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Development and evaluation of low cost finger millet thresher for small farms

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Abstract
Finger millet is a nutritious cereal, but manual harvesting is labor-intensive and results in low grain recovery. To address this, a low-cost, lightweight, and farmer-friendly spiral-type finger millet thresher was developed. The machine consists of a main frame, transporting wheels, feeding hopper, wheel cover, electric motor with switch and plug, grain outlet, husk outlet, threshing shaft, adjustable spring, sieving unit, spiral-type cylinder, threshing section, V-belt, and driven pulley. A trapezoidal mild steel hopper ensures smooth feeding, while the spiral-type cylinder with high-strength steel concave efficiently separates grains from stalks. A vibrating sieve removes chaff and impurities, and power is transmitted from a 0.5 hp electric motor via a properly tensioned V-belt and pulley system. The threshing cylinder shaft is made of high-strength alloy steel to resist bending and torsion, and adjustable concave and sieve angles improve versatility for different crop conditions. Performance tests showed a threshing efficiency of 96.41%, cleaning efficiency of 97.34%, broken grain of 2.76%, and a threshing capacity of 28.60 kg/h. Overall, the thresher enhances harvesting efficiency, reduces grain loss, provides clean grain output, and offers a practical, reliable, and cost-effective solution for small-scale finger millet farming.

Keywords: Finger millet, Spiral-type thresher, Threshing efficiency, Cleaning efficiency, Grain recovery, Small-scale farming, Low-cost design

1. Introduction
Agriculture is the practice of cultivating soil, growing crops, and raising animals to meet human needs for food and resources. One of the oldest crops, millet, is a group of small-seeded grains grown mainly in Asia and Africa, celebrated for their climate resilience and nutritional value. In India, millet is known as bajra or ragi and is widely used in various traditional recipes.

Finger millet (*Eleusine coracana*) is an important cereal crop cultivated in Africa and Asia. Finger millet, rich in calcium, potassium, and dietary fiber is vital in tribal diets but its cultivation has declined because of limited mechanization and weak market support. To revive millets, the Government of India declared 2018 as the National Year of Millets and supported FAO's International Year of Millets 2023, while Chhattisgarh launched the Millet Mission in 2021 to promote *kodo, kutki*, and *ragi* (Chandra and Sahu 2024) [1]. In 2024–25, India reported about 9.2 million ha under millets with 11.57 million tons of production, whereas finger mill*et al*one contributed 1.18 million ha, 1.8 million tones, and a higher productivity of 1.6 t/ha (USDA FAS, 2025). In Chhattisgarh, the area under small millets declined from 2014–15 to 2022–23, but productivity nearly doubled, supported by procurement and subsidies (Painkra *et al*. 2025) [7].

However, threshing of finger millet remains largely manual, causing drudgery and low recovery. To address this, a spiral-type cylinder thresher was developed as a lightweight, affordable, and farmer-friendly solution for improved efficiency, grain quality, and economic returns.

2. Materials and Methods
2.1 Development of Prototype Finger Millet Thresher
Based on the survey analysis and the need for an efficient mechanical thresher for finger millet thresher were developed. The machine consists of a feeding hopper, a spiral-type threshing cylinder with adjustable concave for separation of grains and stalk, removing

lighter particles, and an electric motor to drive the unit. All components are mounted on a common frame fabricated from 35×35×5 mm mild steel angles and 25×5 mm MS flats, providing stability, portability, and ease of operation.

2.1.1 Hopper Design

The hopper made of mild steel, guides un-threshed finger millet into the cylinder. Its inclined trapezoidal shape ensures smooth gravity-fed flow, with a wide mouth for easy loading.
The hopper volume was calculated using Equation 1 (Khurmi and Gupta, 2005) [6]

$$V = \frac{1}{2}(A + B) \times h \times t \quad (1)$$

Where,
V = Volume of hopper, mm^3;
a = Length of upper side of trapezoidal section, mm;
b = Length of lower side of trapezoidal section, mm;
h = Height of trapezoidal section, mm;
t = Thickness of trapezoidal section, mm.
V = 0.019 m^3
Calculated volume: 0.019 m^3, sufficient to handle the target feed rate.

2.1.2 Threshing Cylinder

The threshing cylinder was designed for efficient separation of finger millet grains:

1) Diameter (D): Calculated from peripheral speed formula

$$v = \frac{\pi \times D \times N}{60} \quad (2)$$

Where,
v = Peripheral velocity of the threshing cylinder, m/s;
D = Diameter of threshing cylinder, m;
N = Speed of the threshing cylinder, rpm;
D = 331mm

2) Length (L): Spiral-type cylinder for uniform crop feeding. (Teng *et al*. 2019) [9]

$$L = \frac{\pi \times (D_{out} + D_{in})}{2} \times n \quad (3)$$

Where,
L = Length of the spiral; mm
D_{out} = Outer diameter of the spiral; mm
D_{in} = Inner diameter of the spiral; mm
n = Number of turns or coils; mm.
L = 652mm

3) Spiral angle and number of turns: Designed for minimal grain breakage and efficient threshing.

2.1.3 Concave Design

The concave works with the cylinder to separate grains from straw. Made of high-strength steel, it allows grains to pass while holding straw. (Dangora *et al*. 2006) [2]

$$R_c = \mathrm{Rcy} + C_c \quad (4)$$

Where,
*R*c = Radius of concave, mm;
Rcy = Radius of threshing cylinder, mm;
*C*c = Concave clearance for finger millet crop threshing, mm
Rc = 631.0 mm

We know that,

$$\theta_w = \frac{L_{ca}}{R_c} \quad (5)$$

Where,
θw = Concave wrap angle, degree;
*L*ca = Concave arc length, mm;
L_{ca} = 670 mm

2.1.4 Design of cleaning unit

The cleaning unit separates grains from chaff and straw using vibrating sieves. Fine mesh is used for finger millet, and adjustable angles ensure efficient cleaning with minimal grain loss. (Sharma and Jain 2007) [8]
Volume flow rate of material on the sieve:

$$Q_s = W_s \times t_s \times v_s \quad (6)$$

Where,
*W*s = Sieve width, m;
*t*s = Seed bed thickness, m;
Vs = Oscillating velocity of sieve shaker, m/min

2.1.5 Power Unit

The power needed for threshing was calculated using Goryachkin's drum theory. (Sharma and Jain 2007) [8]

$$P = (A\omega + B\omega^3) + \left[\frac{m(v_2 - v_1)\omega}{1 - f}\right] \quad (7)$$

Where,
P = Total power required for threshing, watts;
m = Feed rate = 0.066 kg/s;
v1 = Initial velocity of plants = 2 m/s;
v2 = Velocity of plant mass after impact = a x ω = 0.85 x 8.5= 7.2 m/s;
ω = Peripheral velocity of threshing drum = 8.5 m/s;
f = Coefficient of material rubbing = 0.6;
A = Moment from the frictional force in bearing = 0.4 to 0.9 N;
B= Factor characterizing the drum's ventilating effect = 0.485 N-s2/m2.
P = 373W (0.5 hp)

2.1.6 Power Transmission Unit

The thresher uses a V-belt and pulley system to transfer power from the motor to the threshing cylinder and cleaning unit. Proper pulley sizes and alignment reduce wear and ensure smooth operation. (Khurmi and Gupta, 2005) [6]
Pulley relation:

$$N_1 D_1 = N_2 D_2 \quad (8)$$

Where,
N1 = Driver pulley speed, rpm;
*N*2 = Driven pulley speed, rpm;
D3 = Diameter of the driver pulley, mm;
D4 = Diameter of the driven pulley, mm.
$D_2 = 120\ mm$

Belt length: (Gates, 2001) [3]

$$L = \pi \times \left(\frac{D_1 + D_2}{2}\right) + 2 \times C + \frac{(D_2 - D_1)^2}{4 \times C} \quad (9)$$

Where,
L = Length of the V-belt, mm;
$D1$ = Diameter of the driving pulley, mm;
$D2$ = Diameter of the driven pulley, mm;
C = Center distance between the pulleys, mm
L = 1132 mm (44.5 inch)

Angle of contact on smaller pulley:

$$\theta = (180 - 2 \propto) \times \frac{\pi}{180} \quad (10)$$

and,

$$\propto = \pi - 2\sin^{-1}\left(\frac{D_2 - D_1}{2C}\right) \quad (11)$$

Where,
θ = Angle of contact of belt on smaller pulley, rad;
$D1$ = Diameter of the larger pulley, mm;
$D2$ = Diameter of the smaller pulley, mm;
C = Center distance between pulleys, mm;
θ = 1.841 rad or 105.48^0

2.1.7 Belt tensions

(IS: 14452-2001)

$$p = (T_t - T_S) \times v \quad (12)$$

and,

$$\frac{T_t}{T_S} = e^{\mu\theta coseccβ} \quad (13)$$

Where,
P = Power transmitted, watt;
T1 = Belt tension on tight side, N;
T2 = Belt tension on slack side, N;
v = Linear velocity of belt, m/s;
μ = Coefficient of friction between belt and pulley material;
θ = Angle of contact, rad;
β = Groove angle, degree.

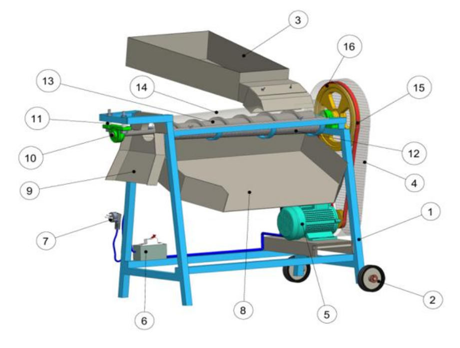
2.1.8 Design of threshing cylinder shaft

The threshing cylinder shaft transfers torque and supports the rotating drum, made of high-strength alloy steel to resist bending and torsion. (Khurmi and Gupta, 2005) [6]

$$\tau_{max} = \frac{1}{2}\sqrt{\sigma^2{}_b + 4\tau^2} \quad (14)$$

2.1.9 Design of main frame

The main frame supports all components and is fabricated from 35×35×5 mm MS angles with 25×5 mm MS flats. Transport wheels, wheel covers, grain outlet, husk outlet, sieving unit, and other auxiliary components are mounted on the frame for ease of field operation.



1. Main frame
2. Transporting wheel
3. Feeding hopper
4. Wheel cover
5. Electric motor
6. Motor switch
7. Motor plug
8. Grain outlet
9. Husk outlet
10. Threshing shaft
11. Adjustable spring
12. Sieving unit
13. Spiral-type cylinder
14. Threshing section
15. . V-Belt
16. Driven pulley

Fig 1: Finger Millet Thresher

2.1.10 Working Principle

The crop is fed into the hopper, where it is guided to the spiral cylinder. The cylinder threshes the panicles, separating grains that pass through the concave while stalks and chaff move forward. The sieves remove lighter particles, and clean grains are collected from the grain outlet, while husk and straw are discharged separately.

2.2. Testing of Developed Machine

The developed finger millet thresher was tested to evaluate its performance under different operating conditions. The feed rate (18, 21, 24, 27, and 30 kg/h), peripheral speed (7.5, 8.5, 9.5, 11.5, and 12 m/s), and concave clearance (3, 6, 9, 12, and 15 mm) were varied during the experiments. These independent variables were analyzed to determine their effects on the dependent variables—threshing capacity, threshing efficiency, cleaning efficiency, and grain damage to assess the overall performance of the machine.

Results

The developed finger millet thresher, powered by a 0.5 hp motor, features a sloped hopper, spiral cylinder with perforated concave, and cleaning sieves. It is low-cost, efficient, and easy for farmers to use, delivering high threshing and cleaning efficiency with minimal grain breakage.

Table 1: The performance evaluation of finger millet thresher

Parameters	Finger millet thresher
Cleaning efficiency, %	97.34
Threshing efficiency, %	96.41
Broken grain, %	2.76
Threshing capacity, kg/h	28.60

Table 2: ANOVA for the effect of feed rate, peripheral speed and concave clearance

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	4125.11	9	458.35	111.40	< 0.0001	significant
A-Feed Rate	1861.41	1	1861.41	452.40	< 0.0001	
B-Peripheral Speed	21.18	1	21.18	5.15	0.0467	
C-Concave Clearance	0.0371	1	0.0371	0.0090	0.9262	
Residual	41.15	10	4.11			
Lack of Fit	20.39	5	4.08	0.9821	0.5077	not significant
Pure Error	20.76	5	4.15			
Cor Total	4166.25	19				

The ANOVA results show that the overall model is highly significant (*p*<0.0001), meaning feed rate, peripheral speed, and concave clearance together influence threshing efficiency. Among the factors, feed rate has a very strong and highly significant effect (*p*<0.0001), peripheral speed has a smaller but significant effect (p ≈ 0.0467), while concave clearance has no significant effect (p ≈ 0.9262). The lack of fit is not significant, indicating the model adequately represents the data.

3.1 Threshing Capacity
The interactive effect of feed rate, peripheral speed, and concave clearance on threshing capacity was significant at the 5% level. The highest capacity of 30 kg/h was observed at a feed rate of 30 kg/h, peripheral speed of 9.5 m/s, and concave clearance of 3 mm, while the lowest capacity of 14.42 kg/h occurred at a feed rate of 18 kg/h, peripheral speed of 9.5 m/s, and concave clearance of 15 mm. Overall, increasing feed rate enhanced threshing capacity, whereas lower feed rates reduced it, with peripheral speed and concave clearance having smaller effects.

3.2 Threshing Efficiency
The interactive effect of feed rate, concave clearance, and their combination on threshing efficiency was significant at the 5% level. The highest efficiency of 98.7% was observed at a feed rate of 24 kg/h, peripheral speed of 9.5 m/s, and concave clearance of 15 mm, while the lowest efficiency of 94.2% occurred at a feed rate of 21 kg/h, peripheral speed of 11.5 m/s, and concave clearance of 9 mm. Overall, increasing feed rate and concave clearance improved threshing efficiency, whereas lower levels of these factors reduced it.

3.3 Cleaning Efficiency
The interactive effect of feed rate, peripheral speed, and concave clearance on cleaning efficiency was significant. The highest efficiency of 99.10% was observed at a feed rate of 30 kg/h, peripheral speed of 12 m/s, and concave clearance of 15 mm, while the lowest efficiency of 94.90% occurred at a feed rate of 18 kg/h, peripheral speed of 7.5 m/s, and concave clearance of 15 mm. In general, higher feed rate and faster speed increased cleaning efficiency, while lower feed rate and slower speed reduced it.

3.4 Broken Grain
The interactive effect of feed rate, peripheral speed, and moisture content on broken grain was significant. The highest broken grain of 4.30% happened at a feed rate of 30 kg/h, peripheral speed of 12 m/s, and higher moisture content, while the lowest of 1.50% occurred at a feed rate of 18 kg/h, peripheral speed of 7.5 m/s, and lower moisture content. In general, higher moisture caused more broken grains, while lower feed rate and slower speed reduced them.

4. Discussion
The developed thresher demonstrated high performance, aligning with previous studies (Teng *et al*., 2019; Dangora *et al*., 2006) [9]. Feed rate strongly affected capacity and efficiency, while excessive speed increased grain breakage. The design successfully reduced drudgery, energy use, and losses compared to manual methods.

5. Conclusion
The developed low-cost finger millet thresher offers a practical and efficient solution for farmers with its thoughtful design and sturdy construction. It features a trapezoidal mild steel hopper, spiral threshing cylinder, high-strength concave, and vibrating sieve cleaning unit, ensuring smooth feeding, effective grain separation, and clean output with minimal breakage. Powered by a 0.5 hp motor and built on a robust frame with portable wheels, the machine is both durable and easy to operate. Performance tests show high efficiency, with a threshing efficiency of 96.41%, cleaning efficiency of 97.34%, broken grain of 2.76%, and a threshing capacity of 28.60 kg/h. Adjustable components allow the machine to suit different crop conditions, and careful adjustment of feed rate and cylinder speed optimizes performance. Overall, this thresher reduces grain loss, simplifies operation and maintenance, and provides a reliable, cost-effective tool that improves productivity while maintaining grain quality for market and storage.

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