Integrating indigenous traditional knowledge and ergonomic efficiency for sustainable millets farming: a study from Koraput, Odisha, India

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Millets offer significant potential for sustainable agriculture in tribal regions, yet the role of Indigenous Traditional Knowledge and the ergonomic burden on farmers, particularly women remain underexplored. This study addresses these gaps by examining the interplay between Indigenous Traditional Knowledge, physical drudgery, and millet farming practices in Koraput, Odisha. Despite wide use of ecologically sound traditional methods, farmers especially women face substantial drudgeries in post-harvest tasks such as threshing, de-hulling, and grinding. A mixed-methods approach was used to collect data from 100 randomly selected tribal farmers across three villages through structured interviews, key informant interviews, focus group discussions, and field observations. The human physical drudgery index was applied to assess ergonomic risks. Findings showed that traditional practices, while sustainable, impose very high physical strain in case of threshing (Drudgery Index = 84.63) and flour making (Drudgery Index = 71.62), ranked as the most drudgery-intensive operations. Improved tools significantly reduced the human physical drudgery index but were underutilized due to affordability, limited access, and cultural preferences. The study highlights the need to integrate validated indigenous traditional knowledge with gender-sensitive ergonomic innovations to enhance sustainability and farmer wellbeing. Policy measures should focus on self-help groups led and or custom hiring services of the machinery, expanding participatory extension, and subsidies for women-friendly equipment. Reducing drudgery while preserving traditional knowledge is key to resilient and inclusive millet-based farming systems.

KEYWORDS

drudgery reduction, ergonomic efficiency, gender, indigenous traditional knowledge, sustainable millets farming, tribal agriculture

1 Introduction

Sustainable agriculture is widely recognized as a vital response to the intertwined global challenges of food insecurity, climate change, soil degradation, and rural poverty (Dubey et al., 2021). It offers an integrated approach to farming that balances productivity with environmental stewardship and social equity. At its heart, sustainable agriculture aims to ensure food and livelihood security for present and future generations by conserving

natural resources and enhancing the resilience of farming communities (Mekouar, 2023; Godfray et al., 2010; Garnett et al., 2013).

In this context, millets, a group of ancient, small-grained cereals such as pearl millet, finger millet, and sorghum, have re-emerged as critical crops in the face of climatic and nutritional challenges. Millets are highly resilient: they require little water, grow well on marginal lands, and are more tolerant to pests and drought compared to many major cereals. Their cultivation can help reduce dependency on resource-intensive crops like rice and wheat, which demand higher inputs and are more vulnerable to climate extremes (FAO, 2021; Yadav et al., 2024; Dubey et al., 2023). Additionally, millets offer a robust nutritional profile, rich in dietary fiber, protein, iron, calcium, and antioxidants, making them effective tools in addressing malnutrition and hidden hunger in developing countries (Sarita and Singh, 2016; Banerjee et al., 2020; Patil et al., 2023). Despite these advantages, millet cultivation remains marginalized in policy frameworks, research funding, and modern agricultural interventions. A critical but often neglected component is the contribution of Indigenous Traditional Knowledge (ITK) as the collective wisdom, practices, and innovations developed by farming communities over generations. Traditional millet farming in tribal regions integrates ecological knowledge, local biodiversity, and adaptive techniques such as intercropping, crop rotation, seed conservation, and natural pest control (Soumya et al., 2025; Sumane et al., 2018). These practices are not only environmentally sustainable but are deeply embedded in the cultural and social fabric of tribal life (Saraogi et al., 2025).

Moreover, the role of ITK in promoting ergonomic efficiency is especially important. Farming in tribal and rural areas is often labor-intensive, with women bearing the brunt of physically demanding tasks like sowing, weeding, harvesting, threshing, and processing. Traditional tools such as locally made sickles, hand threshers, and stone grinders have evolved to meet community-specific needs, often minimizing physical strain and making farming tasks more manageable (Ludovic et al., 2020; Rajan et al., 2023). However, these tools are increasingly being replaced or inadequately supplemented by modern equipment that may be costlier, energy-intensive, or ergonomically unsuited to local contexts. Modern innovations that build on indigenous designs, such as low-cost hand mills or energy-efficient threshers, offer significant potential to reduce drudgery, improve work efficiency, and enhance the quality of life for rural women and smallholder farmers (UN, 2020; Patil et al., 2023). Yet, there remains a significant awareness and accessibility gap. Many farmers are unaware of these technologies or lack the means to acquire them. There is also limited documentation and validation of the ergonomic benefits and cultural relevance of these tools. This gap not only affects the physical wellbeing of farmers especially women but also limits broader adoption of millets in rural livelihoods and national food security strategies.

While much literature available on the agronomic and nutritional benefits of millets, research on community-driven innovations, gendered labor dynamics, and ergonomic aspects of millet farming remains sparse. Latest study in Eastern India has shown that farmers' food literacy plays a decisive role in shaping millet production outcomes, yet such dimensions remain underexplored in Odisha (Swain et al., 2024). Existing studies often adopt a top-down approach, focusing on yield or policy, without engaging with the knowledge systems and labor realities of smallholder and tribal farmers (Giller et al., 2021; Gupta et al., 2025). There is a lack of integrated studies that connect ITK, ergonomic efficiency, gender roles, and sustainability in millet-based systems. Furthermore, traditional knowledge is at risk of being lost as younger generations shift away from farming and local innovations remain undocumented or undervalued. Despite the growing recognition of millets as climate-resilient and nutrition-rich crops, their cultivation and processing in tribal and marginalized communities face multiple challenges. There is an urgent need to understand and integrate Indigenous Traditional Knowledge and ergonomic practices into sustainable agriculture frameworks (Dubey et al., 2022). The lack of awareness, documentation, and policy support for such community-led innovations continues to limit the scalability, inclusiveness, and sustainability of millet-based systems.

This study emerges from a simple but urgent question: *How can we strengthen millet-based farming in a way that honors and builds upon the knowledge and tools already in use by tribal communities?* It seeks to fill the knowledge gap between traditional wisdom and modern sustainability efforts by documenting the role of Indigenous Traditional Knowledge and ergonomically efficient practices in millet farming. It aims to address these critical gaps by exploring how tribal communities utilize indigenous knowledge and ergonomically efficient tools in millet farming. By adopting a mixed-methods approach involving the Human Physical Drudgery Index (HPDI) and participatory tools, the study provides empirical evidence for policy and programmatic action that respects traditional wisdom while promoting labor efficiency. It seeks to document and analyze traditional and improved practices that reduce labor drudgery, enhance ecological resilience, and improve livelihood outcomes. By capturing both the scientific and human dimensions of millet farming, the study contributes to a more holistic and inclusive model of sustainable agriculture, one that values traditional wisdom, respects local labor realities, and supports the food and livelihood security of vulnerable communities.

2 Materials and methods

2.1 Study area

The research was conducted in Koraput district, Odisha, located in the Eastern Ghats Highland agro-climatic zone of India. Recognized as a *Globally Important Agricultural Heritage System (GIAHS)* by the Food and Agriculture Organization (Singh and Rana, 2019), Koraput has an elevation ranging between 500 and 1,600 m above sea level (Figure 1). The terrain is predominantly undulating, comprising hill slopes, uplands, and valleys. The total geographical area of the district is approximately 8,807 square kilometers, of which around 70% is under forest cover or fallow land, and about 25% is classified as cultivable (Government of Odisha, 2014). The district experiences a tropical monsoon climate, receiving an average annual rainfall of 1500–1600 mm, concentrated during the southwest monsoon (June to September). Temperature ranges between 10 °C in winter and

FIGURE 1
Map showing the study area of Koraput in Odisha.
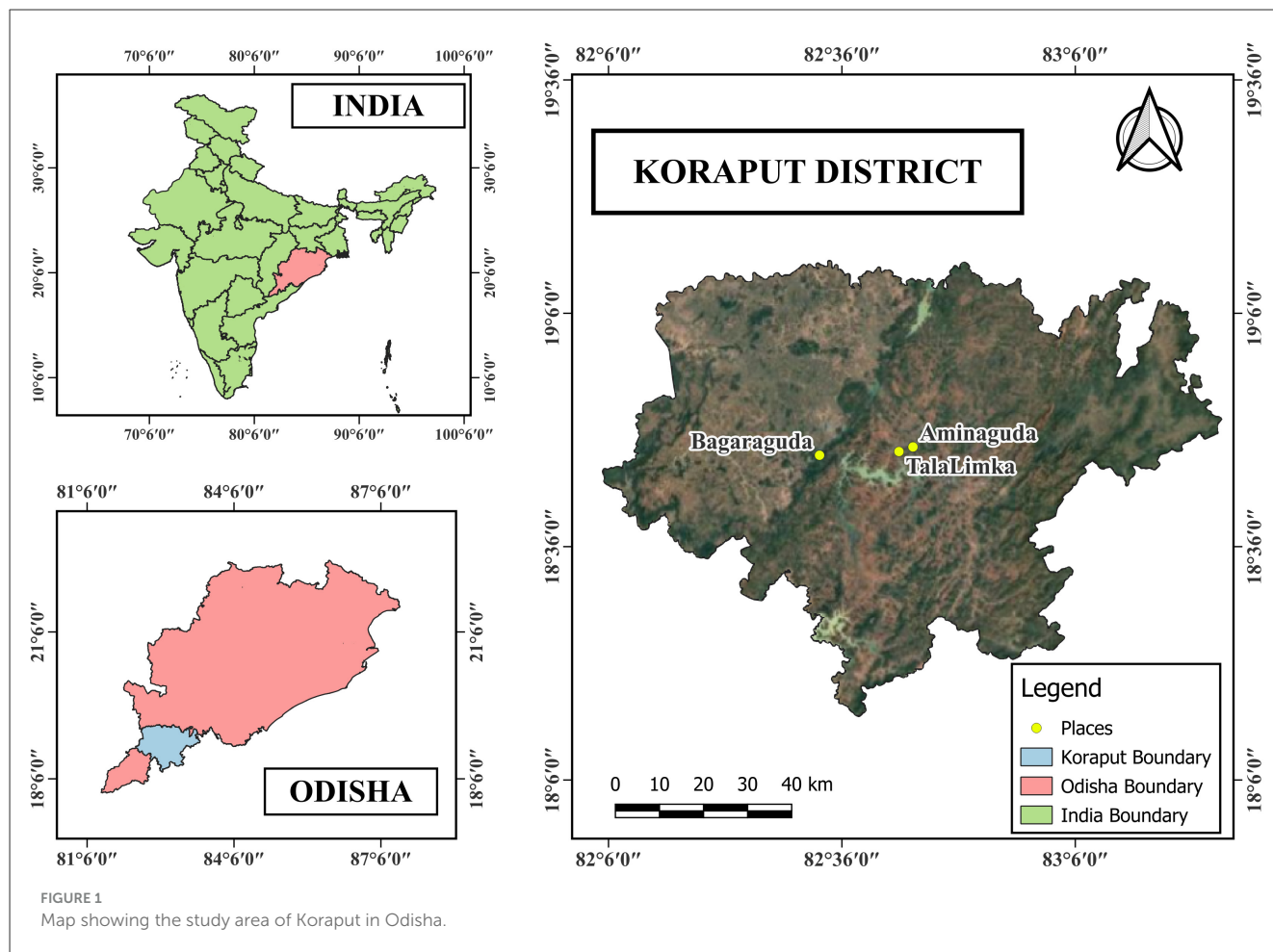
35 °C in summer. Koraput exhibits a diverse land use pattern, with agriculture largely concentrated on terraced and shifting cultivation plots, locally known as *podu* lands. The cropping system is predominantly rainfed, with millets such as finger millet, pearl millet, and foxtail millet occupying a central role. Koraput district has 72,689 ha under millet cultivation, producing nearly 6.1 lakh quintals (Sanabada et al., 2025). It has one of the largest millet cultivation areas in Odisha, with 13.48 thousand hectares under ragi and 1.22 thousand hectares under other millets in 2023–2024 (Directorate of Agriculture Farmers' Empowerment, 2025). The Koraput is among the top most districts in Odisha that producing millets. These are often intercropped with legumes and pulses, forming a biodiverse system well-suited to the agro-ecological conditions. Traditional cropping practices are embedded in Indigenous Traditional Knowledge that ensures environmental sustainability and household-level food security (Soumya et al., 2025; Singh and Gupta, 2024).

2.2 Sampling and participant selection

A multi-stage sampling approach was employed to identify study sites and respondents to achieve objectives of the study (Figure 2). In the first stage, three millet-growing tribal villages; Aminaguda, Bagaraguda, and Talalimika were purposively selected in consultation with local agricultural extension officers and tribal development agencies. These villages were chosen for their demographic diversity, millet cultivation history, and access to traditional knowledge systems.

In the second stage, a list of households engaged in millet farming was obtained from the village administration office (Gram Panchayat) records and cross-verified with inputs from Krishi Vigyan Kendras (KVKs) and local NGOs. From these lists, 100 farmers were randomly selected to participate in the study. The inclusion criteria included (i) minimum 5 years of experience in millet cultivation, (ii) belonging to a Scheduled Tribe household include, *Desia, Kondh, Paroja, Gadaba, Amantya, Bhatara, Koya*, and *Dhurua*, and (iii) willingness to participate in interviews and group discussions. Stratification was applied to ensure representation across gender, age, landholding size, and innovativeness. Special attention was given to include youth farmers, women-headed households, and traditional knowledge custodians to enrich data diversity and reliability.

2.3 Data collection

A mixed-methods design was adopted to capture both quantitative and qualitative dimensions of indigenous knowledge and drudgery in millet cultivation. A pre-tested semi-structured

Agro-ecological & Social Context (Koraput)

⬇

Indigenous Knowledge (ITK) related to millets

↔

Ergonomic labor (Drudgery, Gender Roles)

⬇

Sustainable Millet Farming System

(Traditional vs Improved Practices)

⬇

Data Collection (Survey, KII, FGD, HPDI)

⬇

Analysis & Triangulation

FIGURE 2
Conceptual framework of the study.

interview schedule was administered to all 100 respondents. It was validated by experts and pre-tested with 10 respondents' representative of the sample and not included in the study to ensure the questions were effective and easy to understand. The response from pre-testing helped to refine and re-structure the final data collection schedule. Accordingly, the schedule was finalized with the necessary modifications. They were explained purpose of the data collection and obtained their consent for sharing the data at the beginning. The schedule collected information on socio-demographic profile, landholding, cropping patterns, details of ITK, time spent on different farm operations, postural discomfort, and workload intensity. Ergonomic parameters were quantified using the Human Physical Drudgery Index (HPDI), which incorporates seven weighted indicators: time spent (h/year), task performance frequency, difficulty score, posture type, frequency of posture change, postural discomfort, and load carried or lifted. The methodology followed the framework proposed by Kundu et al. (2021), with scoring criteria for posture and discomfort adapted from Sam and Kathirvel (2008) and Anitha et al. (2019), respectively. A total of 15 Key Informant Interviews (KIIs) were conducted with experienced farmers, women self-help group (SHG) members, agricultural officers, and community elders. These informants were selected for their experiential knowledge of traditional millet practices, land management systems, and historical changes in cropping patterns. Interviews were semi-structured and used guiding prompts to explore the rationale behind indigenous practices, seasonal labor burdens, and changing agro-ecological conditions. Interviews were conducted in the local dialect with the help of translators and were audio-recorded for accuracy.

Six Focus Group Discussions (FGDs) were conducted three with women and three with men each comprising 8–12 participants. FGDs explored group-level knowledge on millet-based cropping systems, seasonal calendars, traditional tools, gender roles, and perceived benefits or constraints of indigenous and modern practices. The discussions also delved into social acceptability, workload distribution, and challenges faced in adopting improved tools or methods. These sessions were guided by participatory rural appraisal techniques and helped identify both consensus and gendered differences in experiences. Field observations were recorded during millet harvesting and post-harvest processing periods to capture real-time data on body posture, tool use, and labor intensity. Observations focused on tasks such as threshing, weeding, drying, de-hulling, and flour making. Photographic and video documentation was used to record ergonomic postures and validate self-reported drudgery indicators. These visuals supported post-survey analyses and interpretation of HPDI results.

2.4 Data analysis and triangulation

Quantitative data were processed using descriptive statistical tools such as means, percentages, and standard deviations. HPDI scores were computed for each operation, and their severity was categorized using ergonomic risk thresholds following Joshi et al. (2024). Comparative analysis was done to assess the difference in drudgery levels between traditional and improved millet farming methods. Qualitative data from KIIs and FGDs were transcribed, translated, and analyzed using thematic

content analysis. Codes were developed inductively to identify recurring themes related to land use decisions, cropping patterns, cultural practices, gender roles, and drudgery perceptions. Triangulation was applied at multiple levels: data from the respondents and KIIs were cross-validated with FGDs; structured interview data were corroborated with field observations; and land use patterns reported by farmers were verified through pictorial images and secondary data (Government of Odisha, 2014). This triangulated, multi-method approach strengthened the internal validity and credibility of the research findings, allowing for nuanced interpretation of indigenous knowledge, gendered labor burdens, and ergonomic risks in tribal millet farming systems.

The physical drudgery experienced by farm women in various post-harvest operations was quantified using the human physical drudgery index (HPDI), as outlined above. Primary data were collected using a structured interview schedule that covered profile characteristics, time spent on each farm activity, frequency of task repetition throughout the production cycle, perceived difficulty of the operation, body posture adopted, postural discomfort, and load or force handled in the selected post-harvest operations in millets. Time spent was recorded as the total number of hours per day devoted to each operation, multiplied by the total number of days the task was performed in a year. Task Performance score was assigned based-on the seasonal frequency of task repetition as 1–2 times = 1, 3–4 times = 2, 5–6 times = 3, 6–7 times = 4, and more than 7 times = 5. The perceived difficulty was rated on a five-point scale adapted from Tripathi et al. (2018) with contextual modifications as, Very Easy = 1, Easy = 2, Neutral = 3, Difficult = 4, and Most Difficult = 5. Body posture during each operation was classified as, upright Trunk flexion/extension (0–20°), Trunk flexion (20–60°) or extension >20°, and Trunk flexion >60° as described by Sam and Kathirvel (2008) assigning score as, upright = 1, trunk flexion/extension (0–20°) = 2, trunk flexion (20–60°) or extension >20° = 3, and trunk flexion >60° = 4, additional points (+1 each) were added if the task involved back twisting, squatting/stooping, static postures held for longer than 1 min, or repetitive movements. The frequency of posture changes was scored as 1–3 times = 1, 4-6 times = 2, 7–9 times = 3, and more than 9 times = 4, perceived discomfort measured using a psychophysical scale given by Anitha et al. (2019) such as Very Light = 1, Light = 2, Moderate = 3, Severe = 4, and Very Severe = 5, and the weight lifted or carried during operations was rated as, 0–5 kg = 1, 5–10 kg = 2, 10–15 kg = 3, 15–20 kg = 4, and more than 20 kg = 5. The overall physical drudgery for each activity was calculated using the human physical drudgery index (HPDI) formula as given below:

$$HPDI = \frac{A + B + C + D + E + F + G^*}{7} 100 \qquad (1)$$

where:

A = time spent (h/year) = time in h/day × total no of days performed in a year

B = task performance score (in Season)

C = difficulty score of activity

D = body posture adopted

E = frequency of postural change

TABLE 1 Categorization of human physical drudgery index (HPDI).

Categorization of HPDI	Action level	Interpretation
<20	I	Low risk, no need to change
20–30	II	Medium risk, change required
30–40	III	High risk
>40	IV	Very high risk, need necessary action immediately

TABLE 2 Different practices of indigenous traditional knowledge and improved practices in millet cultivation.

S. N	Operation	Traditional methods	Improved methods
1	Land preparation	Plowing with bullocks	Tractor plowing
2	Seed treatment	Soaking in cow urine	Chemical seed treatment
3	Sowing	Manual broadcasting	Seed drill sowing
4	Weeding	Manual weeding with a spade	Mechanical weeder
5	Nutrient management	Cow dung & organic manure	Fertilizer sprayer
6	Crop cutting	Manual cutting with sickles	Power reaper
7	Threshing	Beating with bamboo sticks	Pedal-operated thresher
8	Drying	Sun drying on the ground	Solar dryer
9	Winnowing	Traditional Kulla	Power winnower
10	De-hulling	Manual pounding with a stone	Motorized de-huller
11	Flour making	Grinding with a stone mill	Motorized flour mill
12	Flatbread making	Manual kneading and rolling	Automatic roti maker

F = postural discomfort

G = load/force

Based on the calculated Human Physical Drudgery Index (HPDI) values, operations were classified into four action levels (Table 1), as done by Kundu et al. (2021). Different practices of indigenous traditional knowledge and improved practices in millet cultivation in Koraput (Table 2).

3 Results

3.1 Socio-economic characteristics of millet farmers

The socio-economic characteristics of the 100 millet farmers surveyed include demographic, educational, occupational,

TABLE 3 Socio-economic characteristics of millet farmers in Koraput.

S. No.	Variable	Category	Frequency (%)	Mean	Standard deviation
1	Gender	Male	71	1.71	0.46
		Female	29		
2	Age group	Young (<35 years)	46	36.19	9.44
		Middle (35-45 years)	38		
		Old (>45 years)	16		
3	Education	Illiterate	47	1.27	1.28
		Primary (Up to 7th std.)	34		
		Higher Secondary (Up to 12th std)	18		
		Graduate and above	1		
4	Social category	General	0	1.11	0.37
		OBC	2		
		SC	7		
		ST	91		
5	Occupation	Agriculture	69	2.29	0.48
		Subsidiary	1		
		Both	30		
6	Annual Income (₹)	Low (<₹64,200)	31	₹72,489	₹23,721.24
		Medium (₹64,200–₹74,400)	50		
		High (>₹74,400)	19		
7	Family size	Nuclear family	37	0.49	0.70
		Extended family	63		
8	Land holding (ha)	Low (<0.72 ha)	34	1.20	1.12
		Medium (0.72-1.68 ha)	46		
		High (>1.68 ha)	20		
9	Innovativeness	Low	28	4.29	1.51
		Medium	53		
		High	19		

and landholding aspects that influence agricultural decision-making and sustainability practices were identified for the study (Table 3). The results revealed that majority (66.4%) belong to Scheduled Tribes, confirming the tribal dominance in Koraput's agricultural landscape. More than half of the respondents (57.6%) were aged above 40, and only 17.6% were youth (below 30 years), indicating a generational shift away from farming. Landholding size was predominantly marginal; 72% of respondents operated less than 2 acres, consistent with national data on tribal smallholders. Notably, 63.2% of households were headed by males, but women played a primary role in post-harvest operations.

Most households relied on rainfed agriculture, and only 18.4% reported access to any form of irrigation. Education levels were low indicating 44% were illiterate, and only 9.6% had education beyond secondary school. Furthermore, 84% of respondents had annual incomes below Rs. 60,000 (Rs = Indian currency), highlighting the economic vulnerability of the population. Only 13.6% used any improved farm tools regularly, underscoring low mechanization and a dependence on traditional practices.

3.2 Indigenous Traditional Knowledge (ITK) practices in millet farming

Table 4 outlines the ITK practices adopted by the respondents. Seed treatment with ash and cow dung was widely used by 86.4% of farmers, believed to prevent pest infestation and improve germination. Traditional broadcasting of seeds, line sowing with sticks, and hand weeding were still the norm. Organic formulations such as neem leaf extracts and cow urine were commonly used for pest deterrence, showing ecological consciousness among tribal farmers (Figure 3).

TABLE 4 Production practice-wise indigenous traditional knowledge of millet farmers in Koraput.

S. No.	Production practice	ITKs and method	Purpose	Benefit	Respondents (%)
1	Soil selection	Light to medium soil is preferred	Enhances water drainage, promotes growth and yield	Avoid wilting of the crops	50
2	Land preparation	At least one harrowing at the start of the monsoon	Loosens soil, improves aeration in the soil	Better seed germination and crop growth	90
3	Seed treatment	Soaking of seeds in water to remove light-weighted seeds cow urine treatment	Controls insects, ensures seed germination	Improves crop immunity and germination rate	90
4	Sowing method	Sowing from South to North direction and laborers work start in West to East direction	Avoid crop lodging, purity, protects from high wind velocity	Higher survival rate of fine crop	80
5	Indigenous nutrient management	Using farmyard manure, cow dung, animal waste, dried leaves	Provides essential micronutrients	Improves soil fertility and crop yield	60
6	Weed management	Manual weeding using spades find local sickles	Reduces competition for nutrients and keep field clean	Leads to low pest attack and higher yield	90
7	Pest control	Using wood ash or dry wood ash from firewood dissolved in water	Protects plants from insects and diseases	Natural and not expensive	70
8	Disease control	Cow urine and dung fermented for 1 day, applied to soil	Prevents fungal and bacterial diseases	Eco-friendly, improves crop and soil health	65
9	Harvesting	Manual harvesting after performing rituals	Maintains purity of the produce and to avoid yield losses	Ensures better-quality grains	90
10	Threshing	Beating with bamboo sticks manually	Removes husk from seeds	Easy separation of grains	90
11	Drying	Sun-drying in threshing yards	Removes moisture for long storage	Long duration storage till new crop harvest	90
12	Winnowing	Manual winnowing using traditional bamboo trays	Separates husk, dirt material, lighter particles and stones	Improves grain quality	90
13	De-hulling	Removing husk using traditional stone grinders	Enhances taste, avoid losses and improves fermentation	Good for health	80
14	Flour making	Grinding in traditional stone mills	Improves digestion and taste	Easy for making traditional food items	60

Post-harvest ITKs, such as sun drying, manual threshing using sticks, de-hulling by wooden pounders, and grinding on stone mills, were reported by over 70% of households. These practices are deeply embedded in cultural norms and are considered reliable, despite their labor-intensive nature. The continued use of these techniques, especially by women, reflects the embeddedness of ITK in food processing and household-level food security.

3.3 Ergonomic assessment of traditional and improved practices

Table 5 shows the calculated Human Physical Drudgery Index (HPDI) for traditional and improved post-harvest millet operations. The average HPDI for traditional threshing was found to be 27.6, indicating a "moderate to high" ergonomic risk, whereas improved mechanical threshers reduced the HPDI to 12.3. Similarly, de-hulling manually had an HPDI of 29.1 compared to 13.4 using small-scale mechanical de-hullers. Grinding millet with traditional stones showed the highest HPDI (30.2), reflecting prolonged bending posture, repetitive motion, and muscular fatigue, especially among women. Improved grinding tools halved

the drudgery level (HPDI = 14.7; Figure 4). The improvement in ergonomic efficiency through basic mechanization was consistently evident across operations (Table 6), reducing the time spent, discomfort, and physical effort.

3.4 Gendered division of labor and perceived discomfort

Table 7 provides insights into the gender-wise workload distribution and perceived physical strain. Women were involved in over 90% of post-harvest operations, including de-hulling, winnowing, and grinding. More than 80% of women respondents reported moderate to severe discomfort in the back, shoulders, and hands, especially after grinding and pounding tasks. These operations were not only physically taxing but also time-consuming, with women spending 3–4 h daily during peak harvest seasons. In contrast, men were more engaged in land preparation and seed sowing. The drudgery experienced by women severely restricted their time for rest, childcare, or income-generating activities, indicating a need for gender-sensitive ergonomic interventions.

FIGURE 3
Different operations performed by tribal farmers in millet farming in Koraput, Odisha, India.

TABLE 5 Drudgery assessment of millets cultivation under traditional methods.

| S. No.	Operations	Time spent (hs/day)	Task performance score (in season)	Difficulty score of activity	Body posture adopted	Frequency of postural change	Postural discomfort	Load	Human physical drudgery index (HPDI)	Rank
1	Land preparation	0.40	0.39	0.67	0.48	0.89	0.52	0.33	52.50	VIII
2	Seed treatment	0.22	0.24	0.41	0.33	0.35	0.38	0.30	31.72	XII
3	Sowing	0.33	0.32	0.56	0.44	0.53	0.38	0.28	40.64	XI
4	Weeding	0.50	0.40	0.91	0.60	1.11	0.83	0.40	67.76	III
5	Nutrient management	0.14	0.53	0.52	0.50	0.48	0.50	0.30	42.43	X
6	Crop cutting	0.52	0.36	0.65	0.64	0.68	0.86	0.30	57.18	VII
7	Threshing	0.71	0.72	0.93	0.80	1.04	0.97	0.75	84.63	I
8	Drying	0.38	0.51	0.76	0.53	0.80	0.68	0.69	62.07	VI
9	Winnowing	0.53	0.31	0.76	0.51	0.87	0.70	0.68	62.40	V
10	De-hulling	0.38	0.68	0.67	0.61	1.07	0.97	0.34	67.38	IV
11	Flour making	0.39	0.80	0.86	0.59	1.00	0.67	0.71	71.62	II
12	Flatbread making	0.34	0.37	0.65	0.38	0.82	0.48	0.47	50.13	IX
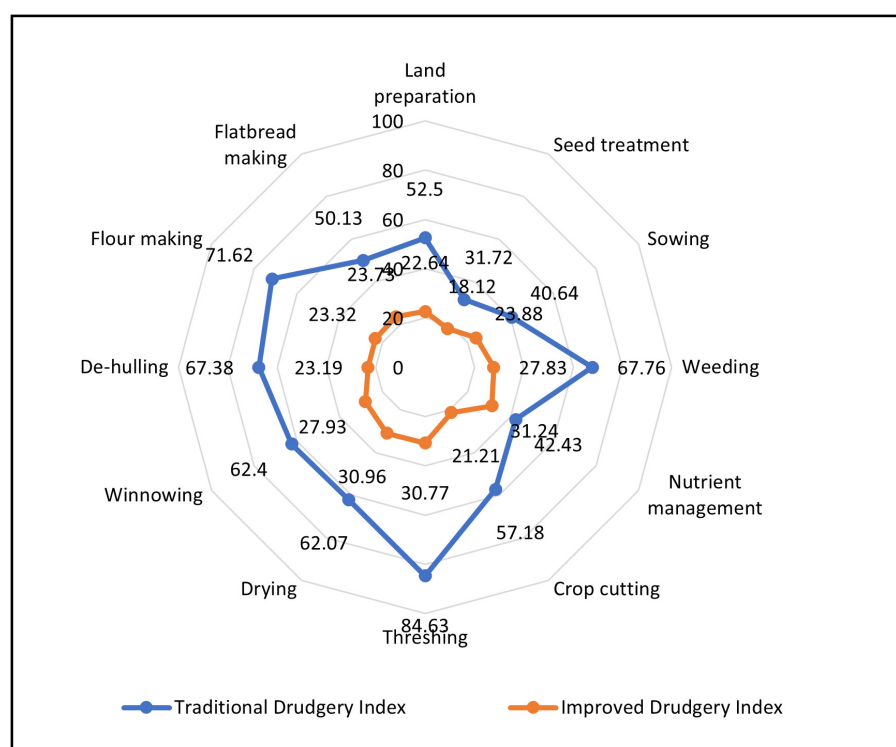
FIGURE 4
Comparison drudgery index between traditional and improved methods.

4 Discussion

The study highlights a strong reliance on Indigenous Traditional Knowledge (ITK) among tribal farmers in Koraput, Odisha, particularly in millet-based cropping systems. The findings confirm that ITKs remain not only culturally rooted but also practically effective in resource-scarce environments. However, the physical drudgery embedded within these traditional methods poses substantial ergonomic risks, especially to women who are central to millet cultivation and processing. One of the main reasons for the persistence of traditional practices, despite the availability of modern tools, lies in the low literacy levels, marginal landholding size, and limited cash income among the farming households. With 84% of the respondents earning below INR 60,000 annually and more than 44% being illiterate, there is limited exposure to formal agricultural innovation systems. As a result, farmers continue to rely on time-tested, low-cost methods using locally available resources, such as cow urine, wood ash, and manual tools. It resonates with Swain et al. (2024), who highlight how indigenous food literacy among farmers in Eastern India strongly influences the adoption and persistence of millet cultivation practices. This aligns with similar observations in tribal regions across India where formal extension systems have limited reach (Sumane et al., 2018; Singh and Gupta, 2024).

The significant role of ITKs was evident in the maintenance of soil fertility, pest and disease control, and the preservation of seed purity. Practices such as using cow dung slurry or ash for seed treatment, intercropping millets with legumes, and manual weeding not only reduce dependence on chemical inputs but also maintain soil health and ecosystem resilience (Altieri, 2018; Gupta et al., 2025). Furthermore, these methods are well-adapted to the local agro-climatic conditions, where erratic rainfall and nutrient-poor soils demand resilient farming systems. In particular, the rotational and intercropping systems observed support both biodiversity conservation and household-level food security, reflecting the multi-functionality of ITKs. Nevertheless, these traditional systems are heavily labor-intensive, particularly in post-harvest operations such as threshing, de-hulling, grinding, and winnowing. The Human Physical Drudgery Index (HPDI) revealed that operations like grinding and threshing had the highest drudgery scores. The main reasons for this are the repetitive nature of the tasks, prolonged stooping or squatting postures, and forceful manual movements using tools that are not ergonomically designed. These findings are consistent with previous studies indicating high musculoskeletal stress in traditional farming systems (Joshi et al., 2015; Nag and Nag, 2004).

The gender-disaggregated data clearly indicate that women bear a disproportionate burden of agricultural drudgery, especially in post-harvest processing. Tasks like manual de-hulling or flour making, performed daily for household consumption, result in repetitive strain injuries and fatigue. The cultural expectation that women are responsible for food preparation and seed preservation further reinforces this labor division. Such observations resonate with broader global findings where women in smallholder systems undertake the most repetitive and time-intensive tasks (UN, 2020; Ramanji et al., 2023). Despite these challenges, the introduction

TABLE 6 Drudgery assessment of millets cultivation under improved methods.

S. No.	Improved method	Time spent (h/day)	Task performance score (in season)	Difficulty score of activity	Body posture adopted	Frequency of postural change	Postural discomfort	Load	Human physical drudgery index (HPDI)	Rank
1	Land preparation	0.13	0.30	0.20	0.16	0.25	0.26	0.28	22.64	X
2	Seed treatment	0.08	0.20	0.20	0.14	0.25	0.20	0.20	18.12	XII
3	Sowing	0.10	0.22	0.37	0.22	0.25	0.23	0.28	23.88	VI
4	Weeding	0.11	0.41	0.24	0.22	0.50	0.23	0.24	27.83	V
5	Nutrient management	0.14	0.53	0.28	0.16	0.48	0.30	0.30	31.24	I
6	Crop cutting	0.08	0.24	0.40	0.11	0.25	0.20	0.20	21.21	XI
7	Threshing	0.42	0.35	0.33	0.17	0.34	0.27	0.28	30.77	III
8	Drying	0.32	0.31	0.41	0.17	0.38	0.29	0.28	30.96	II
9	Winnowing	0.18	0.27	0.29	0.20	0.35	0.36	0.32	27.93	IV
10	De-hulling	0.30	0.25	0.28	0.15	0.25	0.20	0.20	23.19	IX
11	Flour making	0.17	0.30	0.20	0.13	0.30	0.27	0.27	23.32	VIII
12	Flatbread making	0.23	0.24	0.20	0.22	0.33	0.22	0.23	23.73	VII

TABLE 7 Comparison of drudgery index in traditional and improved methods of millet cultivation.

S. N	Operation	Traditional drudgery index	Interpretation	Improved drudgery index	Interpretation
1	Land preparation	52.50	Very high risk, need necessary action immediately	22.64	Medium risk, change required
2	Seed treatment	31.72	High risk	18.12	Low risk, no need to change
3	Sowing	40.64	Very high risk, need necessary action immediately	23.88	Medium risk, change required
4	Weeding	67.76	Very high risk, need necessary action immediately	27.83	Medium risk, change required
5	Nutrient management	42.43	Very high risk, need necessary action immediately	31.24	High risk
6	Crop cutting	57.18	Very high risk, need necessary action immediately	21.21	Medium risk, change required
7	Threshing	84.63	Very high risk, need necessary action immediately	30.77	High risk
8	Drying	62.07	Very high risk, need necessary action immediately	30.96	High risk
9	Winnowing	62.40	Very high risk, need necessary action immediately	27.93	Medium risk, change required
10	De-hulling	67.38	Very high risk, need necessary action immediately	23.19	Medium risk, change required
11	Flour making	71.62	Very high risk, need necessary action immediately	23.32	Medium risk, change required
12	Flatbread making	50.13	Very high risk, need necessary action immediately	23.73	Medium risk, change required

of improved tools and practices demonstrated a clear reduction in physical strain, as reflected in lower HPDI scores for most operations under mechanized conditions. Improved threshers, de-hullers, and grinders helped reduce processing time, posture discomfort, and force exertion—without fully replacing traditional practices. This highlights the complementary role of improved technologies, which when adapted to local contexts, can enhance productivity and reduce health hazards without undermining traditional knowledge systems (Kundu et al., 2021; Nag and Gite, 2020a,b).

However, the study also found low adoption of mechanized tools, largely due to affordability, lack of awareness, cultural preferences, and limited infrastructure for repair or maintenance. For instance, many women reported a preference for stone grinding because it produces "softer" flour and retains the grain's aroma as an insight that reveals deep cultural values associated with food processing, which mechanization must respect if it is to be widely adopted. Therefore, the strategic integration of ITKs and ergonomically improved tools offers a viable pathway toward sustainable and equitable millet farming. This requires participatory co-design of tools with end-users (especially women), localized training programs, and extension services that validate and build upon indigenous practices rather than replacing them. Such integration not only enhances ecological and economic resilience but also promotes social acceptance and ownership, which are key to long-term sustainability.

In sum, this study reinforces the view that ITKs are central to sustainable millet production in tribal areas. They provide ecological wisdom and cultural continuity, but must be supported

with contextually appropriate ergonomic innovations to ensure that sustainability is not achieved at the cost of human wellbeing particularly that of rural women. The findings thus support the dual imperative of preserving local knowledge systems while addressing the ergonomic and gender-equity gaps that currently constrain their full potential.

5 Conclusion

This study addressed key gaps in understanding the role of Indigenous Traditional Knowledge (ITK) and ergonomic efficiency in sustainable millet farming among tribal communities in Koraput, Odisha. The findings reveal that ITK practices such as organic seed treatment, intercropping, and traditional post-harvest methods are ecologically sound and culturally embedded, but are also physically demanding, especially for women. Ergonomic assessment using the Human Physical Drudgery Index (HPDI) revealed that tasks like threshing, de-hulling, and grinding imposed high physical strain, contributing to long-term fatigue and musculoskeletal discomfort. Improved tools significantly reduced drudgery scores across operations, demonstrating the potential of ergonomic interventions. However, adoption remains limited due to low income, knowledge, lack of awareness, and cultural preferences. The study underscores the importance of integrating ITK with gender-sensitive mechanization to enhance productivity while safeguarding farmer wellbeing.

To this end, policy actions should focus on validating ITKs, promoting affordable tools tailored for women, establishing

SHG-led and or custom hiring services of the machineries, and expanding extension services through participatory approaches. The achieving sustainability in tribal agriculture requires dual attention to traditional ecological knowledge and the reduction of labor drudgery, especially for women who are the backbone of millet systems. This integrated approach can guide future research and development programs under NFSM, Tribal Sub-Plan, and millet promotion initiatives toward more inclusive and resilient outcomes.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

RC: Writing – original draft, Methodology, Conceptualization, Writing – review & editing. CS: Writing – review & editing, Project administration. KB: Data curation, Investigation, Writing – review & editing, Formal analysis. PL: Data curation, Formal analysis, Writing – review & editing, Investigation, Software, Methodology.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could not be construed as a potential conflict of interest.

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