Solar-Powered Winnower for Resource Use Efficiency and Sustainable Agricultural Development

Abstract

Winnowing is an age-old agricultural practice that involves separating grain from impurities such as chaff, straw, and husk. The traditional method of using shovels and a sieve to allow the dried grains to fall from a height is time-consuming, uncomfortable, and requires significant manual labour. This approach can quickly tire out labourers, and wind availability can also pose limitations on traditional winnowing operations. Photovoltaic systems are now affordable, low-maintenance, and have lower operating costs compared to traditional electrical power systems. A solar photovoltaic powered winnower was developed and evaluated at the College of Renewable Energy and Environmental Engineering, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar. The bulk density of wheat and pearl millet were found to be 770 kg/m3 and 825 kg/m3, respectively, with an average angle of repose of 34.25 and 27.35 degrees. The performance evaluation of the winnower was conducted at different feed rates for wheat and pearl millet crops. The feed rates for wheat were 110 kg/h, 130 kg/h, 150 kg/h, 170 kg/h, and 190 kg/h, while for pearl millet, they were 480 kg/h, 520 kg/h, 560 kg/h, 600 kg/h, and 640 kg/h. 110 kg/h feed rate was found to be the most suitable for wheat as it resulted in the highest cleaning efficiency of 95.86%, with the lowest grain loss of 0.36% and operating cost of 0.83 ₹/kg. After conducting various tests for pearl millet, it was determined that a feed rate of 480 kg/h was the most suitable. This rate resulted in the best cleaning efficiency of 96.17%, the lowest blow of grain at 0.67%, and the lowest operating cost at 0.19 ₹/kg. The total cost of the Solar Powered Winnower was ₹ 56515.

Keywords: Winnower, Solar Power, Photovoltaic (PV).

Introduction

Winnowing is an agricultural method developed by ancient cultures for separating grain from foreign material like chaff, straw, husk. It involves simple process like throwing the mixture into the air so that the wind blows away the lighter chaff, while the heavier grains fall back down for recovery. The traditional method of using shovels and a sieve to allow the dried grains to fall from a height is time-consuming, uncomfortable, and requires significant manual labour.

The available solar energy in tropical countries like India can be efficiently utilized to provide the source power supply for the post-harvest operations like grain winnowing. In such conditions, solar photovoltaic powered winnower is useful in areas with no utility lines. Photovoltaic systems are often less expensive and require less maintenance and operating cost than conventional electrical powers.

A solar photovoltaic powered winnower was developed and evaluated at College of Renewable Energy and Environmental Engineering, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar Nagar (2023). The developed winnower was tested for varieties of wheat (*GW-451*), pearl millet (*GHB-1129*) and operational parameters were reported.

Objectives

1. To design and development of solar powered winnower
2. To evaluate the performance of the developed solar powered winnower.

3.0 Material and Methods

This chapter deals with the development process and performance evaluation of solar powered winnower. The stepwise methodology is given as under.

i. General consideration for the development of solar-powered winnower for farmers
ii. Terminologies related to grain cleaning
iii. Determination of specifications and selection of various components
iv. Physical Properties of wheat and pearl millet
v. Lab testing and field evaluation of solarpowered winnower
vi. Economic evaluation of solar-powered winnower vii. Instruments used during study

3.1 Key design parameters

i. Selection of unit

A.C. Motor

ii. Determination of wattage of unit

Load	Wattage (w)
A.C. Motor	746 W

iii. Determination of running hours of loads

Load	Number	Wattage	usage
A.C. Motor	1	746	8 hours

iv. Determination of total load

Total load =$1\times 750 \times 8$

Total load =6000

Hence, designed a PV system capable of meeting the daily energy demand of 6000 Wh/day for this motor.

v. Number of PV modules required

$$\text{Array size} = \frac{Array\ load}{insolation \times mismatch\ factor}$$

$$\text{Array size} = \frac{6000}{5.65 \times 0.85}$$

$$\text{Array size} = 1249.34 \text{ Wp}$$

Thus, modules that can deliver 1250 W_p was selected.

3.2 Determination of angle of repose

The angle of repose was calculated by using equation (Varnmakasti et al., 2007)

$$\theta = \tan^{-1}\frac{2H}{D}$$

Where,

ϴ= Angle of repose, degree

H= Height of cone, mm

D= Diameter of cone, mm

3.3 Determination of bulk density

The bulk density of wheat was determined by placing the wheat in container of cylindrical shape. The volume of container was found by measuring diameter and height of cylindrical container. The weight of wheat and pearl millet were measured by using an electric weighing balance. Bulk density of available wheat (GW-451) and pearl millet (GHB-1129) were determined. The bulk density was calculated by using equation (Varnmakasti et al., 2007)

$$\text{Bulk density}\left(\frac{kg}{m^3}\right) = \frac{weight\ of\ sample, kg}{volume\ occupied\ by\ sample, m^3}$$

3.4 Determination of moisture content

The moisture content of wheat (GW-451) and pearl millet (GHB-1129) were measured with the help of hot air oven by oven dry method. The sample with the known weight was kept in oven at +105ºC till the constant weight. The moisture content of sample was determined as per (ASTM D-3173).

$$\text{Moisture content(\%wb)} = \frac{W_2 - W_3}{W_2 - W_1} \times 100$$

Where,

W_1 = weight of empty box, g

W_2 = weight of empty box + sample, g

W_3 = Weight of empty box + sample after drying, g

3.5 Determination of grain and straw ratio

The grain ratio was determined by dividing weight of grain in sample to the weight of the total sample. The weight of grains and weight of straw were measured separately from a selected lot of total samples.

$$\text{Grain and straw ratio} = \frac{Weight\ of\ grain\ in\ sample}{Total\ Weight\ of\ sample}$$

3.6 Air velocity

Air velocity at distance of 10 inch was measured with the help of anemometer.

3.7 Field testing of solar powered winnower

The solar photovoltaic winnower was tested for varieties of wheat and pearl millet namely GW-451 and GHB-1129. The performance of solar powered winnower was conducted at 10-inch distance from the centrifugal blower and at constant feed rate for wheat 110 Kg/h and for pearl millet 480 Kg/h. Testing was carried out as per RNAM test code. The various parameters like feed rate (kg/h), cleaning efficiency (%), blown grain (%) and power consumption (W) were determined as follows.

i. Feed rate

The solar powered winnower was evaluated for performance at 10-inch distance from centrifugal blower at feed constant feed rate. It was determined as,

$$\text{feed rate (kg/h)} = \frac{weight\ of\ wheat\ mixture, kg}{operating\ time, h}$$

ii. Percentage of blown grain

$$\text{Percentage of blown grain} = \frac{F}{A} \times 100$$

Where,

F = quantity of whole grain collected at chaff outlet per unit time, kg

A = Total grain input per unit by weight, kg

iii. Cleaning efficiency

$$\text{Cleaning efficiency} = \frac{I}{J} \times 100$$

Where,

I = Weight of whole grain per unit time at main grain outlet, kg

J = Weight of whole material per unit time at the main outlet, kg

iv. Measurement of energy consumption

Energy consumption for winnowing was calculated by voltage and current which measured by clamp meter.

3.8 Analysis of solar powered winnower for operational difficulties

Field testing operational difficulties were found as follows

i. Irregular inflow of feed from hopper.

During field testing, it was observed that, feed hopper outlet was frequently clogging and interlocking grains and straw.

3.9 Economic Evaluation of Solar Powered Winnower

The economic evaluation of solar powered winnower was carried as per RNAM test code in terms of fixed cost, variable cost, total cost and operating cost as Rs/kg of wheat and pearl millet. The economic values were compared with different winnowing systems like manual operated fan and manual winnowing.

4.0 Results and Discussion

This chapter deals with the results obtained from the study undertaken with the objectives for performance evaluation of solar powered winnower. The results obtained in this study were presented and evaluated under the following sub headings.

4.1 Physical properties of wheat and pearl millet.

4.2 Performance evaluation of solar powered winnower.

4.3 Economic evaluation of solar powered winnower.

4.1 Physical properties of wheat and pearl millet.

Table 1 shows the mean value of angle of repose and bulk density for wheat and pearl millet were found 34.25 and 27.35 degree and 770 kg/m^3 and 825 kg/m^3, respectively.

Table 1: Physical properties of wheat and pearl millet

Sr. No.	Wheat		Pearl millet	
	Angle of repose, degree	**Bulk density, kg/m^3**	**Angle of repose, degree**	**Bulk density, kg/m^3**
1	33.75	765.00	26.72	822.00
2	34.50	790.00	27.35	830.00
3	34.75	755.00	28.49	827.00
4	34.25	765.00	26.56	818.00
5	34.00	775.00	27.63	828.00
Mean	**34.25**	**770.00**	**27.35**	**825.00**

4.2 Performance evaluation of solar powered winnower.

The solar operated winnower was evaluated at constant feed rate of 110 kg/h for wheat and 880 kg/h for pearl millet (Kadam and Dhande, 2016, Jagadale et al., 2017)

4.2.1 Cleaning Efficiency

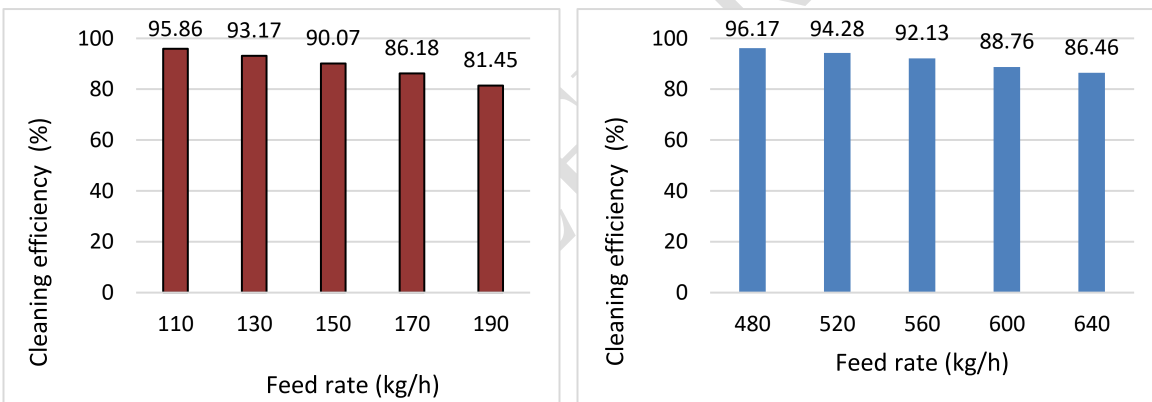

Fig. 1 Cleaning efficiency of wheat and pearl millet with respect to feed rate

The study revealed that the cleaning efficiency for wheat ranged from 81.45% to 95.86%, and for pearl millet, it ranged from 86.46% to 96.17%, depending on the feed rate. The highest cleaning efficiency for wheat was observed at a feed rate of 110 kg/h, with a cleaning efficiency of 95.86%. For pearl millet, the highest efficiency was observed at a feed rate of 480 kg/h, with a cleaning efficiency of 96.17%.

4.2.2 Blown grain with respect to federates

During an experiment, it was observed that increasing the feed rate for wheat and pearl millet had an impact on the amount of blown grain. When the feed rate was set to 110 kg/h for wheat and 480 kg/h for pearl millet, and the grain was blown from 10 inches away from the blower, the amount of blown grain was 36% and 0.67%, respectively.

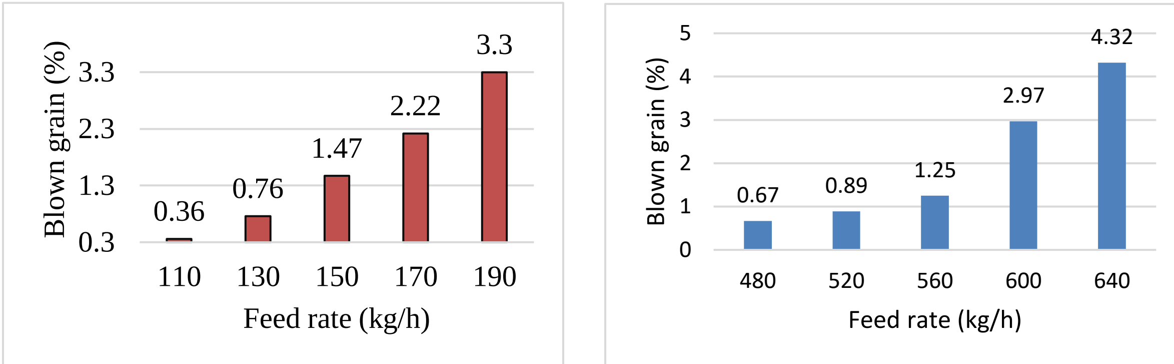

Fig. 2 Blown grain of wheat and pearl millet with respect to feed rate

Increasing the feed rate to 130 kg/h for wheat and 520 kg/h for pearl millet resulted in a blown grain of 0.76% and 0.89%, respectively. A further increase to 190 kg/h for wheat and 640 kg/h for pearl millet resulted in a blown grain of 3.3% and 4.32%, respectively. This clearly indicates that as the feed rate was increased, the amount of blown grain also increased

It was observed that, when we set the feed rate 110 kg/h for wheat and 480 kg/h for pearl millet at 10 inches from the blower blown grain were 0.36 per cent and 0.67 per cent. When feed rate was 130 kg/h blown grain was 0.76 per cent for wheat, 520 kg/h blown grain was 0.89 per cent for pearl millet, at 190 kg/h blown grain was 3.3 per cent for wheat and 640 kg/h blown grain was 4.32 per cent. that clearly shows us when we increase feed rate blown grains was also increased.

4.2.3 Time taken for wheat and pearl millet with respect to feed of mixture

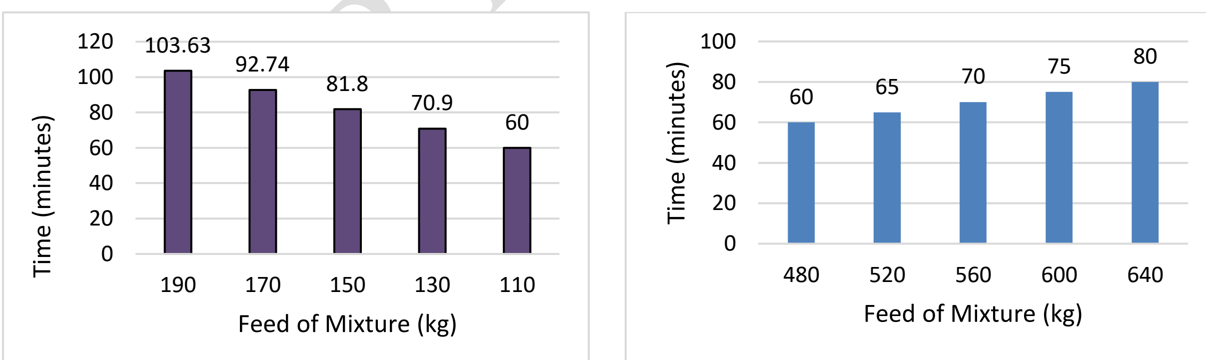

Fig. 3 Time taken for wheat and pearl millet with respect to feed of mixture

It was observed that, it took 60 minutes when 110 kg of wheat was added and 480 kg of pearl millet was added. When 130 kg and 150 kg of wheat were added, it took 70.9 minutes and 81.8 minutes. when 520 kg and 560 kg of pearl millet were added, it took 65 minutes and 70 minutes.

4.2.4 Power consumption for wheat and pearl millet with respect to feed of mixture

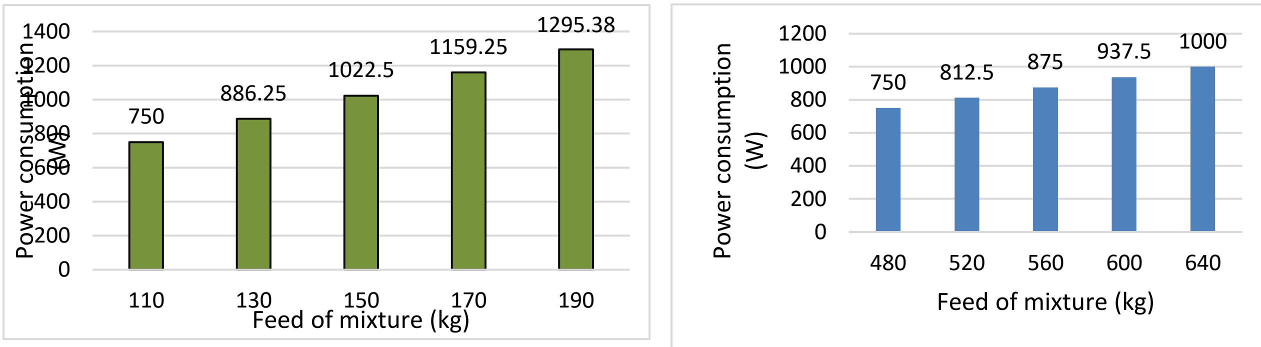

Fig. 4 Power consumption for wheat and pearl millet with respect to feed of mixture

Power Consumption were found varies from the 750 Watt to 1295.38 Watt for wheat and 750 Watt to 1000 Watt for pearl millet at different feed of mixture. The maximum Power Consumption were found 1295.38 Watt at 190 kg feed of mixture for wheat and 1000 Watt at 640 kg feed of mixture for pearl millet. Minimum Power Consumption were found 750 Watt with 110 kg feed of mixture for wheat and 480 kg feed of mixture for pearl millet. The Power Consumption was continuously increased with increased the feed of mixture because when we feed a more mixture it takes more time to clean that’s why power consumption was increased.

4.3 Economic evaluation of solar powered winnower.

The economic parameters of solar powered winnower for the feed rate of 110 kg/h (wheat) and 480 kg/h (pearl millet) were carried out the result obtained is summarized in Table2.

Table 2 Economic evaluation of solar powered winnower

Sr. No.	Economical parameters	Particulars	
		Wheat	Pearl millet
1.	Cost of solar operated winnower (₹)	56515	56515
2.	Total fixed cost (₹/h)	21.77	21.77
3.	Total variable cost (₹/h)	70.57	70.57
4.	Capacity of winnower (kg/h)	110	480
5.	Operational cost (₹/kg)	0.83	0.19

It was observed that, the operating cost of solar operated winnower was found to be 0.83 ₹/kg for the feed rate 110 kg/h for wheat and 0.19 ₹/kg for the feed rate 480 kg/h for pearl millet. which is less than manual operated fan 1.73 ₹/kg (wheat), 0.40 ₹/kg (pearl millet) (M/s. Benson Agro Engineering), manual winnowing operation 1.25 ₹/kg (wheat), 0.89 ₹/kg (pearl millet). Thus, the performance of solar powered winnower is economically feasible than manual operated fan and manual winnowing operation.

It was revealed that, solar powered winnower had very low operating cost than manual operated fan and manually winnowing operation. There was no need of electricity to operate the solar operated winnower.

5.0 Conclusion:

The average angle of repose and bulk density of wheat and pearl millet were found 34.25 and 27.35 degree and 770 kg/m3 and 825 kg/m3, respectively. Performance evaluation of the winnower was carried out for feed rate of 110 kg/h, 130 kg/h, 150 kg/h, 170 kg/h and 190kg/h for wheat crop and 480 kg/h, 520 kg/h, 560 kg/h, 600 kg/h and 640 kg/h for pearl millet. For wheat 110 kg/h feed rate was found most suitable as it registered best cleaning efficiency of 95.86 per cent, minimum blow of grain i.e., 0.36 per cent and lowest operating cost of 0.83 ₹/kg. For pearl millet 480 kg/h feed rate was found most suitable as it registered best cleaning efficiency of 96.17 per cent, minimum blow of grain i.e., 0.67 per cent and lowest operating cost of 0.19 ₹/kg. The total cost of Solar Powered Winnower worked out was ₹ 56515/-

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