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Comparative evaluation of wheat harvesting technologies for smallholder farms in West Champaran, Bihar: Economic and field performance assessment

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Abstract
Timely and efficient wheat harvesting is critical for yield preservation and economic returns, especially in labor-constrained smallholder farming systems such as those in West Champaran district, Bihar. This study assessed three wheat harvesting technologies: manual harvesting plus stationary threshing (T_1), tractor-mounted reaper-cum-binder plus stationary threshing (T_2), and self-propelled combine harvester (T_3). Field trials were conducted on 1-acre plots across ten farmers' fields during the 2022-23 season. Data on labor use, operational costs, fuel consumption, field efficiency, grain losses, yield, and economic returns were collected and statistically analyzed. Mechanized harvesting reduced labor by more than 98%, cut operational costs by up to 38%, and decreased harvest losses by nearly 50% compared to manual methods. The combine harvester (T_3) achieved the highest net returns (Rs 55,645/ha) and benefit-cost ratio (2.71), followed by the reaper-cum-binder (T_2). Field efficiencies exceeded 74% for mechanized methods, substantially outpacing manual harvesting (57%). Despite increased fuel consumption in mechanized treatments, overall profitability improved significantly. The results highlight the economic and ergonomic benefits of mechanized wheat harvesting technologies for smallholder farmers in Bihar and provide a strong rationale for policy and extension support to facilitate their adoption and scale-up.

Keywords: Wheat harvesting, mechanization, combine harvester, reaper-cum-binder, Labor saving, economic analysis, West Champaran, Bihar

1. Introduction
Wheat (*Triticum aestivum* L.) is a major contributor to food security and rural income in India, where states such as Bihar hold significant importance due to their extensive cultivation and reliance on smallholder farming systems (Bhattarai *et al.*, 2020; Van Loon *et al.*, 2020) [3, 15]. West Champaran district, in particular, is characterized by small, fragmented landholdings and a high degree of manual labor input for agricultural operations (Kisku & Singh, 2022) [9].

Traditional wheat harvesting, involving sickle-based cutting and stationary threshing, is increasingly challenged by escalating labor costs, acute workforce shortages, and the pressing need for timely harvest to minimize yield loss and optimize crop rotation (Kumar & Alamgir, 2022) [8].

Manual harvesting requires up to 150 man-hours per hectare in Bihar, resulting in substantial economic and ergonomic burdens (Sekhar & Bhatt, 2014) [13]. Drudgery and associated musculoskeletal disorders are widespread, particularly among women and older farmers who comprise much of the available labor pool. Further, delays in harvesting due to labor scarcity exacerbate grain losses from shattering, pests, and adverse weather (Kumar *et al.*, 2019) [9].

Agricultural mechanization offers a pathway to address these challenges. Particularly, tractor-mounted reaper-cum-binders and self-propelled combine harvesters have been introduced to streamline wheat cutting, bundling, and threshing, promising sharp reductions in labor input and enhanced operational efficiency. Mechanization enables increased cropping intensity, timely residue management, and opportunities for precision agriculture (Van Loon *et al.*, 2020) [15].

Field studies demonstrate labor cost reductions of Rs 1,500-2,500/ha and yield loss prevention of up to 20%.

Despite these advances, mechanization uptake in Bihar is constrained by financial barriers, lack of custom hiring infrastructure, small field sizes, and limited farmer awareness of technology benefits (CSISA Survey, 2014; Farmonaut Report, 2025) [16]. Government and donor initiatives have attempted to address these gaps by supporting equipment banks and knowledge diffusion, yet localized field evidence is essential to inform scalable intervention (Van Loon *et al.*, 2020) [15].

This study investigates wheat harvesting technologies in West Champaran, comparing manual methods, reaper-cum-binder, and combine harvester across ten representative 1-acre farmer fields. The aim is to quantify economic, ergonomic, and field efficiency performance under real-world, smallholder conditions, thus informing regional and national mechanization strategies.

2. Materials and Methods

2.1 Study Location and Design

Field trials were conducted in West Champaran district, Bihar, during the 2022-23 rabi season. Ten farmers were selected via stratified random sampling based on farm size, soil type, and previous yield records to represent typical smallholder conditions and field variability in West Champaran. Each 1-acre trial plot received uniform pre-sowing management, including land preparation, fertilizer application, irrigation schedule, and pest management practices, using the wheat variety DBW-187 to maintain consistency across treatments ((Kumar *et al.*, 2019) [9].

2.2 Treatments

Three wheat harvesting interventions were compared:

- T_1 (Traditional Farmer Practice): Manual sickle cutting and stationary thresher
- T_2 (Semi-Mechanized): The tractor-mounted reaper-cum-binder (Swan Agro Reaper Binder (Model: NSERB 30), working width 1.37 m, age 3 years) was used along with a stationary thresher (Model ABC).
- T_3 (Fully Mechanized): The self-propelled combine harvester working width 3.6 m, year 2021) integrated cutting and threshing functions.

T1; Manual harvesting using sickle +thresher | T.O.2; Wheat cutting using reaper cum binder | T.O.3; Wheat cutting using combine-harvester

Fig 1: Different wheat harvesting technologies

All machinery operations conformed to BIS standards for field performance and safety evaluation (Devani & Pandey, 1985) [6].

2.3 Data Collection and Analysis

Collected data included labor input, fuel consumption, field efficiency, grain losses, yields, and economic returns. Data normality and homogeneity of variances were tested prior to analysis. Statistical comparisons between treatments were performed using one-way ANOVA followed by Tukey's HSD test at a 5% significance level (Kumar *et al.*, 2017) [10]. Each treatment was evaluated across ten independent farmer fields, considered as replications, to capture field-to-field variability under real farm conditions

Fig 2: Data Measurement in manual harvesting

3. Results

The results obtained from the comparative evaluation of three wheat harvesting technologies—manual harvesting with stationary threshing (T_1), tractor-mounted reaper-cum-binder with threshing (T_2), and self-propelled combine harvester (T_3)—are presented here. Data were compiled from trials conducted on 1-acre plots across ten farmers' fields in West Champaran district, Bihar.

3.1 Economic Analysis
Economic analysis of different wheat harvesting operation are presented in Table1. The total labor requirement showed a pronounced reduction with mechanization. Manual harvesting (T_1) demanded the highest labor input of 150 man-hours per hectare, reflecting the intensive nature of sickle harvesting and manual bundling. In contrast, both mechanized treatments (T_2 and T_3) required only 2 man-hours per hectare, including the tractor driver and one helper for the combine harvester (Table 1). This represents a dramatic labor saving exceeding 98%, which can substantially alleviate labor scarcity during peak harvest periods.

The operational costs similarly followed this trend. While the manual method (T_1) incurred the highest harvesting cost of Rs 8063/ha—including Rs 4688 for cutting and bundling, Rs 375 for bundle collection, and Rs 3000 for threshing—treatment T_3 using the combine harvester recorded the lowest overall cost at Rs 5000/ha (Table 1). The reaper-cum-binder (T_2) presented intermediate costs with a 20.93% savings relative to manual practice, highlighting it as a cost-effective intermediary technology. Notably, threshing costs were eliminated in T_3 due to the combine's integrated threshing and cleaning operations.

Table 1: Economic analysis of different treatments of Wheat Harvest operation

S. No.	Parameter	T_1 (Manual+ Thresher)	T_2 (Reaper+ Thresher)	T_3 (Combine Harvester)
1	Total labour requirement (man-h/ha)	150	2	2
2	Harvesting & bundling cost (Rs/ha)	4688	3000	5000
	Bundle collection cost (Rs/ha)	375	375	0
	Threshing cost (Rs/ha)	3000	3000	0
3	Total cost of harvesting operation (Rs/ha))	8063	6375	5000
6	Cost saving vs T_1 (%)	—	20.9	38.0

3.2 Cost of Cultivation and Economic Returns
A detailed breakdown of wheat cultivation costs, returns, and benefit-cost ratios (BCR) is provided in Table 2. Costs for land preparation, seed and sowing, fertilizers and weed control, irrigation, and miscellaneous expenses were uniform across treatments, isolating harvesting operation as the main variable cost

Harvesting operation costs significantly decreased with mechanization, from Rs 8,063/ha in manual harvesting (T_1) to Rs 6,375/ha for the reaper-cum-binder (T_2), and Rs 5,000/ha for the combine harvester (T_3), showing a cost saving of up to 38% relative to manual practice. This reduction reflects the mechanized technologies' efficiency in cutting, bundling, and threshing

Yield slightly improved with mechanization, from 46.2 qt/ha in manual practice to 47.0 qt/ha with the combine harvester, though the difference was small. Gross returns remained constant at Rs 88,110/ha across all treatments, assuming uniform market price. Net returns improved substantially with mechanization, with the highest value of Rs 55,645/ha recorded for T_3, followed by Rs 54,270/ha for T_2, and Rs 52,582/ha for T_1. The benefit-cost ratio (BCR) corroborates this trend, with T_3 showing the best economic efficiency at 2.71, compared to 2.603 for T_2 and 2.48 for T_1. These results clearly demonstrate that mechanized harvesting methods reduce operational costs and improve profitability for smallholder farmers in West Champaran, although yield increases were marginal. Such economic incentives strongly support the adoption of mechanization under local conditions

Table 2: Overall Cost of Cultivation

Practice	T_1	T_2	T_3	SEM	CD
Land preparation	5000	5000	5000	-	-
Seed & sowing	4800	4800	4800	-	-
Fertilizer/weeds	10000	10000	10000	-	-
Irrigation	3750	3750	3750	-	-
Miscellaneous	1260	1260	1260	-	-
Harvesting operation	8063	6375	5000	60.33	0.35
Yield (qt/ha) *	46.2	46.5	47.0	0.36	NA
Gross return	88110	88110	88110	NA	NA
Net return	52582	54270	55645	426.7	1278
BCR	2.48	2.603	2.71	0.019	0.057

*1 quintal (qt) = 100 kg

3.3 Field Efficiency, Fuel Consumption and Harvesting Losses while operation
Mechanized technologies substantially improved field operational efficiency and capacity. The theoretical field capacity ranged from a low 0.014 ha/hr in manual harvesting (T_1) to 0.9 ha/hr using the combine (T_3 Effective field capacity followed this trend, with T_3 recording the highest value (0.67 ha/hr), and treatments significantly different from one another as indicated by Turkey HSD pairwise comparison (a, b, c) (Table 3). Field efficiency (percentage of theoretical capacity achieved) was also significantly different across treatments ($p<0.05$), with the highest efficiency recorded for the reaper-cum-binder at 80%, followed by the combine at 74%, and manual at 57.14%.

Fuel consumption increased from negligible (manual) to 3.7 L/ha for the reaper-cum-binder and 35 L/ha for the combine harvester, with all treatments differing significantly ($p<0.05$). Harvesting losses were substantially reduced with mechanization, from 28.8 kg/ha in manual harvesting to 24.5 kg/ha in the reaper-cum-binder and 15 kg/ha in the combine, all statistically significant differences ($p<0.05$).

Overall, the improvements in operational metrics confirm the efficacy of mechanized wheat harvesting in increasing productivity and reducing losses under smallholder conditions.

Table 3: Field Efficiency and Losses

Parameter	T_1	T_2	T_3	SEm (±)	C.D. (p≤0.05)	F value	P value
Fuel consumption (L/ha)	Nil	3.7	35.0	0.15	0.45	16529.1	0.00
Theo. field cap. (ha/hr)	0.014	0.342	0.90	0.004	0.012	11,971.440	0.00
Eff. field cap. (ha/hr)	0.008 (a)	0.273 (b)	0.67 (c)	0.004	0.0012	6991.6	0.00
Field efficiency (%)	57.14 (a)	80 (b)	74 (c)	0.34	1.01	1231.2	0.00
Harvesting losses (kg/ha)	28.8 (a)	24.5 (b)	15 (c)	0.17	0.51	1701.381	0.00
Note*-(Turkey HSD pairwise comparison) Mean that do not share a letter are significantly different represented by a,b and c; Sem = Standard error in mean; C. D-Critical difference,							

4. Discussion

This study conducted during the 2022-23 wheat season in West Champaran, Bihar, demonstrates that mechanized wheat harvesting technologies provide substantial advantages over traditional manual methods. Mechanization drastically reduced labor requirements—from 150 to 2 man-hours per hectare—addressing critical labor shortages and reducing the physical burden associated with manual harvesting (Kumar & Alamgir, 2022) [8].

Combine harvesters offered the greatest cost savings, reducing total harvesting costs by nearly 38%, and delivered the highest net returns and benefit-cost ratio. Tractor-mounted reaper-cum-binders provided a viable intermediate mechanization option, balancing costs, efficiency, and accessibility for smallholder farmers (Rao & Meena, 2019) [12].

Mechanized harvesting also enhanced field efficiency (up to 80%) and substantially lowered grain losses, thereby improving effective yields and farm profitability. Although fuel consumption was higher in mechanized treatments—especially combine harvesters—the overall economic benefits outweighed these costs (Tafa *et al.*, 2022; Huda *et al.*, 2019) [14, 2].

An important consideration beyond economics and operational metrics is the quality of wheat residue produced. Reaper-cum-binder systems produce longer, coarser straw preferred as feed in small to medium farms with livestock. Conversely, combine harvesters generate finely chopped straw more suitable for residue management but less ideal as fodder. Therefore, farmers with significant livestock are more likely to favor reaper-cum-binder technology, while large-scale farmers may prioritize the efficiency and residue benefits of combine harvesters. This highlights the need for alignment of mechanization options with farm size and resource use (Tafa *et al.*, 2022; Huda *et al.*, 2019) [14, 2].

These findings corroborate regional mechanization research and emphasize the necessity for policy support to improve machinery access through custom hiring, training, and financing schemes (Farmonaut Report, 2025; Kisku & Singh, 2022) [16, 7]. Future multi-season research will help validate these conclusions and explore integration with sustainable practices.

5. Conclusion

The study demonstrates that mechanized wheat harvesting technologies outperform traditional manual harvesting in labor efficiency, cost-effectiveness, field performance, and grain preservation under smallholder farm conditions in West Champaran, Bihar. The self-propelled combine harvester delivered the greatest economic returns and operational efficiency, while the tractor-mounted reaper-cum-binder offers a practical and cost-effective intermediate mechanization option suited to smaller farms.

Mechanization substantially reduces labor input, thereby lowering the risk of harvest delays and the associated yield losses. Although mechanized harvesting methods incur higher fuel consumption, the improvements in net profitability and benefit-cost ratios are remarkable.

Furthermore, residue characteristics differ between technologies: the coarser straw produced by reaper-cum-binders is preferable for livestock feed on small to medium farms, whereas the finely chopped residue from combine harvesters benefits large-scale farms focusing on efficient residue management. This differentiation should guide technology choice based on farm size and integrated farming objectives.

These findings advocate for enhanced access to mechanized harvesting through customized service models, farmer training programs, and institutional support to overcome financial and operational barriers. Scaling up mechanization can significantly contribute to sustainable wheat production, raise farmer incomes, and improve labor welfare in Bihar's smallholder-dominated agricultural systems.

Future research should focus on assessing long-term impacts, regional scalability, and integration of mechanization with conservation agriculture practices to bolster regional food security and environmental sustainability.

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