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Techno-economic feasibility of the solar-powered vermi-compost sieving machine

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Abstract

Vermicomposting is a sustainable organic waste management technique, yet the post-processing stage of sieving vermicompost remains labour-intensive and time-consuming. This study evaluates the techno-economic feasibility of a solar-powered vermicompost sieving machine as a substitute for conventional manual sieving. The machine was assessed on the basis of capital cost, operational cost, labour savings, output capacity, profit/loss analysis, benefit-cost ratio, payback period, and break-even point. Results indicate that the solar-powered sieving machine achieves a total annual output of 3,600 quintals at a total cost of Rs. 88,875 per year, with a benefit-cost ratio of 5.0 and a payback period of only 0.19 years. The machine processes 500 kg h⁻¹, compared to only 120 kg h⁻¹ by manual method, representing a fourfold increase in throughput. The integration of solar energy eliminates electricity costs and promotes eco-friendly agricultural mechanization. The findings strongly support large-scale adoption of the machine for sustainable and profitable organic farming operations.

Keywords: Vermicompost, Solar energy, Sieving machine, Techno-economic analysis, Benefit-cost ratio, Organic farming, Sustainable agriculture

Introduction

Vermicomposting is a decomposition process involving interactions between earthworms and microorganisms (Domínguez *et al.*, 2009) [1]. The growth of earthworms in organic wastes has been termed vermiculture, and the managed processing of organic wastes by earthworms to produce casts is termed vermicomposting (Edwards *et al.*, 2010). Since its scientific development and widespread adoption during the late twentieth century, vermicomposting has gained global recognition as an effective waste management strategy that simultaneously improves soil fertility, enhances nutrient availability, and supports sustainable agricultural production (Edwards and Bohlen, 1996; Domínguez and Edwards, 2011) [4]. Among the commonly used earthworm species, *Eisenia fetida* is the most widely preferred worldwide because of its rapid reproduction, high waste conversion efficiency, and adaptability to diverse environmental conditions. In tropical regions, particularly India, *Perionyx excavatus* and *Eudrilus eugeniae* are also extensively used owing to their fast growth and efficient vermicomposting performance (Suthar, 2007). In India, vermicompost production is widely practiced through farmer-level units, self-help groups and commercial units. According to the National Centre of Organic Farming (NCOF, 2021), India produced/registered about 3.73 lakh tonnes of vermicompost during 2020-21, while the reported production was about 26.60 lakh tonnes during 2019-20 as documented by NCOF (2020). These figures represent state-reported production/availability and may not include all farm-level vermicompost produced and used directly by farmers. It generally has a fine granular structure, dark brown to black colour, earthy smell, good porosity and high moisture-holding capacity. These physical properties make vermicompost suitable for improving soil structure, aeration and water retention (Edwards and Arancon, 2004).

Sieving is the process of separating fine mature vermicompost from earthworms, cocoons, undecomposed residues and larger particles. Common methods include manual hand sieving, rotary drum sieving and vibrating/mechanical sieving (Kabudake *et al.*, 2020). Rotary sieving is more suitable for large-scale use because it reduces labour, saves time and gives more

uniform vermicompost (Gómez-Águila *et al.*, 2022). The main objective of the research was to design and develop a solar-powered vermicompost sieving machine for efficient separation of fine vermicompost from coarse particles, earthworms and undecomposed residues. The study also aimed to evaluate the performance of the machine in terms of sieving efficiency, output capacity, power requirement and operational suitability. This machine designed for the sieving vermicompost from two in one action because the hammer shaft set in sieving cylinder and rotating opposite direction of cylinder. In this machine used the DC motor. Further, the research focused on optimizing the operating parameters and assessing the techno-economic feasibility of the machine by comparing it with the traditional manual sieving method. The main purpose of the research, this analysis incorporates several cost parameters, including maintenance, wear and tear, energy consumption, and the labor required to operate the machine. The primary objective of this study is to evaluate the economic feasibility of the vermicompost screening machine. To accurately assess its techno-economic feasibility, a break-even point analysis, payback period calculation, and cost-benefit ratio analysis were conducted (Singh *et al.*, 2023). The main aim of this paper was to analyze the total cost of the machine and determine the feasibility and economic viability of a solar power vermicompost sieving machine for farmers, local and small manufacturer.

Discription and working principle of solar-powered vermicompost sieving machine

The developed solar-powered vermicompost sieving machine consisted of a feeding hopper, rotary sieving drum, hammer unit, main frame, DC motor, pulley-belt transmission system and solar photovoltaic power unit. The machine works on the principle of rotary screening and size separation. Solar energy received by the photovoltaic panels is converted into electrical energy and supplied to the DC motor through the battery and control unit. The motor transmits power to the rotating sieving drum and hammer shaft through the belt-pulley mechanism. When mature vermicompost is fed through the hopper, the rotating drum continuously agitates the material, allowing fine vermicompost particles to pass through the selected mesh openings, while coarse particles, undecomposed residues, stones and impurities are discharged from the outlet. The

hammer unit breaks small lumps and improves the flow of material, resulting in uniform and efficient sieving of vermicompost. A 48 V, 1000 W DC motor was used to provide the necessary speed to the machine. The machine consumes maximum 0.264 kWh of electricity. The total cost of the sugarcane peeling machine was ₹75,000.

Materials and Methods

During testing, the machine was evaluated based on several independent and dependent parameters. Independent parameters included sieve size, RPM, feeding rate, and moisture percentage, while dependent parameters included screening efficiency, throughput capacity, material loss, and power consumption. The machine's daily operational capacity was set at 8 hours; however, prior to economic evaluation, the machine was optimized using a 'Full Factorial Experimental Design' (CRD). The machine's capacity was assessed by operating it for 8 hours a day with one laborer. Electricity costs were excluded from the operational expenses, as solar energy units are available on most farms. The economic analysis factored in the average daily wages for unskilled (₹500) and skilled (₹800) labourers in India, based on data provided by the U.P. Labour Commissioner for April 1, 2026 (Anon., 2026). The machine was compared against a manually operated vermicompost screen—which requires a third person for feeding—over an 8-hour vermicompost screening process. Both manual and machine work was conducted in similar environmental conditions.

Fixed Cost Per Annum

The fixed annual cost is a summation of the interest cost, depreciation cost, insurance cost and housing tax per year of the machine. The annual charges of interest were calculated as 10% average investment on the machine (BIS: 9164-1979) ^[5]. The useful life of the power-operated chaff cutter was described to be 10 years (Sunil *et al.* 2016) ^[11]; on this behalf, the useful life of the machine was taken 10 years. The salvage value of the machine was taken 10% of the purchase price (Mishra *et al.*, 2017) ^[6]. The formula for interest rate, depreciation cost, insurance cost and house tax is given in Eq. 1, 2, 3 and 4, respectively.

Total fixed cost (Rs/year)

$$\begin{aligned}
 &= \text{Depreciation} + \text{Interest} + \text{Insurance} + \text{House Tax} \quad \dots\dots\dots 1 \\
 \text{Depreciation cost} &= \frac{\text{Machine Cost} - \text{Salvage Value}}{\text{Useful life of machine (year)}} \quad \dots\dots\dots 2 \\
 \text{Interest Value} &= \frac{\text{Machine Cost} + \text{Salvage Value}}{2} \times \text{Interest rate}\% \quad \dots\dots\dots 3 \\
 \text{Insurance} &= 2\% \times \text{cost of machine} \quad \dots\dots\dots 4 \\
 \text{House tax (H)} &= 1\% \times \text{cost of machine} \quad \dots\dots\dots 5
 \end{aligned}$$

Variable cost per annum

The variable cost of the machine involves repair and maintenance cost of the machine which was considered 5% of the machine cost (Singh and Mehta, 2015) ^[9], operator cost and the electricity charges are also included in the variable cost of the machine. The formula for calculation of operator cost of the workers and total variable cost is given in Eq. 5 and 6, respectively.

$$\text{Operator cost} = \text{Daily charge} \times \text{Working hours of the machine in a year} \quad \dots\dots\dots 6$$

$$\begin{aligned}
 \text{Total variable cost per annum} &= \text{Repair and maintenance cost} \\
 &+ \text{Operator cost} + \text{Electricity cost} \quad \dots\dots\dots 7
 \end{aligned}$$

Total operational cost of machine per annum

The total operational cost of the machine per annum was the summation of the fixed cost and variable cost of the machine.

Total operational cost of machine (Rs/year) = Total fixed cost + Total variable cost 8

Calculation of sieving cost by machine (Rs/quintal)

$$= \frac{\text{Total operational cost of the machine (Rs / year)}}{\text{Machine productivity (q/year)}} \dots\dots\dots 9$$

Machine Productivity per Year

Machine productivity per year is the total quantity of material processed by a machine in one year. It depends on the output capacity of the machine and the total annual operating hours. In farm machinery evaluation, annual productivity is calculated by multiplying machine capacity with yearly working hours (Kepner *et al.*, 1978; Hunt, 2001).

Machine productivity per year = Machine capacity (kg/h) × Operating hours per year 10

Benefit-Cost Ratio (BCR)

Benefit-cost ratio is an economic indicator used to judge whether a machine or technology is financially feasible. It is calculated by dividing the annual monetary benefit or saving obtained from the machine by the annual cost of operation. If the BCR is greater than 1, the machine is considered economically viable (Hunt, 2001; Kepner *et al.*, 1978).

$$\text{Benefit Cost Ratio} = \frac{\text{Annual benefit or saving}}{\text{Operational cost of the machine}} \dots\dots\dots 11$$

Payback period

The payback period of the machine was calculated by dividing the operational cost of the machine by the annual profit of the machine

$$\text{Payback period} = \frac{\text{Operational cost of the machine}}{\text{Annual profit}} \dots\dots\dots 12$$

Break-even point

For a vermicompost sieving machine, the break-even point per quintal indicates the minimum quantity of vermicompost that must be sieved annually to recover the machine cost.

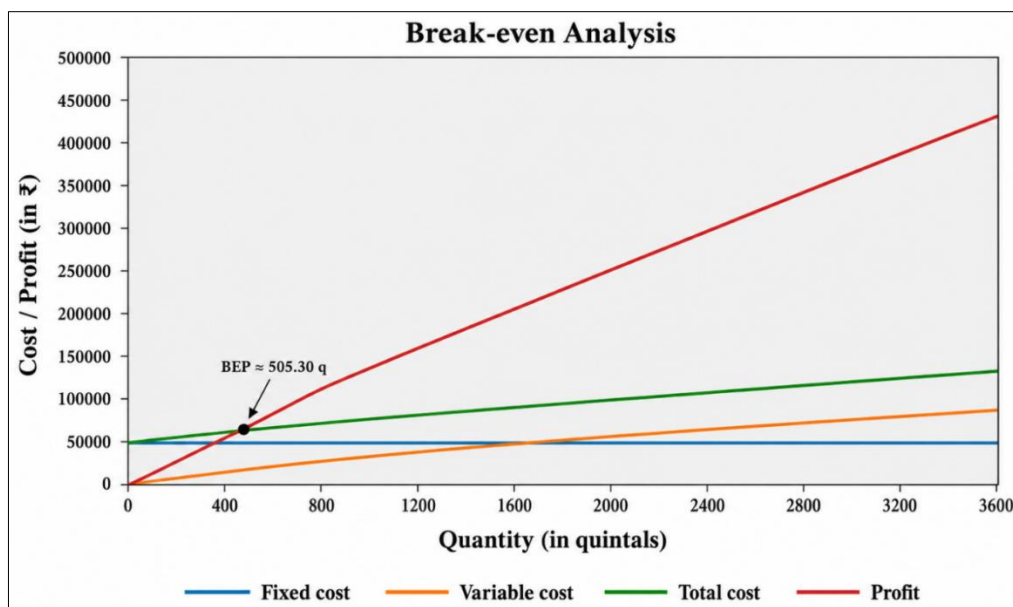
$$\text{Payback period} = \frac{\text{Fixed Cost}}{\text{profit}(\frac{\text{₹}}{\text{Quintal}}) - \text{Variable Cost}(\frac{\text{₹}}{\text{Quintal}})} \dots\dots\dots 13$$

Results and Discussion

S. No.	Parameter	Value
	Cost of Machine with Panel	= ₹ 75,000 + ₹ 2,00,000 = ₹ 2,75,000
1	Fixed Cost Depreciation Cost per year @10% (₹) Interest cost per year @10% (₹) Insurance cost per year @2% of machine cost (₹) Housing tax per year @1% of machine cost (₹) Total fixed cost per annum (₹)	₹ 24750 ₹ 15125 ₹ 5500 ₹ 2750 ₹ 48125
2	Variable cost per annum (₹) Repair and maintenance @ 5% of machine cost (₹) Wages (₹) of one worker per annum Electric charges per annum Total variable cost per annum (₹)	₹ 13750 ₹ 72000 ₹ 00 ₹ 85750
3	Total operational cost of machine per annum (₹)	₹ 133875
4	Machine's productivity per annum sieving cost of the machine (V/q)	₹ 37.19/q
5	Wages of three workers for manual peeling of sugarcane Capacity of manual peeling of three workers (q/day) Cost of manual peeling of sugarcane (₹/q)	₹ 1500 9.6 ₹ 156.25/q
6	Saving/profit per quintal (₹/q)	₹ 119.06
7	Saving/profit per year (₹/year)	₹ 4,28616
8	Benefit cost-ratio	3.20
9	Payback period (year)	0.31 year
10	Break-even point	505.30 q

The techno-economic evaluation demonstrated that the developed solar-powered vermicompost sieving machine is both technically efficient and economically feasible for commercial vermicompost production. The total capital investment of the machine, including the solar photovoltaic system, was ₹2,75,000, resulting in an annual fixed cost of ₹48,125, comprising depreciation, interest, insurance, and housing tax. The annual variable cost was estimated at

₹85,750, of which labour constituted the major component, while electricity cost was eliminated through the utilization of solar energy. Consequently, the total annual operational cost was ₹1,33,875. With a machine capacity of 500 kg/h, the annual productivity reached approximately 3,600 quintals, resulting in a screening cost of only ₹37.19 per quintal, compared with ₹156.25 per quintal for the manual method.



The machine generated a net saving of ₹119.06 per quintal and an annual profit of ₹4,28,616 over conventional manual screening. Furthermore, the benefit-cost ratio of 3.20, payback period of 0.31 year, and break-even point of 505.30 quintals clearly indicate the financial viability and rapid investment recovery of the developed machine. These findings confirm that the integration of solar photovoltaic technology with mechanized vermicompost screening substantially reduces operating costs, enhances processing capacity, and provides a sustainable and profitable alternative for commercial organic waste management.

Conclusion

The present study demonstrated that the developed solar-powered vermicompost sieving machine is a technically efficient, economically viable, and environmentally sustainable alternative to conventional manual vermicompost screening. The integration of a photovoltaic power system eliminated electricity costs while maintaining a high processing capacity of 500 kg/h, which was more than four times greater than the manual screening capacity. The techno-economic analysis revealed a low screening cost of ₹37.19 per quintal, a benefit-cost ratio of 3.20, a payback period of only 0.31 year, and a break-even point of 505.30 quintals, confirming the rapid recovery of the initial investment and long-term economic profitability. The substantial reduction in labour requirement and operational cost, together with increased productivity and consistent screening performance, makes the developed machine suitable for commercial vermicompost producers, farmer producer organizations, self-help groups, and rural entrepreneurs. Overall, the developed machine has significant potential to promote sustainable organic waste management, renewable energy utilization, and environmentally friendly agricultural mechanization, thereby supporting the expansion of organic farming and enhancing farmers' income through efficient vermicompost production.

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