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Techno-economic feasibility of a solar-powered chaff cutter for sustainable fodder processing on small and marginal farms

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Abstract

Fodder preparation is one of the most labour-intensive operations on Indian dairy and livestock farms, and the chaff cutter (locally known as the "kutti" machine) is the primary implement used to reduce roughage into a size that improves palatability, reduces wastage and eases digestion. This paper presents a techno-economic feasibility assessment of a power-operated chaff cutter and compares a grid-electricity-driven configuration with a solar-photovoltaic-powered configuration of the same machine. The technical evaluation covers throughput capacity, chaff-length control and specific energy consumption under varying blade number, moisture content and operating speed. The economic evaluation follows standard farm-machinery costing procedure, computing fixed cost, variable cost, benefit-cost ratio (BCR), payback period and break-even point (BEP) for both configurations. Results show that the conventional grid-powered unit has a lower total annual operating cost and a marginally higher BCR, while the solar-powered unit, despite roughly 5.2 times higher capital investment, remains commercially attractive because of its short payback period and comfortable break-even margin relative to its annual processing capacity. The findings indicate that both configurations are technically sound and economically viable, and that the solar-powered variant offers a resilient, low-recurring-cost alternative for farms with unreliable grid supply.

Keywords: Chaff cutter, techno-economic feasibility, fodder processing, solar energy, break-even point, benefit-cost ratio, farm mechanization

1. Introduction

Livestock rearing is closely integrated with crop farming across rural India, and a large share of farm households keep at least one milch animal for household consumption or supplementary income. Feeding practices, however, remain largely traditional: crop residues such as jowar, bajra, maize stover, wheat and paddy straw, and sugarcane tops are commonly fed whole or hand-chopped, which increases feed wastage, lowers intake and makes the material more difficult for animals to digest. Mechanical chopping of fodder into uniform, shorter pieces increases the surface area available for rumen microbial action, reduces selective feeding and wastage, and allows roughage to be blended more easily with concentrates.

The chaff cutter is the implement historically used for this operation, ranging from simple hand- or flywheel-operated units to tractor-PTO-driven and electric-motor-driven machines capable of processing several tonnes of fodder per hour. Conventional manually or hand-operated cutters, however, are associated with a high incidence of hand and finger injuries and require considerable physical effort, which has motivated continuing research into safer, power-operated designs ^[1] that mitigate the potential for serious injuries and enhance operational efficiency compared with conventional cutter designs. At the same time, electricity-driven machines expose farms in areas with an unreliable grid supply to frequent downtime, which has renewed interest in renewable-energy-coupled alternatives such as solar-photovoltaic-powered chaff cutters.

Before any farm machine is recommended for adoption, it must be shown to be both technically workable and economically worthwhile. A techno-economic feasibility study therefore evaluates

a machine on two complementary fronts: (i) technical feasibility, which examines whether the design performs its intended function reliably, efficiently and safely under field conditions, and (ii) economic feasibility, which examines whether the benefits generated by owning and operating the machine justify its capital and running costs over its working life. This paper reports such a combined assessment for a power-operated chaff cutter, comparing a standard grid-electric configuration with a solar-powered configuration of the same base machine, with the objective of guiding farmers, machinery manufacturers and extension agencies on the relative merits of the two options.

2. Literature Review

A substantial body of agricultural-engineering literature deals with the design, modification and safety of chaff cutters. Early design and fabrication studies have focused on redesigning the feeding and cutting mechanisms of the conventional flywheel-type cutter to reduce the risk of hand injury while keeping the machine affordable for small farmers ^[1], noting that the rural landscape of an agricultural country such as India is dominated by crop production and livestock rearing that depend heavily on chaff cutter machines. Related work on human-powered units has explored flywheel-based energy storage as a means of amplifying the muscular energy a single operator can deliver to the cutting mechanism, establishing empirical torque and output relationships for such systems ^[3].

Ergonomic studies have quantified the physiological cost of operating hand-powered chaff cutters. Field trials with women farm workers operating a commercial hand-driven cutter recorded a rise in heart rate from a resting baseline in the high-70s to low-80s beats per minute to well over 100 beats per minute during operation, confirming the physical strain associated with manual chopping and reinforcing the case for power-operated alternatives ^[2]. Subsequent design-modification work has continued to target the same problem, aiming to reduce the manual drudgery involved in fodder chopping and coconut de-husking type operations on small holdings ^[6].

Performance evaluation studies of power-operated chaff cutters provide the technical benchmarks against which new designs are commonly compared. A five-horsepower, three-phase electric chaff cutter tested on jowar, maize and sugarcane fodder recorded cutting efficiencies in the range of about 96.6-97.9 percent for dry fodder and 97.5-98.1 percent for wet fodder, with an idling power draw of roughly 0.42 kWh and output rates of about 621-623 kg/h for dry fodder and 1,710-1,816 kg/h for wet fodder during a 23-hour continuous run without mechanical breakdown ^[9]. Such results establish that well-designed power-operated cutters can sustain high throughput and efficiency over extended duty cycles, which is a precondition for the economic analysis undertaken later in this paper.

On the market and adoption side, industry analyses describe a shift toward electrically driven, energy-efficient chaff-cutting equipment, with the electric segment of the broader grass/chaff cutter market valued in the hundreds of millions of dollars and projected to continue growing through the next decade as farmers recognise the operational-cost and environmental advantages of electric over purely mechanical designs ^[5]. Buying-guide literature aimed at farmers similarly notes a continuing shift from hand-crank and tractor-PTO drives toward electric-motor-driven units, and links the growing adoption of chaff cutters to broader trends in farm mechanization and animal-nutrition optimisation, particularly in regions where dairy farming is expanding ^[8]. Practical guidance on machine selection stresses that the appropriate cutter type depends on

farm size and the mix of dry and green fodder to be processed, and highlights labour and waste savings as the main drivers of adoption for smallholders ^[7].

Economic feasibility methodology for agricultural machinery is well established. The classical framework for a project feasibility study separates technical, market, financial and economic components, and treats the benefit-cost ratio and break-even analysis as the principal tools for judging profitability, generally accepting a project as economically viable when the benefit-cost ratio is at or above unity ^[11]. In cost-accounting terms, the break-even point is the output level at which total revenue exactly equals total cost, so that output below this level represents a loss and output above it represents a profit, with the linear break-even quantity obtained by dividing fixed cost by the contribution margin per unit ^[12]. Comparable costing procedures have been applied to other power-operated farm implements: an economic analysis of tractor-operated cotton harvesters, for example, reported break-even areas of about 1,255 ha and 1,543 ha and payback periods of roughly 3.2 and 6.4 years for a cotton stripper and a cotton picker respectively ^[13], illustrating how widely the same benefit-cost and break-even framework is used across different classes of farm machinery.

Taken together, the literature indicates that (i) power-operated chaff cutters are technically mature and can deliver high cutting efficiency and throughput, (ii) manual and hand-operated units remain physically demanding and carry safety concerns, and (iii) a standard benefit-cost/break-even costing procedure is the accepted method for judging the economic viability of such machines. The present study builds on this base by applying the same costing procedure to compare a grid-powered and a solar-powered configuration of a single chaff-cutter design.

3. Materials and Methods

3.1 Description of the Machine

The machine evaluated is a flywheel-type power-operated chaff cutter with a rated output of about 500 kg of chopped fodder per hour, fitted with an adjustable blade assembly that allows the operator to select one, two or four cutting blades to vary the length of cut. Two power configurations of the same base machine were considered: (i) a conventional configuration driven by a grid-connected electric motor, and (ii) a solar-powered configuration in which the same motor is driven from a dedicated solar-photovoltaic panel and battery system, removing dependence on grid electricity.

3.2 Technical Performance Evaluation

The machine was evaluated for throughput capacity, length of cut and specific energy consumption while processing sugarcane-top fodder and Napier grass, following the general test procedure prescribed for power chaff cutters under Indian Standard IS:9164-1979. A three-factor, three-level full factorial design with three replications (81 experimental runs) was used, with number of blades (1, 2 and 4), cutter shaft speed (1200, 1600 and 2000 rpm) and fodder moisture content (80, 85 and 90% wet basis) as the independent variables ^[1].

3.3 Economic Feasibility Methodology

The economic evaluation followed the standard farm-machinery costing procedure used in Indian agricultural-engineering practice, under which the annual fixed cost (depreciation, interest on investment, and housing/insurance/taxes) and annual variable cost (repair and maintenance, labour, and electricity) are summed to obtain the total annual operating cost. This total

is then combined with the annual value of output to derive three feasibility indicators: the benefit-cost ratio, the payback period and the break-even point, computed for each of the two power configurations as follows:

Benefit-Cost Ratio (BCR) = Benefit from the machine (Rs/year) ÷ Total operating cost of the machine (Rs/year)

Payback Period (years) = Total capital cost (Rs) ÷ Net annual profit from the machine (Rs/year)

Break-Even Point (quintal/year) = Fixed cost (Rs/year) ÷ [Selling price (Rs/quintal) – Variable cost (Rs/quintal)]

Depreciation was computed on a straight-line basis over an assumed working life of 10 years (14,400 operating hours), interest on the average value of investment, and housing/insurance/taxes as a fixed percentage of the capital cost, in line with the standard costing convention for Indian farm machinery ^[14].

4. Results and Discussion

4.1 Technical Performance

Throughput capacity was found to depend jointly on blade number, cutter shaft speed, moisture content and crop type, with blade number exerting the dominant effect. Across the 81-treatment factorial, measured throughput ranged from 16.7 kg/h (Napier grass, one blade, 1200 rpm, 80% moisture content) to 636.0 kg/h. The two-blade configuration consistently produced the highest throughput, reaching 636.0 kg/h for sugarcane and 553.0 kg/h for Napier grass at a cutter shaft speed of 1600 rpm and 90% moisture content; increasing the blade number further

to four did not raise throughput and in several treatments gave a lower output than two blades, reflecting increased cutting resistance and material congestion in the cutting chamber. The length of cut was governed primarily by the number of blades engaged: a single blade produced a coarser chaff of about 42-46 mm, two blades produced an intermediate length of about 28-31 mm, and four blades produced a fine chaff of about 18.6-21.0 mm, giving the operator direct control over fodder palatability and digestibility; cutter shaft speed, moisture content and crop type had only minor secondary effects on chaff length. Specific energy consumption ranged from about 0.29 kWh to 1.44 kWh across the tested combinations, depending on operating speed, moisture content and the number of blades engaged. The best-observed operating combination—two blades, 1600 rpm, 90% moisture content, sugarcane—delivered 636.0 kg/h throughput at a specific energy consumption of 0.77 kWh and a mean chaff length of 30.2 mm. These trends are consistent with the higher cutting efficiencies (96-98 percent) and output rates reported for comparable power-operated units in the wider literature, confirming that the tested design performs within the expected technical range for this class of machine.

4.2 Cost Structure

Table 1 summarises the annual fixed-cost build-up for the two configurations. The solar-powered unit carries a substantially higher capital cost, almost entirely attributable to the solar-panel system, which pushes its annual depreciation, interest and housing/insurance/tax charges well above those of the grid-powered unit.

Table 1: Annual fixed-cost comparison of the grid-powered and solar-powered chaff cutter

Cost item	Unit	Grid-powered chaff cutter	Unit	Solar-powered chaff cutter
Cost of machine	Rs	45,000	Rs	45,000
Cost of solar-panel system	Rs	--	Rs	1,90,000
Total capital cost	Rs	45,000	Rs	2,35,000
Useful life	years	10	years	10
Useful life	h	6,000	h	6,000
Depreciation	Rs/yr	4,050	Rs/yr	21,150
Interest on investment	Rs/yr	2,475	Rs/yr	12,925
Housing, insurance, tax	Rs/yr	743	Rs/yr	3,877
Total fixed cost	Rs/yr	7,268	Rs/yr	37,950

Table 2 presents the corresponding variable-cost build-up, comprising annual maintenance, labour and electricity charges, together with the resulting total annual operating cost for each configuration

Table 2: Annual variable-cost comparison and total annual operating cost

Cost item	Unit	Grid-powered chaff cutter	Unit	Solar-powered chaff cutter
Maintenance	Rs/yr	1,238	Rs/yr	6,462
Working days per year	days	300	days	300
Operating hours per year	h	600	h	600
Labour charge (@ Rs 500/day)	Rs/yr	37,500	Rs/yr	37,500
Total variable cost	Rs/yr	38,738	Rs/yr	43,962
Total annual operating cost (fixed + variable)	Rs/yr	46,006	Rs/yr	81,912

On a per-unit basis, the total annual operating cost translates to a processing cost of about Rs 15.34 per quintal of fodder for the grid-powered machine and about Rs 27.30 per quintal for the solar-powered machine, at a common rated output of 500 kg/h and an assumed annual output of 3,000 quintals (300 working days per year, 2 hours of operation per day) for both configurations. The higher unit cost of the solar configuration is

a direct consequence of its larger fixed-cost base rather than any difference in throughput.

4.3 Profitability and Feasibility Indicators

Table 3 compares the resulting profitability and feasibility indicators for the two configurations, taking a common custom-hiring charge of Rs 75 per quintal of chopped fodder.

Table 3: Profitability and economic-feasibility indicators of the two configurations

Indicator	Grid-powered chaff cutter	Solar-powered chaff cutter
Processing cost (Rs/quintal)	15.34	27.30
Profit (Rs/quintal)	59.66	47.70
Annual profit (Rs/year)	1,78,980	1,43,100
Benefit-cost ratio	3.89	1.75
Payback period (years)	0.26 ($\approx$ 3.1 months)	0.57 ($\approx$ 6.8 months)
Break-even point (quintal/year)	771	1,717
Rated annual output (quintal/year)	3,000	3,000

Both configurations are unambiguously feasible by the benefit-cost ratio criterion, since both exceed the minimum acceptance threshold of unity by a wide margin ^[11]. The grid-powered machine is the more profitable of the two in absolute terms: it earns a substantially higher benefit-cost ratio (3.89 versus 1.75), a markedly shorter payback period, and reaches its break-even output at only 771 quintals, well under a third of its rated annual capacity of 3,000 quintals. The solar-powered machine, despite carrying roughly 5.2 times the capital investment of the grid-powered unit, still recovers its full investment in about 6.8 months and reaches break-even at 1,717 quintals, comfortably below its 3,000-quintal annual capacity, so that about two-fifths of the machine's rated annual output is realised as clear profit. The sub-one-year payback periods obtained for both configurations compare favourably with the multi-year payback periods reported for larger, more capital-intensive machines such as tractor-operated cotton harvesters ^[13], reflecting the relatively low capital cost of the base machine assumed in this study, operated for 300 days a year.

4.4 Comparative Discussion: Grid-Powered versus Solar-Powered Operation

The choice between the two configurations is therefore less a question of basic viability, since both are economically sound, and more a question of risk profile and operating context. The grid-powered unit offers the lower unit cost of processing and the higher return per rupee invested, and is the more attractive option wherever grid electricity is reliable and reasonably priced. The solar-powered unit carries a substantially larger upfront cost and a lower benefit-cost ratio, but converts a recurring electricity expense into a one-time capital cost, insulates the operation from grid outages and tariff increases, and remains profitable well before its rated capacity is reached. For farms in areas with an unreliable or costly grid supply, or where uninterrupted fodder processing is operationally important, the solar-powered configuration therefore represents a resilient and still-profitable alternative, consistent with the broader industry trend toward electrically driven and energy-efficient chaff-cutting equipment ^[5].

5. Conclusion

This study evaluated the technical and economic feasibility of a power-operated chaff cutter in grid-powered and solar-powered configurations. On the technical side, the machine achieved its highest throughput (636.0 kg/h for sugarcane and 553.0 kg/h for Napier grass) with a two-blade configuration at 1600 rpm and 90% moisture content, produced chaff lengths controllable between about 18.6 mm and 46 mm by varying blade number (1, 2 or 4), and operated within a specific-energy range of 0.29-1.44 kWh, with the best-observed combination consuming 0.77 kWh. On the economic side, both configurations returned benefit-cost ratios well above unity, sub-one-year payback periods, and break-even outputs comfortably below their rated annual processing capacity of 3,000 quintals. The grid-powered

configuration is the more profitable option in absolute terms (BCR 3.89, payback 0.26 year, break-even 771 quintals), while the solar-powered configuration, despite a substantially higher capital outlay, remains clearly viable (BCR 1.75, payback 0.57 year, break-even 1,717 quintals) and offers the additional advantage of independence from grid electricity. Both configurations can therefore be recommended for adoption by small and marginal livestock-keeping farms, with the choice between them best guided by the reliability and cost of local grid supply rather than by feasibility alone. Future work could extend this analysis with a multi-year discounted-cash-flow evaluation and a sensitivity analysis of fodder price, electricity tariff and solar-panel cost, to test the robustness of the feasibility indicators reported here.

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