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Design, development and field evaluation of small agricultural tools and equipment for small farms in western Uttar Pradesh, India

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Abstract

Small farms in western Uttar Pradesh rely on manual harvesting for vegetables that are picked individually, often using hand plucking or a knife. This study developed and evaluated a lightweight Multi-Purpose Scissor for Agriculture and compared 17 additional tools and methods across key field operations. The scissor weighed 150 g and measured 187.2 mm in overall length. Its serrated blade was designed to aid cutting, while a notched blade helped retain the stalk during cutting; the handle loops were informed by anthropometric data for Indian agricultural workers. Across okra, bottle gourd, sponge gourd, bitter gourd and brinjal, the scissor reduced the Strain Index by 44–69%, bringing scores into the study's defined safe range for four crops. Output increased by 9–11% for the three gourds, while the brinjal harvesting rate declined by 29%. The tool also avoided the 2–3% produce loss recorded with hand plucking and received favourable ratings from all 30 participating farmers. Comparative trials in two villages of Meerut district showed that a power weeder reduced labour demand from about 167 to 8–10 person-h ha^{-1}. Improved sickles reduced physiological workload during rice harvesting, whereas the brush cutter used for harvesting produced an extremely heavy workload. The findings indicate that small-farm mechanisation should combine appropriate hand tools, small powered implements and shared access to larger machines, with selection based on both field performance and operator workload.

Keywords: Agricultural hand tools; Small-farm mechanisation; Ergonomics; Strain Index; Vegetable harvesting; Western Uttar Pradesh

Article highlights

- A 150 g harvesting scissor was developed using anthropometric information relevant to Indian agricultural workers.
- The scissor reduced Strain Index scores by 44–69% across five vegetables and reached the study-defined safe range in four crops.
- Seventeen tools and methods were compared across field operations to assess labour, cost, field performance and operator workload.

1 Introduction

Small and marginal holdings account for a large share of farms in India, making the suitability and affordability of agricultural equipment important considerations in mechanisation planning. Global assessments likewise show that small farms are widespread, particularly in South Asia and sub-Saharan Africa [1]. In India, the 2015–16 Agriculture Census reported an average operational holding of 1.08 ha, with small and marginal holdings comprising about 86% of holdings [2]. In western Uttar Pradesh, farms commonly combine sugarcane, rice or wheat with vegetables on relatively small plots. Although tractors and machines are widely used for operations such as tillage and threshing, planting, weeding and harvesting may still require substantial manual labour [3, 4]. The economics of mechanisation therefore depend not only on machine capacity but also on plot size, crop pattern, labour availability and access to hiring services [4, 5].

Many manual farm operations also place sustained demands on the musculoskeletal system. Weeding, transplanting and sickle harvesting can involve prolonged bending or squatting and repeated hand and wrist movements. Research on agricultural work has documented musculoskeletal risks, injuries and physical drudgery, including among women who perform a substantial share of hand-intensive tasks [6–9]. These demands coincide with seasonal labour constraints, making timely completion of field operations difficult for some farms [4, 10].

Vegetable harvesting presents a particular design challenge because fruits are often picked individually from within a dense canopy. In okra, gourds and brinjal, hand plucking or knife cutting can damage stems and fruit, while poorly controlled cutting may expose workers to cuts or discomfort. General-purpose scissors may be difficult to position around individual stalks, and handle dimensions that do not suit the intended users can affect grip and control [11–14]. A crop-flexible hand tool designed around these constraints could address a task for which larger machines are not always practical on small plots.

A further challenge is that evidence on farm implements is often reported operation by operation, using different sites and performance measures. Studies have evaluated sugarcane planters, reaper-binders, power weeders and modified brush cutters, but comparisons that consider field capacity, labour, operating cost and operator workload together can help farmers and extension services select equipment more appropriately [10, 15–19].

This study had two linked aims: to design and evaluate a multi-purpose harvesting scissor for small-scale vegetable production, and to compare selected tools and machines used for other common field operations in western Uttar Pradesh. The specific objectives were to:

1. design and develop a light, multi-purpose harvesting scissor from the hand dimensions of Indian farm workers;
2. evaluate the scissor for work output, Strain Index, grip fatigue, produce loss and user comfort in five vegetables, and demonstrate it on farmers' fields;
3. compare the field capacity, labour and cost of small tools and equipment with traditional methods and with larger machines for sugarcane planting, sowing, transplanting, weeding and cereal harvesting; and
4. measure the physiological and postural workload of the hand tools and small machines, and use the results to match the level of mechanisation to each operation.

The study contributes field evidence in three areas. First, it documents the development and farm evaluation of a harvesting scissor from user-identified problems through anthropometric design and farmer assessment. Second, it considers operator workload alongside output, labour and operating cost rather than treating field capacity as the sole measure of performance. Third, it compares 17 tools and methods on a four-rung mechanisation ladder. Because the trials cover different operations and periods, the ladder is intended as a practical comparison of options rather than a controlled head-to-head test of every implement.

2 Materials and methods

2.1 Study area and design

The work comprised two parts (Fig. 1). Part A covered the design and evaluation of the scissor during 2022–23 on the vegetable-based integrated farming system model at ICAR–IIFSR, Modipuram, and on nearby farmers' fields. The tool was also demonstrated to vegetable growers. Part B comprised comparative trials of other tools and equipment in Pahadpur village, Mawana block (29° 6′ 51″ N, 77° 50′ 33″ E) and Pawersa village, Sardhana block (29° 5′ 48″

N, 77° 48′ 21″ E), Meerut district, during the rabi season of 2019–20 and kharif season of 2020. Average farm holdings were 0.7–0.8 ha, with individual plots of 0.2–0.4 ha. Soils ranged from silt loam to sandy loam, with bulk density of 1.38–1.40 Mg m^{-3}, pH 7.8–7.9 and organic carbon of 0.58–0.62%. Each implement was tested three times in each village, giving six observations per treatment. Ergonomic trials of other hand tools were conducted between 2018 and 2022 on field-crop, vegetable and fruit-based farming system models at Modipuram.

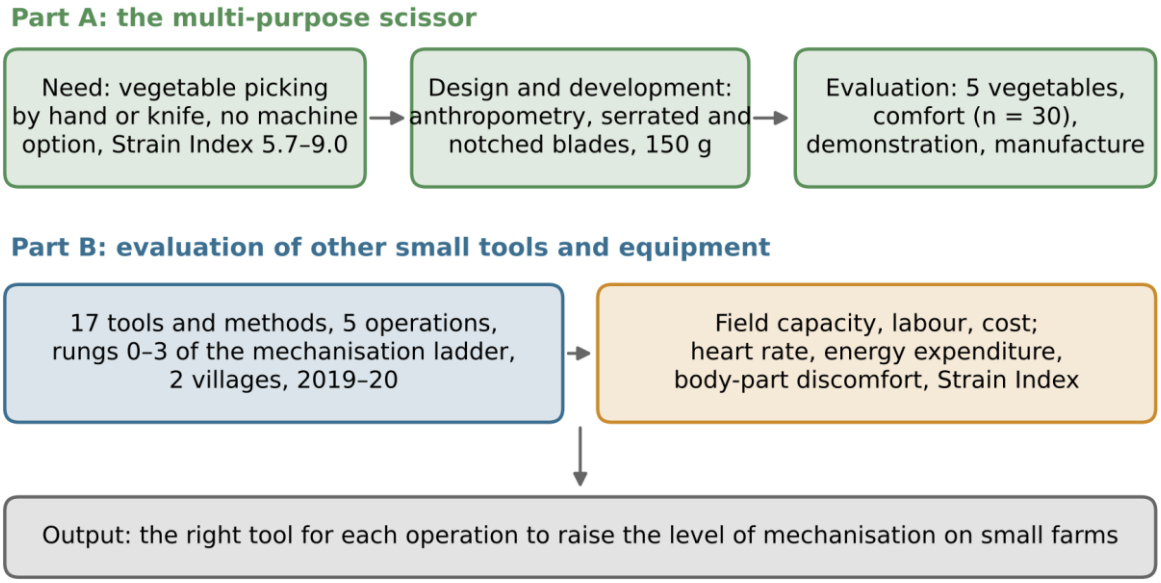


Fig. 1 Framework of the study. Part A: design, development and evaluation of the Multi-Purpose Scissor for Agriculture. Part B: evaluation of other small tools and equipment on the mechanisation ladder

2.2 Design and development of the multi-purpose scissor

The design requirements were based on problems reported by workers during harvesting with their usual methods, including broken fruit or branches, uprooted plants, and cuts, scrapes or pain around the palm and thumb. The design targets were low mass, one-handed operation, secure positioning of the stalk during cutting, a compact blade suitable for use within a crop canopy, and finger loops suited to the intended users. Loop dimensions were informed by published anthropometric data for Indian agricultural workers and established guidance on hand-tool design [11–14].

The scissor consists of two blades connected by a hinge pin (Table 1, Fig. 2). One blade has a serrated cutting edge and the other a notch intended to help hold the stalk during cutting. The blades extend into elliptical thumb and finger loops with plastic grips. The blades and pin were specified as die steel 31. The components were modelled in CAD, and prototypes were

manufactured by M/s M.A. Ghani & Sons, Meerut, which has since taken up its commercial production.

Table 1 Specifications of the Multi-Purpose Scissor for Agriculture

Item	Specification
Material of blades and pin	Die steel 31
Mass	150 g
Overall length	187.2 mm
Blade length	50 mm
Cutting edges	One blade serrated; one blade with a notched edge
Thumb loop (elliptical)	25 × 30 mm
Finger loop (elliptical)	25 × 40 mm
Hinge pin	7.5 × 5 mm
Handle grip	Sturdy plastic, sized for adult hands
Uses	Harvesting vegetables, fruits and flowers; pruning small stems and leaves

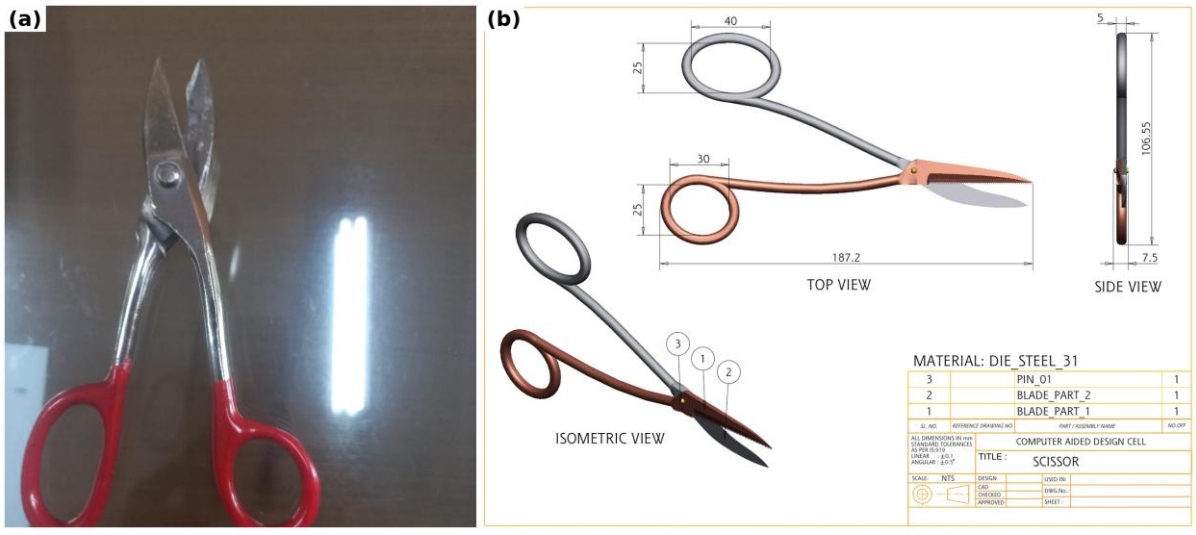


Fig. 2 The Multi-Purpose Scissor for Agriculture: (a) the manufactured tool; (b) CAD drawing with top, side and isometric views (dimensions in mm; 1, blade 1; 2, blade 2; 3, hinge pin)

2.3 Physiological and ergonomic measures

The same core ergonomic measures were applied to the scissor and other hand tools. Hand and wrist risk was assessed with the Strain Index (SI) of Moore and Garg [20], Eq. (1):

$$\mathrm{SI} = \mathrm{IE} \times \mathrm{DE} \times \mathrm{EM} \times \mathrm{HWP} \times \mathrm{SW} \times \mathrm{DD} \quad (1)$$

The six multipliers represent intensity of exertion, duration of each exertion, efforts per minute, hand/wrist posture, work speed and daily task duration. The interpretation used here classified

SI ≤ 3 as safe, values between 3 and 7 as uncertain, and SI ≥ 7 as hazardous [20]. Grip strength of the working hand was measured with a hand dynamometer before and after each harvesting trial [21]. Grip fatigue (GF, %) was calculated as the percentage fall in grip strength, Eq. (2):

$$\mathrm{GF} = \frac{\mathrm{GS_{before}} - \mathrm{GS_{after}}}{\mathrm{GS_{before}}} \times 100 \quad (2)$$

In Eq. (2), GS is grip strength (kgf). Heart rate was recorded at rest while seated and during steady work. The difference between working and resting heart rate (ΔHR) was calculated. Energy expenditure (EE, kJ min^{-1}) was estimated from working heart rate (HR, beats min^{-1}) using the relationship reported for Indian workers [22], Eq. (3):

$$\mathrm{EE} = 0.159 \times \mathrm{HR} - 8.72 \quad (3)$$

Workload was classed from EE as very light (up to 5.0 kJ min^{-1}), light (5.1–7.5), moderately heavy (7.6–10.0), heavy (10.1–12.5), very heavy (12.6–15.0) or extremely heavy (above 15.0) [22]. Postural discomfort was rated on a body-part map and summed as the body-part discomfort score (BPDS) [23].

2.4 Evaluation of the scissor

The scissor was compared with each farmer's usual method as hand plucking or knife cutting in five crops: okra, bottle gourd, sponge gourd, bitter gourd and brinjal. Three to five workers participated for each crop, and each method was repeated three times. Work output (kg h^{-1}), Strain Index, grip fatigue and produce loss were recorded.

After the harvesting trials, 30 farmers assessed the scissor using a four-point Likert scale, from strongly disagree to strongly agree. The questionnaire covered functionality, safety, produce quality, portability, grip and fit, surface feel, slipping, blisters, posture, ease of use, muscle discomfort, numbness, perceived pressure, weight and required force. These factors were selected with reference to published work on hand-tool comfort [14]. The scissor was subsequently demonstrated to bottle-gourd and bitter-gourd growers in their own fields.

2.5 Other small tools and equipment evaluated

The tools were grouped into four rungs of a mechanisation ladder (Table 2). Rung 0 represented the farmers' usual practice with locally available tools; Rung 1 included improved hand tools and hand-pushed implements; Rung 2 covered small engine-driven machines carried by an operator or walked behind; and Rung 3 included tractor-drawn or self-propelled machines used as higher-mechanisation comparators. The 17 tools and methods included five manual baselines. Experienced local operators tested traditional and improved methods on adjacent

158 plots where feasible. Sugarcane bud chipping and okra picking with a ring cutter were included
159 in the ergonomic assessments.

160 **Table 2** Tools and methods evaluated, by operation and rung of the mechanisation ladder

Operation	Rung 0: traditional	Rung 1: improved hand tool or manual implement	Rung 2: small power machine	Rung 3: tractor or self-propelled
Vegetable harvesting	Hand plucking or knife	Multi-purpose scissor (this study); okra ring cutter	–	–
Sugarcane planting	Manual planting	–	–	Tractor-drawn sugarcane planter
Sowing	Manual dibbling	Single-row seed-cum-fertiliser dibbler	–	Multi-crop seed drill
Transplanting	Manual transplanting	Easy seedling transplanter	–	–
Weeding and inter-culture	Indigenous hand tools (khurpi)	Improved spade; three-tyne wheel weeder	Brush cutter with rotary tiller; power weeder-cum-rotary tiller	–
Cereal harvesting	Indigenous sickle	CIAE improved sickle; Falcon sickle	Brush cutter with harvesting attachment	Self-propelled reaper binder
Sugarcane bud chipping	Knife	Bud chipper (ICAR–IISR), bending and seated	–	–

161

162 **2.6 Field performance**

163 The field tests followed standard procedures for testing farm machinery [24]. Theoretical field
164 capacity (TFC), effective field capacity (EFC) and field efficiency (FE, %) were calculated
165 with Eqs. (4)–(6):

166 $$\mathrm{TFC} = \frac{W \times S}{10} \quad (4)$$

167 $$\mathrm{EFC} = \frac{A}{T} \quad (5)$$

168 $$\mathrm{FE} = \frac{\mathrm{EFC}}{\mathrm{TFC}} \times 100 \quad (6)$$

169 where TFC and EFC are in ha h^{-1}, W is the effective working width (m), S is the forward speed
170 (km h^{-1}), A is the area covered (ha) and T is the total time (h), including turns, adjustments and

stoppages. The time needed per hectare (T_{ha}, h ha^{-1}) and the labour requirement (LR, person-h ha^{-1}) were then obtained from Eqs. (7) and (8):

$$T_{\mathrm{ha}} = \frac{1}{\mathrm{EFC}} \tag{7}$$

$$\mathrm{LR} = N \times T_{\mathrm{ha}} \tag{8}$$

where N is the number of workers in the crew (given in Tables 4–7). Fuel use was measured by the fill-and-refill method. The cost of operation was the sum of fixed costs (depreciation, interest and housing) and variable costs (fuel, lubricant, repair and labour) [25]. Labour saving (LS, %) and cost reduction (CR, %) relative to the manual baseline were calculated with Eqs. (9) and (10):

$$\mathrm{LS} = \frac{L_{\mathrm{m}} - L_{\mathrm{i}}}{L_{\mathrm{m}}} \times 100 \tag{9}$$

$$\mathrm{CR} = \frac{C_{\mathrm{m}} - C_{\mathrm{i}}}{C_{\mathrm{m}}} \times 100 \tag{10}$$

where L is labour, C is cost, and the subscripts m and i stand for the manual and the improved or mechanised method. Where a result is a range, savings were worked out from the midpoints.

2.7 Statistical analysis

For the scissor, the two harvesting methods were compared separately for each crop using a t-test or one-way analysis of variance, as appropriate, at $p \leq 0.05$. Farmer comfort responses were summarised as counts and percentages. Field-performance data were analysed in IBM SPSS Statistics 26 using analysis of variance, with implement or method as the treatment; means were compared using the least significant difference (LSD) test at $p \leq 0.05$. The small number of replications should be considered when interpreting inferential results.

3 Results and discussion

3.1 The need for a harvesting tool

Harvesting vegetables was a demanding hand-intensive operation in these trials. With hand plucking or knife cutting, Strain Index values ranged from 5.7 to 9.0 across the five crops (Table 3), placing the work in the uncertain-to-hazardous categories under the thresholds adopted in this study. Workers described or demonstrated wrist twisting to detach brinjal, holding gourds while cutting with a knife, and occasional damage to plants or fruit (Fig. 3). The okra ring cutter increased output by approximately 17% and reduced the plant damage reported for hand picking, but it was suitable for only one crop. The scissor was therefore

developed to provide a single hand-tool option across several vegetables where machine harvesting was not practical.



Fig. 3 Vegetable harvesting in the trials: (a) okra with the scissor; (b) bottle gourd with the scissor, woman worker; (c) bottle gourd with the scissor, male worker; (d) traditional knife used for gourds; (e) sponge gourd with the scissor; (f) bitter gourd with the scissor; (g) brinjal harvesting

3.2 Performance of the scissor

The scissor reduced Strain Index scores in all five crops: by 44% in okra, 47% in bitter gourd, 55% in sponge gourd, 56% in bottle gourd and 69% in brinjal (Table 3; Fig. 4). Scores for bottle gourd, sponge gourd and brinjal fell to 2.7–2.8, within the safe category defined for this analysis; bitter gourd reached 3.0, at the category boundary. In okra, the score declined from 6.8 to 3.8. Grip fatigue was significantly lower in okra, bottle gourd and sponge gourd, with reductions of 39–58%. The blade geometry was intended to help retain and cut the stalk, potentially reducing the need for forceful pulling or wrist twisting; however, the present trials did not directly measure cutting force or wrist angle.

Output increased significantly by 9–11% in bottle gourd, sponge gourd and bitter gourd, while the change in okra was not statistically significant. Brinjal showed a different trade-off: output decreased from 142 to 101 kg h^{-1}. Hand detachment was faster in this crop, but it was associated

with a Strain Index of 9.0 in the tested conditions. The scissor therefore reduced the measured ergonomic risk while sacrificing some harvesting speed. Hand harvesting resulted in 2–3% produce loss in the trials, whereas no loss was recorded with the scissor; this result should be interpreted in relation to the limited trial duration and replication.

Table 3 Work output and ergonomic stress in vegetable harvesting by the farmers' method and with the multi-purpose scissor (means of three replications)

Crop	Parameter	Farmers' method	Scissor	Change (%)	p
Okra	Work output (kg h^{-1})	7.01	7.20	+2.7	NS
	Strain Index	6.76	3.76	−44.4	0.009
	Grip fatigue (%)	2.99	1.53	−48.8	< 0.001
Bottle gourd	Work output (kg h^{-1})	193.20	213.59	+10.6	0.002
	Strain Index	6.03	2.66	−55.9	0.016
	Grip fatigue (%)	3.27	1.99	−39.1	0.017
Sponge gourd	Work output (kg h^{-1})	39.12	42.71	+9.2	0.014
	Strain Index	5.93	2.66	−55.1	0.023
	Grip fatigue (%)	3.46	1.46	−57.8	0.001
Bitter gourd	Work output (kg h^{-1})	57.31	62.96	+9.9	< 0.001
	Strain Index	5.66	3.00	−47.0	0.009
	Grip fatigue (%)	3.45	3.15	−8.7	NS
Brinjal	Work output (kg h^{-1})	142.15	100.84	−29.1	< 0.001
	Strain Index	9.00	2.76	−69.3	0.005
	Grip fatigue (%)	3.23	2.31	−28.5	NS

Note: NS, not significant at $p \leq 0.05$.

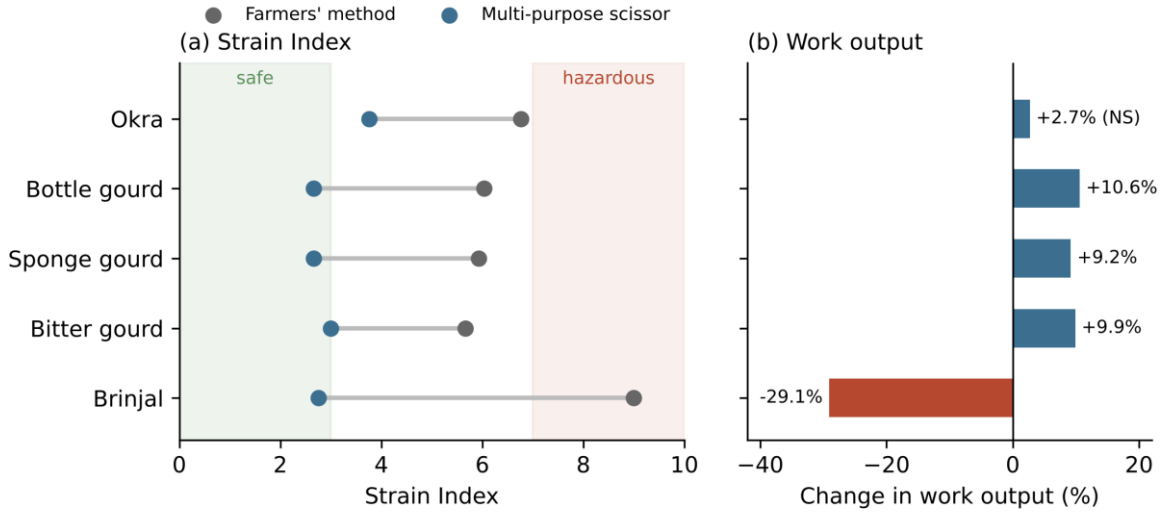


Fig. 4 Effect of the multi-purpose scissor on (a) the Strain Index, with the safe (≤ 3) and hazardous (≥ 7) bands shaded, and (b) work output relative to the farmers' method; NS, not significant

3.3 Farmers' assessment, demonstration and uptake

Farmer responses were generally favourable and broadly consistent with the field measurements (Fig. 5). All 30 respondents selected an agreement category for the listed statements, and all strongly agreed with statements concerning functionality, safety, produce quality, portability, fit, grip feel and resistance to slipping or blister formation. Responses were more mixed for perceived effort and weight: only 33% strongly agreed that the tool required little force and 60% that it was lightweight, the rest agreeing somewhat. These responses identify weight and operating force as priorities for further design refinement, potentially including a return spring or lighter blade, subject to testing.

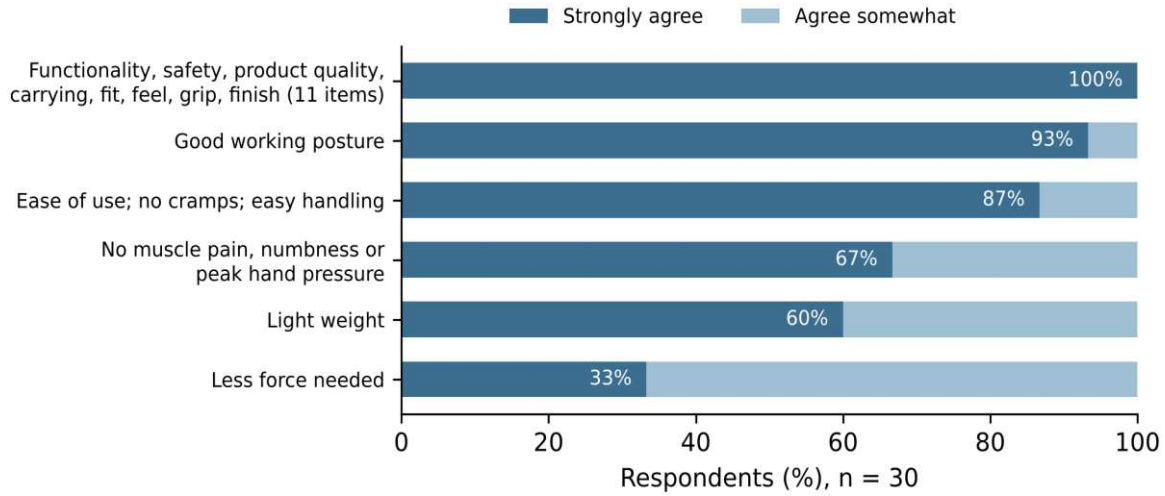


Fig. 5 Comfort assessment of the multi-purpose scissor by 30 farmers on a four-point Likert scale; no respondent chose either disagree option

The scissor was demonstrated to bottle-gourd and bitter-gourd growers on their own fields (Fig. 6). At the time of reporting, M/s M.A. Ghani & Sons, Meerut, was manufacturing and selling the tool, and a patent application had been filed. The reported field use supports its practical potential, although broader adoption, durability and long-term comfort were not assessed systematically in this study.



Fig. 6 Demonstration of the multi-purpose scissor on farmers' fields: (a) bottle gourd; (b) and (c) bitter gourd

3.4 Evaluation of other small tools and equipment

3.4.1 Sugarcane planting

The tractor-drawn sugarcane planter reduced the reported labour requirement from 280–300 to 28 person-h ha^{-1}, a reduction of about 90% (Table 4). Its effective field capacity was 0.18 ha h^{-1}, corresponding to approximately 5.6 h ha^{-1} with a five-person crew. Operating cost declined from Rs 10,172 to Rs 4,975 ha^{-1}, a reduction of Rs 5,197 ha^{-1} (about 51%). The planter maintained 750 mm row spacing, compared with a wider 700–900 mm range under manual

planting. These findings are consistent with published work on mechanised sugarcane planting in the region [10]. Because the planter requires a tractor and turning space, custom hiring may be more accessible than individual ownership for farms with small plots.

Table 4 Performance of the tractor-drawn sugarcane planter and manual planting

Parameter	Sugarcane planter	Manual planting
Effective working width (mm)	1500	–
Row spacing (mm)	750	700–900
Operating speed (km h^{-1})	1.62	–
Theoretical field capacity (ha h^{-1})	0.27	–
Effective field capacity (ha h^{-1})	0.18	–
Field efficiency (%)	66.7	–
Time per hectare (h ha^{-1})	5.56	8–16
Crew (no.)	5	18–37
Labour requirement (person-h ha^{-1})	28.0	280–300
Fuel consumption (l ha^{-1})	24.0	–
Cost of operation (Rs ha^{-1})	4975	10,172

Note: Means of six observations. LSD (p = 0.05): effective field capacity 0.032 ha h^{-1}; cost Rs 892 ha^{-1}. Field capacity terms are not given for manual planting, which was done by a gang rather than a single implement; its crew size is labour divided by time.

3.4.2 Sowing and transplanting

The multi-crop seed drill completed sowing in approximately 2.5–2.9 h ha^{-1}, compared with about 33 h ha^{-1} for manual dibbling (Table 5). With a two-person crew, the drill required 5.0–5.7 person-h ha^{-1}, representing an estimated labour reduction of about 84%; reported operating cost was approximately 47% lower. The single-row dibbler required more time than the drill but reduced labour by about 40% and cost by about 30% relative to manual dibbling. Its lower power requirement and compact design may suit orchard rows and plots that are difficult to access with a tractor.

The easy seedling transplanter increased the planting rate from 5–8 to 11–14 seedlings min^{-1} and reduced the estimated time per hectare from 83–111 h to 33–53 h. Because it required two workers, the reduction in labour input was more modest (about 12%), although the reported transplanting cost fell by approximately 38%. In addition to time and cost, the upright working posture may be an advantage over prolonged manual transplanting in a squatting or bent position.

Table 5 Performance of sowing and transplanting methods

Parameter	Multi-crop seed drill	Single-row dibbler	Manual dibbling	Easy transplanter	Manual transplanting
Operating speed (km h^{-1})	2.80	0.8–1.0	0.4–0.5	0.42–0.56	0.22–0.29
Seedlings planted (no. min^{-1})	–	–	–	11–14	5–8
Theoretical field capacity (ha h^{-1})	0.50	0.08	0.05	0.04	0.02
Effective field capacity (ha h^{-1})	0.35–0.40	0.05	0.03	0.019–0.030	0.009–0.012
Field efficiency (%)	70–80	62.5	60.0	47.5–75.0	45.0–60.0
Time per hectare (h ha^{-1})	2.5–2.9	20.0	33.3	33.3–52.6	83.3–111.1
Crew (no.)	2	1	1	2	1
Labour requirement (person-h ha^{-1})	5.0–5.7	20.0	33.3	66.7–105.3	83.3–111.1
Cost of operation (Rs ha^{-1})	1200–1800	1800–2200	2500–3200	1400–2000	2500–3000

Note: Means or ranges of six observations. Time per hectare = 1/EFC; labour = crew × time. LSD (p = 0.05): effective field capacity 0.028 ha h^{-1}; cost Rs 420 ha^{-1}.

3.4.3 Weeding and inter-culture

Weeding results illustrate the value of matching machine size to the operation (Table 6). The power weeder-cum-rotary tiller required 8.3–10.0 h ha^{-1}, compared with about 167 h ha^{-1} for the khurpi, corresponding to an estimated labour reduction of 94%. Its reported operating cost was Rs 1,800–2,500 ha^{-1}, compared with Rs 5,500–6,500 ha^{-1} for hand weeding. Similar benefits have been reported for power weeders in vegetable and row crops [17, 18]. The rotary-tiller attachment for a brush cutter also reduced labour input, to approximately 12.5–14.3 person-h ha^{-1}, and may be an option for farmers who already own a compatible brush cutter.

Among manually operated implements, the three-tyne wheel weeder covered about 3.3 times the area of the khurpi and reduced labour demand by approximately 70%, without fuel use. Its standing operating posture also reduced the need for sustained forward bending. The improved spade provided a smaller labour saving of about 25%. Faster weeding may help farmers complete the operation within the appropriate crop stage, although yield effects were not measured in these trials.

Table 6 Performance of weeding and inter-culture implements

Parameter	Power weeder-cum-rotary tiller	Brush cutter with rotary tiller	Three-tyne wheel weeder	Improved spade	Indigenous tools (khurpi)
Working width (mm)	600	450	250	180	150
Operating speed (km h^{-1})	2.0–2.5	1.5–2.0	1.0–1.2	0.5–0.8	0.4–0.6
Theoretical field capacity (ha h^{-1})	0.15	0.09	0.03	0.01	0.008
Effective field capacity (ha h^{-1})	0.10–0.12	0.07–0.08	0.02	0.008	0.006
Field efficiency (%)	66.7–80.0	77.8–88.9	66.7	80.0	75.0
Time per hectare (h ha^{-1})	8.3–10.0	12.5–14.3	50.0	125.0	166.7
Crew (no.)	1	1	1	1	1
Labour requirement (person-h ha^{-1})	8.3–10.0	12.5–14.3	50.0	125.0	166.7
Fuel consumption (l ha^{-1})	4.0–5.5	2.5–3.0	–	–	–
Cost of operation (Rs ha^{-1})	1800–2500	2200–3000	3200–4000	4500–5200	5500–6500

Note: Means or ranges of six observations. Time per hectare = 1/EFC; labour = crew × time. LSD (p = 0.05): effective field capacity 0.014 ha h^{-1}; cost Rs 580 ha^{-1}.

3.4.4 Cereal harvesting

Cereal harvesting showed a wide difference in labour demand among the tested methods (Table 7). The self-propelled reaper-binder harvested one hectare in about 3.52 h, compared with 275 h ha^{-1} for the indigenous sickle. Labour requirement declined from 275 to 31 person-h ha^{-1} (about 89%), while the reported harvesting cost fell from Rs 8,500–9,500 to Rs 2,703 ha^{-1}. These findings are consistent with studies evaluating reaper-binders for wheat [15, 16]. Timely harvesting may also reduce exposure to shattering, lodging and adverse weather, although these losses were not quantified in the present study.

The brush cutter with a harvesting attachment offered a smaller-machine alternative. With a two-person crew, the reported labour requirement was 83 person-h ha^{-1} and operating cost was Rs 4,500–5,500 ha^{-1}, but petrol consumption reached 24 L ha^{-1}. Field efficiency was approximately 20%. This option may be useful on small or irregular plots that are unsuitable for a reaper-binder, but fuel use and operator workload need to be considered [19]. The Falcon and CIAE improved sickles reduced labour demand by approximately 27% and 15%, respectively, relative to the indigenous sickle.

Table 7 Performance of cereal harvesting systems

Parameter	Reaper binder	Brush cutter	Falcon sickle	CIAE sickle	Indigenous sickle
Working width (mm)	1220	500–1250	500	500	500
Operating speed (km h^{-1})	3.60	1.80	–	–	–
Theoretical field capacity (ha h^{-1})	0.44	0.12	–	–	–
Effective field capacity (ha h^{-1})	0.28	0.024	0.0050	0.0043	0.0036
Field efficiency (%)	64.7	20.1	–	–	–
Time per hectare (h ha^{-1})	3.52	41.5	200	234	275
Crew (no.)	9	2	1	1	1
Labour requirement (person-h ha^{-1})	31	83	200	234	275
Fuel consumption (l ha^{-1})	3.52 (diesel)	24.0 (petrol)	–	–	–
Cost of operation (Rs ha^{-1})	2703	4500–5500	6500–7500	7000–8200	8500–9500

Note: Means or ranges of six observations. LSD ($p = 0.01$): effective field capacity 0.018 ha h^{-1}; cost Rs 620 ha^{-1}. Theoretical field capacity and field efficiency are not defined for hand sickles; their effective field capacity is 1/time.

3.5 Physiological workload of hand tools and small machines

Field capacity alone does not describe the physical demands placed on the operator (Table 8). In the on-station rice trials, the brush cutter achieved a field capacity of 0.045 ha h^{-1}, around 3.5 times the 0.013 ha h^{-1} recorded for an improved sickle. However, working heart rate reached 168 beats min^{-1} and estimated energy expenditure reached 18.0 kJ min^{-1}, classified as extremely heavy work under the adopted scale [22]. Work at this level is hard to sustain through a full working day [26]. The operator carries the engine on a harness and controls a vibrating shaft while moving through the crop. These results indicate that productivity gains should be weighed against workload, and that work-rest arrangements and equipment fit warrant attention. The study did not test a specific rest-break schedule.

The improved sickles showed a different pattern: modest changes in work rate accompanied by lower physiological demand. In rice, the Falcon sickle reduced working heart rate from about 120 to 107 beats min^{-1} and estimated energy expenditure from 10.4 to 8.2 kJ min^{-1}, shifting the workload classification from heavy to moderately heavy. In wheat, all three sickles were in the light or very-light categories, and estimated energy expenditure was lowest with the Falcon sickle. Body-part discomfort scores were also lower with the improved sickles than with the local sickle. These findings support considering handle design and blade performance

alongside output [9]. Pea sowing with the single-row dibbler in papaya and banana alleys remained very heavy work (13.6–14.9 kJ min^{-1}), suggesting that the implement's mass, wheel size or performance on uneven orchard paths merits further assessment.

Table 8 Physiological workload of harvesting and sowing with different tools (mean ± SD)

Operation	Tool	Working heart rate (beats min^{-1})	ΔHR (beats min^{-1})	Energy expenditure (kJ min^{-1})	Workload class
Rice harvesting	Indigenous sickle	120.33 ± 3.05	44.00 ± 5.29	10.41 ± 0.48	Heavy
	Falcon sickle	106.66 ± 2.51	24.00 ± 1.00	8.24 ± 0.40	Moderately heavy
	Brush cutter	168.33 ± 4.16	76.00 ± 2.64	18.04 ± 0.66	Extremely heavy
Wheat harvesting	Indigenous sickle	86.66 ± 0.66	12.33 ± 0.33	5.05 ± 0.10	Light
	CIAE sickle	86.33 ± 0.88	9.66 ± 1.20	5.00 ± 0.14	Very light
	Falcon sickle	83.33 ± 0.66	10.66 ± 0.33	4.50 ± 0.10	Very light
Pea sowing in papaya	Single-row dibbler	140.33 ± 2.51	52.66 ± 5.29	13.59 ± 0.40	Very heavy
Pea sowing in banana	Single-row dibbler	148.66 ± 4.04	60.00 ± 1.00	14.91 ± 0.64	Very heavy

Note: Energy expenditure from Eq. (3); workload class after Varghese et al. [22].

3.6 Sugarcane bud chipping

For sugarcane bud chipping, posture was strongly associated with the measured ergonomic outcome (Table 9; Fig. 7). The Strain Index was 60.8 with the traditional knife and 11.2 when the bud chipper was used while bending; both values were in the hazardous category under the thresholds applied here. When the chipper was used from a seated position, the index fell to 2.8, within the study-defined safe category, and body-part discomfort was lower. Output remained within approximately 14–16 buds min^{-1} across the conditions. Germination was 93.7% for chips prepared with the chipper and 80.8% for the traditional method. Bud chips carry little stored food and are easily injured [27], so a cleaner cut is the likely reason for the higher germination; germination was not recorded separately for each posture.

Table 9 Ergonomic and germination results for sugarcane bud chipping (mean ± SD)

Parameter	Traditional knife	Bud chipper, bending	Bud chipper, seated
Body-part discomfort score	17.00 ± 0.00	15.66 ± 0.57	9.33 ± 0.57

Strain Index	60.80 ± 0.00	11.23 ± 1.96	2.76 ± 0.40
Output (buds min^{-1})	15.66 ± 0.57	15.33 ± 1.15	14.00 ± 0.00
Germination of bud chips (%)	80.76 (894 of 1107)	93.65 (295 of 315)	



Fig. 7 Sugarcane bud chipping: (a) with the traditional knife; (b) with the bud chipper in a bending posture; (c) with the bud chipper while seated

3.7 Matching the tool to the task

Across operations, the results suggest that no single level of mechanisation is optimal for every small-farm task (Fig. 8). Tractor-drawn or self-propelled equipment sharply reduced labour demand in sugarcane planting, sowing and cereal harvesting, but purchase cost, field access and turning space may limit individual ownership on 0.2–0.4 ha plots. Custom-hiring services can provide access to these machines. For weeding, small powered implements achieved large labour savings at lower reported operating costs than manual methods. Improved hand tools were less productive than powered machines but required no fuel and often reduced physical demand. Vegetable harvesting remained dependent on a hand tool in this comparison, making the scissor relevant to a task that is difficult to mechanise with larger equipment.

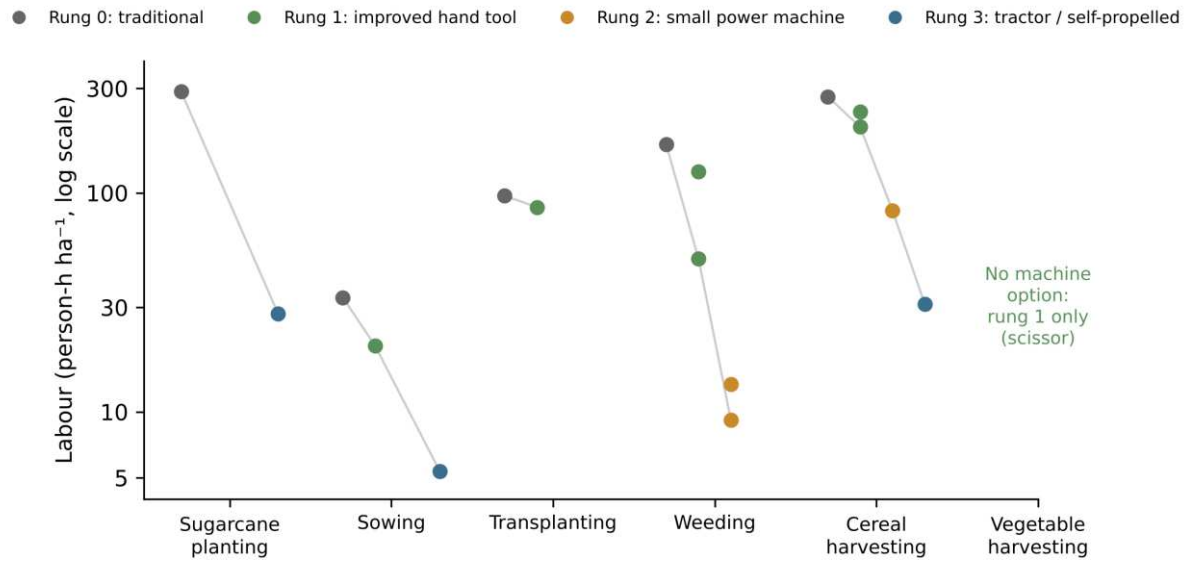


Fig. 8 Labour requirement for each operation at each rung of the mechanisation ladder (midpoints of the ranges in Tables 4–7; log scale). Lines join the lowest-labour option at each rung. Vegetable harvesting has no option above rung 1

Three practical implications follow. First, support and custom-hiring programmes should consider improved hand tools and small powered implements alongside tractors and combines. Second, field evaluations should report operator workload as well as field capacity, labour and cost, since the fastest option in these trials—the brush cutter—also produced the highest measured workload. Third, small, frequent and selective tasks such as vegetable picking warrant dedicated tool design because conventional machinery may not suit their working conditions.

The study has limitations. Comparative field trials were conducted in two villages and across two seasons in the irrigated western plain zone. Ergonomic assessments involved relatively small groups, and scissor trials covered five vegetables over periods shorter than a full working day. Several results are based on three replications, so precision and generalisability are limited. Further work should assess the tool across more locations, quantify cutting force and wrist posture, test durability and long-term comfort, and document adoption and maintenance costs.

4 Conclusions

This study developed and evaluated a 150 g Multi-Purpose Scissor for Agriculture and compared other small tools and machines used in common farm operations in western Uttar

Pradesh. The results support operation-specific mechanisation rather than a single machine-led approach. The principal findings are as follows:

1. The scissor reduced Strain Index scores by 44–69% across five vegetables and brought scores into the study-defined safe category in four crops. Output increased by 9–11% in bottle gourd, sponge gourd and bitter gourd, while it declined by 29% in brinjal. The tool avoided the 2–3% produce loss recorded with hand plucking and received favourable ratings from all 30 participating farmers. Its lower brinjal harvesting rate highlights a trade-off between speed and measured ergonomic risk.
2. The power weeder-cum-rotary tiller and brush-cutter rotary attachment reduced labour demand for weeding by approximately 92–94% relative to the khurpi. Improved sickles reduced physiological strain in rice and wheat harvesting, although the size of the benefit depended on the crop.
3. The seated bud-chipping arrangement reduced the Strain Index from 60.8 with a traditional knife to 2.8, while the reported germination rate for chipper-prepared material was higher than for the traditional method. The germination comparison should be interpreted cautiously because posture-specific germination results were not reported for all conditions.
4. Tractor-drawn and self-propelled machines reduced labour requirements by about 84–90% for selected planting, sowing and harvesting operations, but their cost and access requirements favour custom hiring on small plots. By contrast, the brush cutter used for cereal harvesting imposed an extremely heavy workload despite its higher field capacity.

Mechanisation support for small farms should therefore include shared access to larger machines, affordable small powered implements and ergonomically designed hand tools. Equipment selection should account for crop and plot conditions, labour and operating costs, and the physical workload imposed on operators.

Declarations

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Author contributions V. P. Chaudhary: conceptualisation, methodology, design and development of the multi-purpose scissor, field trials, data analysis and writing of the original draft. Nisha Verma: ergonomic measurements, comfort assessment, co-development and field testing of the scissor, and review and editing of the manuscript. Both authors read and approved the final manuscript.

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Data availability The data generated and analysed during this study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate Human participants: The study was approved by the Institute Ethics Committee constituted by the Director, ICAR–Indian Institute of Farming Systems Research, Modipuram, Meerut. All procedures involving human participants followed the principles of the Declaration of Helsinki, and informed consent was obtained from all individual participants included in the study.

Plant material: No wild plants were collected. All plant material in this study came from common cultivated crops, namely okra, bottle gourd, sponge gourd, bitter gourd, brinjal, sugarcane, rice, wheat, pea, papaya and banana. These crops were grown under routine farm management on the integrated farming system models of ICAR–IIFSR, Modipuram, and on farmers' own fields in Pahadpur and Pawersa villages, Meerut district, with the permission of the farmers. The vegetables harvested during the trials and the sugarcane canes used for bud chipping were taken from these crops as part of normal harvesting. The field work and the handling of plant material complied with the institutional guidelines of ICAR–IIFSR and with the relevant national guidelines and legislation of India. No endangered, protected or wild species were involved, and no species listed by the IUCN or under CITES was used; therefore, no specific permissions or licences were required for the plant material.

Consent for publication The participants shown in Figs. 3, 6 and 7 gave consent for their photographs to be published.

Competing interests The authors declare no other competing interests.

Use of AI-assisted technologies During preparation of this manuscript, generative AI-assisted tools were used to support language editing and code drafting. The authors reviewed and edited all content and take full responsibility for the publication.

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