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Body discomfort and work efficiency of farm women in finger millet threshing: Traditional practices versus power-operated thresher

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Abstract
Millets are ancient grains traditionally cultivated in hilly and rural regions worldwide, especially in Asia and sub-Saharan Africa. Recently, they have gained recognition for their resilience and contributions to food, feed, nutrition, and fodder security. Despite this, millet cultivation and consumption have declined due to lifestyle shifts and the labour-intensive nature of post-harvest tasks, particularly threshing. Manual threshing is inefficient, physically demanding, and disproportionately impacts women, leading to gender-based labour disparities and lower agricultural productivity. To address these issues, Krishi Vigyan Kendra (KVK) Palghar introduced the Vivek Millet Thresher-cum-Pearler (VMTCP), a power-operated thresher designed to enhance threshing efficiency and reduce drudgery during finger millet threshing. Its performance was evaluated against traditional manual methods based on threshing capacity, labour and cost savings, efficiency, and ergonomic impact, which is measured using the Body Part Discomfort Score (BPDS) and Overall Discomfort Rating (ODR). Results indicated significantly higher efficiency (98.2% vs. 82.8%) and decreased physical discomfort (mean BPDS: 3.7 vs. 7.4). Following the successful deployment of the VMTCP, the Finger Millet Thresher-cum-Pearler (FMTCP), developed by DBSKKV, Dapoli, was introduced to overcome limitations related to the availability and maintenance of VMTCP units. On-farm testing showed that the FMTCP maintained comparable efficiency and ease of operation, making it a viable alternative for farmers. In conclusion, both VMTCP and FMTCP serve as transformative tools for small and marginal farmers, particularly tribal women. They improve agricultural productivity, lessen physical strain, and encourage millet consumption, thereby supporting sustainable agriculture, enhancing rural livelihoods, and contributing to national and global food security.

Keywords: Finger millet, millet thresher, farm women, sustainable crop, food security

1. Introduction

Finger millet [*Eleusine coracana* (L.) Gaertn.], commonly known as Ragi, is a vital food crop in the tribal and hilly regions of India, as well as in several Asian and African countries (Sawant *et al*., 2013; Divate *et al*., 2016) [1, 2]. It adapts well to a wide range of agro-climatic conditions and is notable for its excellent storage qualities; its seeds can be preserved for many years without significant insect damage. Finger millet is recognised as one of the most nutritious cereal grains and is increasingly promoted as a "Super Food" or "Nutri-Cereal" (Pradhan *et al*., 2010) [3]. Under rainfed conditions, the crop typically yields around 10 quintals per hectare, whereas under irrigated conditions, yields can reach up to 25 quintals per hectare (Powar *et al*., 2019) [4]. In India, finger millet is cultivated on approximately 2.5 million hectares, producing around 2.6 million tonnes of grain annually. The main producing states include Karnataka, Odisha, Maharashtra, Tamil Nadu, and Andhra Pradesh. However, according to Kumar *et al*. (2013) [5], the average yield in Maharashtra remains low (1062 kg/ha), primarily due to limited mechanisation in cultivation and post-harvest processing. In Maharashtra, key districts for FM production include Thane, Palghar, Raigad, Ratnagiri, and Sindhudurg along the coast, and Nashik, Pune, Satara, and Kolhapur in the west, with Nashik having the largest cultivation area, followed by Kolhapur, Ratnagiri, and Palghar (Powar RV and VV Aware, 2021) [6]. Other significant challenges comprise high labour demands, lack of modern technology, and low returns on investment, all of which contribute to the declining cultivation area of finger millet.

Women play a crucial role in agriculture globally, contributing significantly to food production, food security, and the sustainability of rural economies. Their involvement spans every stage of agricultural activity from planting and harvesting to processing and marketing, and is often more extensive than that of men. In millet farming, women are central to various operations, particularly in seeding, transplanting, harvesting, and post-harvest processing. In traditional finger millet cultivation, threshing is a labour-intensive process involving either beating the crop with sticks or trampling the panicles under the feet of bullocks. This stage, which separates the grains from the stalks, is especially demanding and relies heavily on manual labour.

It is also one of the most time-consuming and energy-intensive tasks, requiring approximately 19.9 kJ/min of physical exertion (Singh *et al*. 2015a; Sial, *et al*., 2022) [7, 8]. Women, who form the backbone of this workforce, often experience adverse health effects such as back pain, hand injuries, and respiratory issues due to prolonged exposure to dust and repetitive physical strain. The reliance on outdated and laborious threshing methods not only affects women's physical well-being but also limits productivity and economic efficiency. Mechanisation of millet threshing can significantly reduce the drudgery faced by women and other labourers, while also enhancing the quality and marketability of the final product (Singh *et al*., 2015b) [10]. Also, there is a need to prepare the threshing yard and transport the harvested crop to the yard. Additionally, farmers must ensure the availability of labour and tractors during the peak threshing period. Therefore, there is an urgent need for suitable, low-cost mechanisation tailored to the needs of marginalised farming communities. Assessing and implementing simple, high-output, low-operating-cost millet threshers with superior threshing performance, it is preferable to adopt a power-operated thresher, as this holds global importance for improving processing efficiency, reducing physical strain on women, and supporting the sustainable production and consumption of millets. Similarly, the pearling operation of finger millet is performed by different methods such as rubbing grain in a gunny bag, leg pounding, and stone grinding (Jatta), which also involve a lot of drudgery (Singh *et al*. 2002) [9].

The Palghar district of Maharashtra state, which is noted for cultivating millets, is predominantly inhabited by tribal groups, and finger millet, also known as Nagali, is the primary crop farmed by them. In the finger millet production catchment region of the district, tribal farmers consume finger millet in the form of bread (Bhakari) and curry (Ambil) and eat at least one meal per day. Despite their high nutritional value, millets are on the verge of extinction. The district has enormous potential for income generation at the local level through finger millet processing and value addition. However, consumption and area under millets are decreasing in the district as people's lifestyles change and more drudgery is connected with finger millet threshing (Divate et. al., 2019) [11]. In recent years, there has been increasing interest in mechanised solutions to alleviate the burdens associated with manual labour in agriculture. Mechanised threshers promise not only higher productivity but also potential benefits for the health and well-being of farm women by minimising repetitive strain injuries and musculoskeletal discomfort. The introduction of mechanical threshers among finger millet-growing farmers is a means of overcoming the aforementioned challenges. By mechanising the threshing process, these tools reduce physical strain, save time, and enhance threshing efficiency. Additionally, they minimise grain loss, ensuring better returns for farmers. For farm women, these innovations not only alleviate health risks but also empower them by enabling more efficient use of their time and energy.

Considering the current socioeconomic conditions of millet-growing tribal farmers, high-capacity threshers are unsuitable, and even small-sized threshers with advanced features are difficult to implement (Singh *et al*., 2002) [9]. KVK, Palghar, conducted on-farm trials to assess the suitability of the two types of power-operated thresher cum pearler for threshing finger millet in the production catchment area. This study evaluates the field performance and ergonomic effects of a power-operated millet thresher compared to conventional threshing methods.

2. Materials & Methods

The study was conducted in the Jawhar and Mokhada blocks of Palghar district, Maharashtra, which have the largest tribal population and the highest area under finger millet cultivation from 2018-19 to 2022-2023. Two villages from each block, Ramnagar and Dehere (Jawhar), Beriste and Ase (Mokhada), were randomly selected for on-farm testing. Before implementation, a baseline survey of 100 households was conducted in 2018-19 to document indigenous threshing methods, associated constraints, and health risks. Participant selection was finalised through group meetings and training-cum-awareness programmes, aimed at assessing the need for introducing a millet thresher among farmers.

2.1 Discomfort assessment and Introduction of the millet thresher

Initially, the Vivek Millet Thresher cum Pearler (VMTCP), developed by VPKAS, Almora, Uttarakhand, was introduced during 2018-19 and 2019-20 for on-farm testing in the selected villages. Alongside its evaluation, a discomfort assessment was conducted to study the physical strain experienced by farmers during threshing operations. The assessment employed two techniques, Overall Discomfort Rating (ODR) and Body Part Discomfort Score (BPDS), following the method proposed by Corlett and Bishop (1976) [15]. Ten female participants were selected for the study, and the experiment was carried out under controlled field conditions. To ensure full cooperation, the subjects were briefed on the objectives of the experiment and familiarised with the procedures.

2.2 Overall Discomfort Rating (ODR)

A 10-point psychophysical rating scale (0=no discomfort, 10=extreme discomfort) was used to assess ODR. The mean ODR was calculated by summing the ratings provided by each of the ten subjects and dividing by the number of participants.

2.2.2 Body Part Discomfort Score (BPDS)

For evaluating BPDS, each subject identified all body parts experiencing discomfort, beginning with the most painful (assigned 1 point), followed by the next most painful (2 points), and so on. The BPDS for each subject was calculated by multiplying the discomfort rating by the number of body parts in each category. A preliminary study revealed that the participants experienced the greatest discomfort in the arm, shoulder, back, waist, and leg during prolonged operation of the equipment. Therefore, BPDS data were collected only for these body parts. The total BPDS for each subject was obtained by summing the individual scores of all reported body parts.

2.2. Performance evaluation and demonstration of Vivek Millet Thresher cum Pearler

The Vivek Millet Thresher-cum-Pearler (VMTCP), developed by VPKAS, Almora, Uttarakhand, was evaluated under on-farm conditions in the selected villages of Palghar district, with trials conducted in the Jawhar block during 2018-19 and in the Mokhada block during 2019-20. One trial was conducted in each of the four selected villages to assess the suitability of the thresher for finger millet. Following the village-level trials, the machine was demonstrated over the next three years (2019-20 to 2021-22) on a large scale across farmers' fields to promote wider adoption and assess its practical suitability under tribal farming conditions.

2.2.1 Vivek Millet Thresher cum Pearler

This thresher was developed at VPKAS, Almora, and Uttarakhand. Two models of the machine are available: an electric-operated thresher and an engine-operated thresher. It is powered by a 1 HP motor and uses canvas strips as the threshing element. For the present study, the electric model was used, and its detailed specifications are presented in Table 1. Here, only ear heads are used as the feeding material. The machine operates on the principle of impact and shear applied to the grain to accomplish threshing, de-husking, and pearling. The threshing drum is fitted with six leather flaps that act as cutting devices, providing gentle impact and shear to minimise grain damage. A blower is attached to the machine to facilitate the complete cleaning of the grains. Interchangeable sieves are provided, allowing different operations such as threshing, de-husking, and polishing. In the Vivek Millet Thresher-cum-Pearler, threshing and pearling are carried out in a double-pass system to ensure efficient processing.

Table 1: Detailed technical specification of the Vivek millet thresher cum Pearler

Machine specification	**Length:** 660 mm **Width:** 310 mm **Height:** 1040 mm **Weight:** 45 kg **Power source:** 1 hp electric motor, Threshing drum speed: 750 rpm
Motor specification	**Power:**750 watt RPM1425 **Insulation level:** B Class **Voltage:** 220-230 **Ampere:** 7.6 **Phase:** Single **Outer dia. of motor pully :** 62 mm, Manufacture of motor: Crompton greaves

The performance of VMTCP was evaluated using a local finger millet variety with 10 to 12 % (wb). The performance parameters, threshing capacity, threshing efficiency, pearling capacity, pearling efficiency, and cost of threshing were measured using the respective formulas.

Threshing capacity

The threshing capacity was estimated by weighing the total grain (whole and damaged) received per hour at the main grain output of the thresher, as presented in Eq 1 (Mohsenin, 1970) [12].

$$\text{Threshing Capacity (kg/h)} = \frac{\text{Weight of grains threshed (kg)}}{\text{Time taken (h)}}$$

$$\text{Pearling Capacity (kg/h)} = \frac{\text{Weight of grains pearled (kg)}}{\text{Time taken (h)}}$$

$$\text{Threshing Efficiency (\%)} = \left(1 - \frac{\text{Weight of unthreshed panicles (kg)}}{\text{Total weight of grains in the sample (kg)}}\right) \times 100$$

Pearling capacity

The pearling capacity was estimated by measuring the weight of the total dehusked grain (comprising both dehusked and husked components) collected per hour at the main grain output of the thresher, as presented in Eq. 2.(Mohsenin, 1970) [12].

$$\text{Pearling Capacity (kg/h)} = \frac{\text{Weight of grains pearled (kg)}}{\text{Time taken (h)}} \quad \ldots\ldots\ldots\ldots(2)$$

Threshing efficiency

Threshing efficiency is the ratio of the quantity of unthreshed grains obtained from all outlets per unit time to the quantity of total grain input per unit time. It was calculated by Eq. 3. (Mohsenin, 1970) [12].

Pearling Efficiency

Pearling efficiency was calculated by counting the number of un-pearled grains from 100 grains collected from the main grain outlet using Eq. 4. (Mohsenin, 1970) [12].

$$\text{Pearling Efficiency (\%)} = \left(1 - \frac{\text{Weight of unpearled grains (kg)}}{\text{Total weight of grains fed (kg)}}\right) \times 100$$

Cost of the threshing operation

The cost of the threshing operation was calculated by considering both fixed and variable costs. Fixed costs included depreciation, interest, taxes, insurance, and shelter, while variable costs comprised repairs and maintenance, fuel, lubrication, and operator charges. The total operation cost of the finger millet thresher cum pearler, expressed in Rs/kg, was estimated by combining the fixed and operational costs of the machine, based on the following assumptions. The cost of operation was calculated using prevailing market rates during the season and at the location of use.

Three replications of each observation were conducted. Additionally, the farmers were trained to operate the machine. Their opinions were recorded after each field experiment throughout the threshing process.

2.3 Comparison with manual threshing (Hand Beating Method)

For comparison, a one-time study on manual threshing of finger millet was carried out during 2019-20 in each of the selected villages under similar field conditions. The traditional practice involved beating harvested panicles with wooden sticks and subsequently hand-separating the grains. The performance of manual threshing was evaluated using the same parameters as for the VMTCP, namely threshing capacity, threshing efficiency, cleaning efficiency, grain damage, and pearling efficiency. The same subjects who operated the VMTCP also participated in manual threshing to maintain uniformity. A known quantity of finger millet ear heads having 12-14% moisture content (wb) was used as the test material. The ear heads were spread over the threshing yard to a thickness of 10-15 cm, and the time required to thresh the known quantity by hand using long wooden sticks was recorded.

2.4 Introduction of Finger Millet Thresher cum Pearler (FMTCP): Following the successful testing and large-scale demonstration of the VMTCP during 2019-20 to 2021-22, another machine, the Finger Millet Thresher cum Pearler (FMTCP) developed by Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth (DBSKKV), Dapoli, was introduced during 2021-22 for on-farm evaluation. The evaluation of FMTCP was confined to its technical performance parameters in terms of threshing capacity, threshing efficiency, cleaning efficiency, pearling efficiency, and cost of operation, and the results were compared with those obtained for manual threshing (2019-20) and VMTCP (2019-20 to 2021-22).

4.4.1 Finger Millet Thresher cum Pearler

The major components of the FMTCP developed by DBSKKV, Dapoli, Maharashtra, include a threshing drum, a pearling drum, and a cleaning unit consisting of a sieve walker and blower. The threshing drum comprises a threshing cylinder, a concave threshing sieve, and an outer casing. The machine is designed to carry out the three key post-harvest operations: threshing, pearling, and cleaning, continuously in a single unit, thereby eliminating the need for multiple traditional methods that are labour-intensive and time-consuming. The machine is powered by a 2 HP single-phase electric motor. It weighs 145 kg and can be transported easily along small rural and hilly roads. The detailed technical specifications are presented in Table 2.

Table 2: Detailed technical specifications of the Finer Millet Thresher and Pearler

Sr. No	Parameter	Specification
1.	**A) Threshing drum**	
	• Diameters, mm	200
	• Length, mm	300
	• Thickness of canvas support (M.S flat plate), mm	3
	• Concave clearance, mm 5	5
	• Threshing sieve size, mm 2	2
2.	**B) Pearling drum**	
	• Diameters, mm	200
	• Length, mm	180
	• Thickness of canvas support (M.S flat plate), mm	3
3.	**C) Sieve Walker**	
	• Length, mm	375
	• Width, mm	250
	• Height, mm	222

3. Results and Discussion

3.1 Baseline Survey of Manual Threshing Practices (2018-19): Threshing is the process of separating grains from the panicle, usually by rubbing, stripping, or beating the harvested crop. In the case of finger millet, threshing is traditionally performed either by beating with bamboo sticks or by treading the crop panicles under oxen's feet. To evaluate the prevailing threshing practices, a baseline household survey was conducted during 2018-19 among 100 farm families in the study area. The results revealed that the majority of households practised threshing by beating with bamboo sticks (82%), followed by treading under the feet of bullocks (12%), and trampling with tractors or motorcycles (6%) (Figure 1). Additionally, Figure 2 illustrates the distribution of threshing methods and the level of female involvement in millet cultivation.

In the case of bulk threshing, some farmers spread the crop evenly on the floor and allowed tractors to pass over it. However, the majority reported that manual threshing on mud floors was more common, which resulted in higher levels of impurities such as mud, sand, and dust particles in the grain. This not only reduced grain quality but also necessitated additional post-harvest cleaning, thereby increasing cost, labour, and time requirements. Manual threshing was found to be time-consuming, labour-intensive, and inefficient, often leading to significant quantitative and qualitative losses. Moreover, delays in threshing due to labour shortages or untimely rains frequently caused deterioration of the harvested crop when it was not threshed, cleaned, dried, and stored promptly. Regarding pearling practices, three methods were identified, namely rubbing grains in gunny bags, hand pounding and stone grinding (Jatta). More than 98% of farmers used stone grinding for pearling millet after threshing.

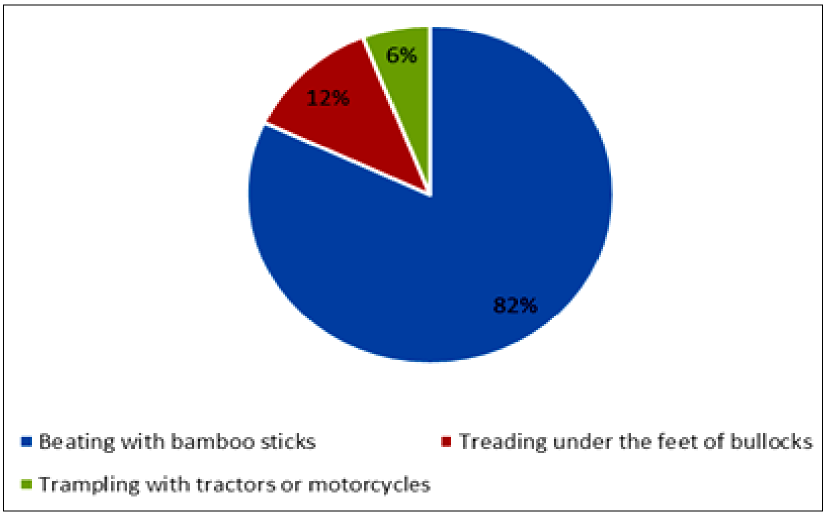

Fig 1: Threshing methods of finger millet (survey of 100 households)

The survey also revealed gender-specific participation in post-harvest operations. Women constituted the primary workforce in threshing, cleaning, and drying, while men contributed comparatively less. Female respondents reported several health-related problems associated with threshing, including musculoskeletal disorders such as pain in the hands, wrists, and back, as well as hand injuries, swelling, and redness in the fingers. In addition, respiratory issues were frequently reported due to exposure to dust generated during threshing on mud floors. Similar findings were reported by Shrivastava *et al*. (2021) [13] and Chapke *et al*. (2024) [14], who documented high levels of drudgery and health risks among women engaged in millet threshing.

Fig 2: The distribution of threshing methods and the level of female involvement in millet cultivation (A. Manual threshing, B. Treading under the feet of bullocks, C. Trampling of millet crop with tractors, D. Involvement of farm women in finger millet transplanting)

These findings highlighted the urgent need for introducing mechanised threshing technologies for finger millet. Mechanisation can potentially reduce drudgery, minimise grain losses, improve grain quality, lower health risks for women farmers, and increase the overall efficiency of post-harvest operations. Additionally, it allows farmers to complete threshing in a shorter timeframe, thereby reducing the risk of weather-related damage to the harvested crop. The development and dissemination of affordable, small-scale threshers specifically designed for finger millet has the potential to significantly improve livelihood security, particularly for women farmers who predominantly undertake post-harvest activities.

3.2 Assessment of body discomfort during manual and mechanical threshing

The selected female subjects were asked to report to the field at 8:00 a.m. It was ensured that all participants were in good health, had a sound sleep on the previous night, and consumed a regular breakfast. They were free from stimulants, tobacco, and recent strenuous physical activity. Before the experiment, the subjects were briefed about the objectives of the study and familiarised with the operation procedures to ensure their full cooperation.

3.2.1 Overall Discomfort Rating (ODR)

The female workers were asked to perform threshing operations using both the traditional stick-beating method and the mechanical thresher. Each trial lasted for 30 minutes without rest. After the completion of both manual and mechanical threshing operations, ODR and BPDS were recorded. As shown in Table 3, the ODR score for threshing of finger millet with wooden sticks was significantly higher (8.4±0.41) compared to mechanical threshing using the VMTCP (3.7±0.69). The greater discomfort associated with manual threshing can be attributed to the constant sitting posture and repetitive beating motion, which caused severe hand and wrist pain, backache, swelling, and redness of the fingers. Prolonged awkward postures further increase the risk of musculoskeletal strain. In contrast, the ODR score for threshing with the VMTCP was considerably lower and fell close to the moderate discomfort range, indicating its ergonomic advantage over the manual method.

Table 3: Overall Discomfort Rating by female worker

Sr. No	Threshing operation/ Method	Overall Discomfort Rating	Subjective Feeling
1	Traditional threshing (Using a Bamboo stick)	8.4±0.41	Very highly painful
2	Threshing by Vivek millet thresher cum pearler	3.7±0.69	Moderate

The results of the present study showed significantly higher discomfort scores during manual threshing compared to mechanical threshing, which is consistent with earlier findings by Shrivastava *et al*. (2021) [13] and Chapke *et al*. (2024) [14], who reported high levels of drudgery, backache, and hand injuries among women engaged in traditional millet threshing. Similar reductions in discomfort with the use of improved threshers like pedal-operated, motor-operated operated have also been reported in ergonomic evaluations of millet threshers (Prabhat Guru, 2015; Pratibha Joshi *et al*., 2015) [18, 10]. These findings confirm that the introduction of mechanical threshers like VMTCP substantially reduces physical strain and improves ergonomic safety.

3.3.2 Body Part Discomfort Score (BPDS)

The BPDS reported by female workers after manual threshing of finger millet and threshing with the VMTCP is presented in Table 4. The BPDS values for manual threshing using a bamboo stick ranged from 69 to 78, whereas those recorded during threshing with VMTCP ranged from 34 to 41. This indicates that traditional threshing methods induced nearly double the discomfort compared to mechanical threshing. The higher BPDS values during manual threshing were mainly due to sustained awkward postures and repetitive striking motions, which resulted in discomfort localised in the right shoulder, right arm, neck, right palm, lower back, right thigh, left thigh, and right foot across all participants.

Table 4: Body Part Discomfort Score (BPDS) reported by female workers for threshing of finger millet

Sr. No	Threshing operation/ Method	Body Part Discomfort Score (BPDS)	Comments
1	Traditional threshing (Using a Bamboo stick)	74	Threshing of finger millet done by beating with the help of bamboo sticks results in more body part discomfort due to the following reasons • Squatting posture as well as continuous sitting during threshing, bending of legs for hours may lead to many musculoskeletal, fatigue. • Neck strain can occur in manual threshing due to looking down for long periods. • Repetitive hand motions and gripping, causing fatigue. • Continuous holding a stick in the hand • results in swelling, redness in the palm • Raising arms and holding positions for extended periods, causing discomfort • Back pain due to the adoption of a prolonged, strenuous sitting posture for a long time. • Waist discomfort may arise from static loading of muscles in this region because of a slightly bent posture during the operation of threshing.
2	Threshing by Vivek, millet thresher cum pearler	37	The Body Part Discomfort Score (BPDS) was reduced with the use of Vivek millet thresher cum pearler for finger millet thresher, with the following reasons • Mechanical threshing reduces bending but may still involve some lifting. • Operators may move around more. • Neck forearms strain is often less due to better posture.

In contrast, threshing with VMTCP reduced the intensity and spread of discomfort, reflecting the ergonomic advantage of mechanised threshing over traditional practices. These findings are in line with Chapke *et al.* (2024) [14] and Joshi *et al.* (2015) [10], who reported that the introduction of mechanical threshers in tribal regions of India not only reduced physical strain but also encouraged higher adoption rates due to improved efficiency and reduced health risks. These results clearly indicate that mechanical threshing significantly lowers both overall discomfort and localised musculoskeletal strain compared to traditional manual methods, thereby reducing drudgery and improving occupational health among female workers.

3.3 Performance evaluation, large-scale demonstration, and adoption

3.3.1 Performance evaluation of Finger millet thresher cum Pearler

The performance of the FMTCP and manual threshing was evaluated at selected farmers' fields to assess their efficiency and to demonstrate the benefits of mechanical threshing technology. Local varieties of finger millet were used for the evaluations. The results of the performance evaluation of the VMTCP in two tribal blocks of Palghar district indicated only minor variations between the Jawhar (2018-19) and Mokhada (2019-20) villages. The comparative performance characteristics of the millet thresher with manual threshing, as given in Table 5, clearly demonstrate the superiority of VMTCP in terms of operational efficiency and capacity.

Manual threshing capacities ranged between 9.54-12.25 kg/h, while VMTCP capacities were consistently higher, ranging between 34.6-36.2 kg/h**.** On average, VMTCP achieved 35.20±0.77 kg/h, which is more than three times higher than manual methods (10.83±1.18 kg/h**).** Similarly, pearling capacity improved from an average of 11.78±0.43 kg/h under manual methods to 56.15±1.18 kg/h with the VMTCP, indicating nearly a five-fold increase**.** Manual threshing efficiency was slightly higher (97.03±0.89%**)** than VMTCP **(**93.35±1.72%**).** This marginal reduction (3-4%) is likely due to higher throughput in mechanical threshing, which occasionally leaves a small fraction of grains unthreshed. However, pearling efficiency was comparable between methods (Manual: 93.25±0.96%**,** VMTCP: 94.25±0.96%**),** showing no significant disadvantage of mechanization. Time requirement per quintal was drastically reduced with VMTCP (2.84±0.06 hr/q**)** compared to manual threshing **(**9.32±1.01 hr/q**).** This corresponds to a 69.52% saving in time and labour**,** which has direct implications for drudgery reduction, cost savings, and timely post-harvest operations, particularly important in the rainy season. These findings align with earlier studies (Shrivastava *et al*., 2021; Chapke *et al*., 2024) [13, 14], which also reported that small-scale millet threshers significantly reduced drudgery and time while maintaining acceptable threshing and pearling efficiencies. Thus, large-scale demonstrations in tribal villages validate the practical feasibility and socio-economic benefits of VMTCP over traditional threshing methods.

Table 5: Comparative performance characteristics of VMTCP with manual threshing

Block/ Year	Village	Method of threshing	Threshing Capacity (kg/h)	Pearling Capacity (kg/h)	Threshing Efficiency (%)	Pearling Efficiency (%)	Time Requirement (hr/q)
Jawhar (2018-19)	Ramnagar	Manual (Stick)	9.54	12.3	98.2	94	10.48
		VMTCP	34.6	54.8	91.8	95	2.89
	Korthad	Manual (Stick)	12.25	11.6	97.2	92	8.16
		VMTCP	36.2	56	93	93	2.76
Mokhada (2019-20)	Ase Beriste	Manual (Stick)	10.26	11.3	96.5	94	9.75
		VMTCP	35.4	55.4	92.8	95	2.82
		Manual (Stick)	11.25	11.9	96.2	93	8.89
		VMTCP	34.6	58.4	95.8	94	2.89
Average		Manual (Stick)	10.83 ± 1.18	11.78 ± 0.43	97.03 ± 0.89	93.25 ± 0.96	9.32 ± 1.01
		VMTCP	35.20 ± 0.77	56.15 ± 1.18	93.35 ±1.72	94.25 ± 0.96	2.84 ± 0.06

Table 6: Cost economic analysis of Vivek Millet Thresher-cum-Pearler

Sr. No.	Particulars	Cost (Rs)
1	Initial cost (C), Rs.	27440
2	Salvage value (S), Rs.	2744
3	Life of the machine (L), years	10
4	Interest rate (i), %	12
5	Working hours per year (H), h	240
6	Total fixed cost, Rs./h	19.56
8	Fuel cost, Rs./h (Electricity Charge (Rs./kWh)	4.50
7	Wages for operator, Rs /h (Rs 300/ day for operator and helper, Rs. 200/ day) (Rs./h)	62.50
8	Repair and maintenance (Rs /h), 10 % of initial cost	11.43
9	Total variable cost, Rs./h	78.43
10	Total cost of operation, Rs./h	97.99
11	Cost of threshing operation (Rs./Kg)	2.80
12	Cost of pearling operation (Rs./Kg)	1.74
13	Total cost of threshing and pearling (Rs./Kg)	4.54
14	Total cost of threshing and pearling (Rs/Kg) by the Manual method (The traditional threshing and pearling (beating with a stick and hand pounding) process of finger millet grain takes eight hours of effort for 35 kg of grain. considering wages @ Rs. 300 per day.)	8.57

The cost economic analysis of VMTCP is presented in Table 6. The cost of the machine was Rs. 27440/-. (Including GST). The economic analysis of the VMTCP revealed that the total cost of operation was Rs. 97.99 per hour, consisting of Rs. 19.56/h as fixed cost and Rs. 78.43/h as variable cost. Labour wages (Rs. 62.50/h/h) contributed the largest share (63.78%) of the operational cost, followed by repair and maintenance (11.66%) and electricity (4.59%). The unit cost of threshing and pearling was calculated at Rs. 2.80/kg and Rs. 1.74/kg, respectively, with a total mechanised cost of Rs. 4.54/kg. In contrast, the traditional manual method required Rs. 8.57/kg, almost double the mechanised cost. Thus, the use of VMTCP reduced the cost of threshing and pearling operations by about 47.02%, in addition to lowering labour demand and drudgery.

These findings highlight that group ownership and wider adoption of VMTCP can further enhance cost-efficiency and benefit smallholder farmers.

3.3.2 Large-Scale Demonstration and Adoption (2019-20 to 2021-22): The superior performance of the VMTCP encouraged wider adoption among tribal farmers. Large-scale demonstrations and training programs were conducted over three years to create awareness and provide hands-on operational experience, as presented in Table 7. As part of the scaling-up strategy, six machines were distributed to selected Self-Help Groups (SHGs) in the Jawhar and Mokhada blocks for collective use. These SHGs operated the machines not only for their members but also extended services to other farmers on a custom-hiring basis at affordable rates. Feedback from users highlighted improved efficiency, reduced physical drudgery, and significant savings in time and cost compared to manual methods. This participatory approach, combining performance evaluation, capacity-building, and community-level ownership, proved effective in accelerating the adoption of mechanised post-harvest technologies in smallholder and tribal farming systems. The positive impact of capacity-building programmes and demonstrations has also been highlighted by Jadhav & Pirabu (2019) [16] and Divate *et al*. (2023) [17], who reported similar findings.

Table 7: Trainings and Demonstrations on VMTCP in Jawhar and Mokhada Blocks

Year	Trainings Conducted (No.)	Villages Reached (No.)	Farmers Trained (No.)	Women Participants (%)	Demonstrations Conducted (No.)
2019-20	3	4	55	41	3
2020-21	4	5	79	68	3
2021-22	4	6	111	65	5

3.3.3 Farmer Feedback and Acceptability

Farmer feedback collected during and after the large-scale demonstrations indicated that the Millet VMTCP was highly feasible and user-friendly. Farmers reported that the VMTCP was highly feasible for finger millet threshing compared to manual methods. Key advantages highlighted included higher output, improved threshing efficiency, reduced grain damage, and lower drudgery. The thresher also helped minimise health hazards associated with manual threshing, allowing farmers to save time for other farm activities. Farmers found the VMTCP easy to operate and handle, requiring minimal maintenance and storage space. Repairs could be performed locally, and due to its lightweight design and provision of handles, two people could easily transport it between fields. In contrast, manual threshing required a specially prepared threshing yard and transportation of harvested material, often involving tractors, additional manpower, longer time, and higher costs. The VMTCP, being portable, eliminated the need for a threshing yard, reducing labour and transport requirements and thereby saving both time and operational costs**.**

3.4 Performance evaluation of finger millet thresher cum pearler

The finger millet thresher cum pearler developed by DBSKKV, Dapoli, was introduced, as the availability of VMTCP units in local markets was limited, and farmers often faced difficulties in accessing or repairing them. Therefore, on-farm testing was done for its acceptability in the previous training programme conducted in villages. The VMTCP has promising options but needs a double pass to complete threshing as well as the pearling operation. The performance evaluation of FMTCP is presented in Table 8.

Table 8: Performance evaluation of FMTCP developed by DBSKKV, Dapoli

Parameter	Value
Threshing efficiency (%)	96.83 ± 0.19
Pearling efficiency (%)	98.00 ± 0.57
Time requirement (hr/ q)	2.86 ± 1.01
Cost of threshing with pearling (Rs/kg)	3.89

FMTCP that performs all operations, *viz*., threshing, pearling, and cleaning in a single pass with better performance. The cost of threshing by FMTCP, developed by DBSKKV, Dapoli, is Rs 3.89 per kg. The cost of the machine is Rs 44330 and offers locally serviceable technology to meet farmers' needs. This comparative analysis not only ensured scientific validation of the new machine but also addressed the farmers' demand for easily available, locally serviceable threshing technology. Hence, the introduction of FMTCP was justified as a step toward expanding the choice of mechanised solutions for finger millet processing, reducing drudgery, and facilitating wider adoption among smallholder and tribal farmers. Importantly, by enhancing efficiency, reducing post-harvest losses, and lowering labour dependence, the FMTCP contributes to climate-smart agriculture practices and strengthens food and nutritional security at both household and community levels. Hence, farmers were encouraged to adopt FMTCP as a viable alternative to conventional practices and VMTCP, ensuring greater productivity, sustainability, and resilience in millet-based farming systems.

4. Conclusion

The study clearly demonstrated that mechanised threshing using the VMTCP and the FMTCP is far superior to traditional stick-based methods. Both machines significantly reduced drudgery, body discomfort, and health risks, particularly for women farmers who shoulder most post-harvest labour. VMTCP achieved over three times higher threshing capacity and nearly five times higher pearling capacity than manual methods, with a 70% reduction in labour time. The FMTCP, developed by DBSKKV, Dapoli, performed comparably while offering the added advantages of local availability and easier repair. Large-scale demonstrations, distribution of machines to women's SHGs, and custom hiring services enhanced adoption, creating avenues for income generation and collective use. Mechanisation not only improved efficiency and reduced costs but also empowered women by reducing strain, safeguarding health, and allowing time for other productive activities. From a policy perspective, these findings emphasise the need to scale up mechanised threshing technologies in millet-growing tribal regions through targeted subsidies, women-centric SHG support, and custom hiring centres. Integrating such interventions into rural development and millet promotion schemes can accelerate adoption, reduce rural drudgery, and strengthen food and livelihood security while advancing goals of gender equity and sustainable agriculture.

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