.045m

1 CFM= 1.69901 m^3/hr

Volume of air displaced per second= $\frac{50\times1.69901}{3600} = 0.023597 m^3/s$

Speed of Air from Fan= $\frac{0.023597}{\pi 0.045^2} = 3.71 m/s$

Following this, a series of calculations were done to determine the best angle to place the fan at:

Distance travelled by mixture before 1st fan=0.15m

Initial velocity= 0m/s

Acceleration due to gravity= 9.8m/s^2

$$v = \sqrt{u^2 + 2as}$$

$$v = \sqrt{0^2 + 2 \times 9.8 \times 0.15} = 1.72\text{m/s}$$

Considering Angle to be 30° from horizontal:

Vertical velocity of wind= 3.71cos30 = 3.21 m/s

Horizontal velocity of wind= 3.71sin30 = 1.86 m/s

Vertical force of the wind-

$$N_w = 0.5 \times \rho \times v^2 \times A$$
$$= 0.5 \times 1.225 \times 3.21^2 \times 13.5 \times 10^{-6}$$
$$N_w = 8.52 \times 10^{-5} N$$
$$\rho = density\ of air, v = velocity\ of\ air,$$
$$A = surface\ area\ of\ rice\ exposed$$

Mass of 1 rice grain= 2 X 10^{-5} kg

Weight of 1 rice grain= 2X 10^{-4} N

Net vertical force on rice grain= 8.52 X 10^{-5} + 2 X 10^{-4} = 2.85 X 10^{-4} N

Acceleration of rice grain-

$$a = \frac{2.85 \times 10^{-4}}{2 \times 10^{-5}} = 14.26\ m/s^2$$

Time spent in front of the fan-

$$s = ut + \frac{1}{2}at^2$$
$$0.06 = 1.72t + \frac{1}{2} \times 14.26 \times t^2$$
$$0 = 7.13t^2 + 1.72t - 0.06 = 0.031s$$

Horizontal distance moved by rice $= 0.031 \times 1.86$

$$= 0.0576\ m = 5.7cm$$

Considering Angle to be 45° from horizontal:

Vertical velocity of wind= 3.71cos45 = 2.62 m/s

Horizontal velocity of wind= 3.71sin45 = 2.62 m/s

Vertical force of the wind-

$$N_w = 0.5 \times \rho \times v^2 \times A$$
$$= 0.5 \times 1.225 \times 2.62^2 \times 13.5 \times 10^{-6}$$
$$N_w = 5.69 \times 10^{-5} N$$

Mass of 1 rice grain= 2 X 10^{-5} kg

Weight of 1 rice grain= 2X 10^{-4} N

Net vertical force on rice grain= 5.69 X 10^{-5} + 2 X 10^{-4} = 2.569 X 10^{-4} N

Acceleration of rice grain-

$$a = \frac{2.569 \times 10^{-4}}{2 \times 10^{-5}} = 12.85\ m/s^2$$

Time spent in front of the fan-

$$s = ut + \frac{1}{2}at^2$$
$$0.06 = 1.72t + \frac{1}{2} \times 12.85 \times t^2$$
$$0 = 6.425t^2 + 1.72t - 0.06 = 0.031s$$

Horizontal distance moved by rice $= 0.031 \times 2.62$

$$= 0.08122\ m = 8.1cm$$

Considering Angle to be 60° from horizontal:

Vertical velocity of wind= 3.71cos60 = 1.855 m/s

Horizontal velocity of wind= 3.71sin45 = 3.21 m/s

Vertical force of the wind-

$$N_w = 0.5 \times \rho \times v^2 \times A$$
$$= 0.5 \times 1.225 \times 1.855^2 \times 13.5 \times 10^{-6}$$
$$N_w = 2.85 \times 10^{-5} N$$

Mass of 1 rice grain= 2 X 10^{-5} kg

Weight of 1 rice grain= 2X 10^{-4} N

Net vertical force on rice grain= 2.85 X 10^{-5} + 2 X 10^{-4} = 2.285 X 10^{-4} N

Acceleration of rice grain-

$$a = \frac{2.285 \times 10^{-4}}{2 \times 10^{-5}} = 11.425\ m/s^2$$

Time spent in front of the fan-

$$s = ut + \frac{1}{2}at^2$$
$$0.06 = 1.72t + \frac{1}{2} \times 11.425 \times t^2$$
$$0 = 5.7125t^2 + 1.72t - 0.06 = 0.032s$$

Horizontal distance moved by rice $= 0.032 \times 3.21$

$$= 0.10272\ m = 10.3cm$$

Considering Angle to be 90° from horizontal:

Vertical velocity of wind= 3.71cos90 = 0 m/s

Horizontal velocity of wind= 3.71sin90 = 3.71 m/s

Vertical force of the wind-

$$N_w = 0.5 \times \rho \times v^2 \times A$$
$$= 0.5 \times 1.225 \times 0^2 \times 13.5 \times 10^{-6}$$
$$N_w = 0\ N$$

Mass of 1 rice grain= 2 X 10^{-5} kg

Weight of 1 rice grain= 2X 10^{-4} N

Net vertical force on rice grain= 0 + 2 X 10^{-4} = 2 X 10^{-4} N

Acceleration of rice grain= $a = \frac{2\times10^{-4}}{2\times10^{-5}} = 10\ m/s^2$

Time spent in front of the fan-

$$s = ut + \frac{1}{2}at^2$$
$$0.06 = 1.72t + \frac{1}{2} \times 10 \times t^2$$
$$0 = 5t^2 + 1.72t - 0.06 = 0.032s$$

Horizontal distance moved by rice $= 0.032 \times 3.71$

$$= 0.11872\ m = 11.9cm$$

Since the pipe diameter is 140 mm and the hopper would be releasing the mixture closer to the centre of the pipe, 60° from the horizontal was chosen to be the optimal angle.

4.2: Battery:

The battery was the next component to be finalized. It was decided that the fans mentioned above would be connected in parallel, and since each fan was of 12V and 0.28A, the rating of the battery was also decided to be 12V. Next, the duration for which the machine would be continuously working was approximated. For that, at least 6 hours was decided, which then helped calculate the capacity of the battery:

The current required to power the system: 0.56A
Hours to be used= 6 hours
Ampere hour= $0.56 \times 6 = 3.36$ Amp hour

Furthermore, the type of battery to be used was decided to be Lead Acid. Despite having a smaller life span, less efficient, and lower depth of discharge when compared to the Lithium-ion batteries, Lead-acid batteries were chosen because the experimental model required little energy to operate, and the battery's depth of discharge and efficiency would not matter if its size were considerably larger than the amount needed. This led to Sealed Lead-acid batteries being chosen because they were cheaper than lithium-ion batteries and safer than Flooded Lead Acid batteries [15, 16]. After finalizing these two details, the best possible battery available in the market to meet the project's needs was 7.2Amp hr with a maximum current of 2.16 A.
The maximum power of the battery was then calculated to be= 2.16 x 12= 25.92W

4.3: Solar Panel:

Given all the specifications of the battery, the details of the solar panel were decided next. The aim was to buy the cheapest solar panel that would meet the project's needs. For this, the power consumption of the fans was calculated, which came out to be 12 x 0.56= 6.72W. It was then decided that the panel's maximum power must be greater than the power consumption of the fans so that the energy in the battery never gets depleted and always has power in it to keep the system running. This led to the 20W solar panel being bought as the only readily available options were 10W and 20W, and the problem with 10W was that more often than not, the power it would be generating would be less than 7W leading to the 20W panel being the right fit.

4.4: Charge Controller:

The last component to be finalized was the charge controller. The only requirement was that it should be 12V and have two ports for the load so that the battery could also be used alternatively when the machine was not being used. So, the cheapest and most reliable option was chosen.

After the component sizing, all the parts were assembled to create the model, as shown in Figures 8 and 9.

Figure 8: Complete Set up

Figure 9: Close up of Winnowing Machine

5. *Costing*

Since one of the objectives of this project is to make it cost-efficient, the following are the prices of the components used:

Table 1: Parts and their costs

Component	Number Bought	Price per unit (inclusive of taxes)	Sub-total
CPU Cooling Fan	2	₹275 ($3.69)	₹550 ($7.38)
Charge Controller	1	₹492 ($6.60)	₹492 ($6.60)
Wire	2.5 meters	₹20 (0.27)	₹50 ($0.67)
Switch	1	₹7 ($0.094)	₹7 ($0.094)
PVC Pipe	0.5 meter	₹100 ($1.34)	₹50 ($0.67)
Hopper	1	₹50 ($0.67)	₹50 ($0.67)
Solar Panel (20-Watt)	1	₹1250 ($16.77)	₹1250 ($16.77)
Lead Acid Battery	1	₹650 ($8.72)	₹650 ($8.72)
White Oil Paint	1	₹80 ($1.07)	₹80 ($1.07)
		Total:	₹3179 ($42.65)

As can be seen, the cost of this entire set-up was just ₹3179 ($42.65) compared to the lakhs of rupees (thousands of dollars) charged by companies that sell their machine.

Along with the extremely low cost, all components are available online and can be fixed by any mechanic, making it much easier to service as well in case the machine gets damaged.

6. Testing, Results, and Analysis

To test the prototype's efficiency, a mixture of wheat grains and husk were weighed and put into the hopper. The contents of the output port were then separated by handpicking into husk and grains to reweigh and note how much of the original mass of each component was present in the output port.

While preparing the mixture, it is vital to ensure that the mixture should contain the maximum possible husk to grain ratio that farmers can encounter. So, logically, it was found that the highest ratio possible was 1:1 since each grain would peel to give only one husk. Therefore, we knew that an equal number of grains and husk should be present in the mixture.

To prepare the mixture quickly, 50 grains of wheat were weighed, and 50 whole husk pieces were weighed to find a ration in the mass. The grains weighed 2.22g (2.22×10^{-3} kg), while the husk weighed approximately 0.11g (0.11×10^{-3} kg), showing that the one husk particles constitute 5% of the mass of 1 grain.

Table 2: Results of testing

Test No.	Mass of husk before ($\times10^{-3}$ kg)	Mass of grains before ($\times10^{-3}$ kg)	Mass of husk after ($\times10^{-3}$ kg)	Mass of grains after ($\times10^{-3}$ kg)	Efficiency for husk	Efficiency for grain
1	1	20	0.04	16.42	96.00%	82.10%
2	1	20	0.05	15.98	95.00%	79.90%
3	2	40	0.10	33.07	95.00%	82.68%
4	2	40	0.12	32.85	94.00%	82.13%
5	3	60	0.14	47.90	95.33%	79.83%
6	3	60	0.17	47.54	94.33%	79.23%
				Average Efficiency:	94.94%	80.98%

Post this, three mixtures of different masses were made while keeping the husk and grains ratio constant. The result of the same can be found in the following Table 2.

As can be seen, the machine is highly efficient in clearing out the husk from the sample by reaching efficiencies of 95% and above. However, it can be seen that the amount of wheat that is collected at the output chute is only roughly 80% of the original value. This can be attributed to the wide range of mass of each grain, causing the extremely light ones to escape along with the husk possibly. Apart from this, a plastic bowl was used to collect the grains at the output chute, due to which many grains were bouncing out of the container.

7. Possible Modifications to Improve Machine

7.1: Cloth Bag:

A different utensil can be used to collect the grains at the output chute, which would have a damping effect and prevent the grains from bouncing out of the container. The ideal thing to be used is a cloth bag attached at the end. This collection system would allow the farmer to collect large amounts of grain without replacing the collection utensil frequently while also dampening the fall of the grains. It must be kept in mind that if a cloth bag is being used, the entire system must be suspended in the air to prevent the rice grain from bouncing off the floor.

7.2: Segregation Tube:

A tube can also be installed in place of the husk's opening to collect the husk more orderly. In a current manner, the husk is just blown out of the machine, laying scattered once through the opening, but installing a tube there would make collecting the husk also much easier for the farmer.

8. Conclusion

After analyzing all the data gathered using this machine and the price of components used, it can be ascertained that the proposed model is efficient at winnowing grains and has met its other goals of being cost-effective, renewable, and easy to repair. Barring a few minor modifications, this project does seem ready to use in the agriculture sector. This machine will be a significant help to all the farmers in India as it helps them reduce their processing time at low costs.

9. Declaration

Competing interests: None declared
Funding: None
Ethical Approval: Nor required

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