***Original Research Article***

**Ergonomic Assessment of a Battery-Operated Cereal Harvester for Women Farm Workers in the NEH Region**

**Abstract**

A battery-powered, walking-type cereal crop harvester was developed, incorporating anthropometric data of women from the North Eastern Hill (NEH) region, to address the issues of drudgery, rapid fatigue, and occupational health risks commonly faced by female agricultural workers. The study involved a comparative ergonomic evaluation of manual harvesting using a sickle and mechanical harvesting using the developed harvester on paddy variety PR-126. Nine female participants were categorized into three age groups: AF (20–24 years), BF (25–29 years), and CF (30–34 years). The ergonomic parameters, including Heart Rate (HR), Increase in Heart Rate (∆HR), Energy Expenditure Rate (EER), Oxygen Consumption Rate (OCR), and Body Part Discomfort Rating (BPDR), were recorded and analyzed. The results demonstrated a significant reduction in physiological stress and physical discomfort with the use of the developed harvester. Compared to manual harvesting, average heart rate was reduced by 14.03%, and the increase in heart rate (ΔHR) was 52.87% lower. Similarly, EER and OCR were decreased by 32.17% and 14.63%, respectively. BPDR values, especially for the lower back, shoulders, and wrists, showed an average reduction of 27.2%, indicating improved operator comfort.

These findings validate the ergonomic and operational advantages of the battery-operated harvester. It serves as a viable, health-conscious, and labour-efficient alternative to traditional harvesting methods, promoting occupational well-being and supporting the broader goal of gender-sensitive mechanization in agriculture.

**Keywords:** Ergonomic assessment, Occupational health, Battery-powered harvester, Physiological workload, NEH region.

**1. Introduction**

Agriculture remains a labour-intensive sector, with nearly half of the workforce being female, particularly in developing countries like India. The mechanization level in the North East Hill (NEH) regions of India, which include Sikkim, is considerably lower compared to other regions. This is primarily due to limited access to modern agricultural machinery, the precipitous-terrains and the fragmented landholdings. The mechanization index in the NEH region is approximately 40%, which is lower than the national average of 70%, as per Singh *et al.* (2020). Traditional manual harvesting methods are predominant in Sikkim, where organic farming is proactively promoted, which further restricts the adoption of mechanized alternatives. Studies by Sharma and Das (2021) state that introducing lightweight compact-sized battery-powered harvesters could enhance efficiency by 30-40% while reducing labour fatigue in NEH regions. Therefore, there is an immediate need for the development of region-specific mechanization strategies to enhance productivity and alleviate the physical strain on female workers.

Harvesting grain and paddy crops requires arduous physical labour, which exposes workers to the risk of postural stress due to changes in repetitive positions and a high energy expenditure rate, resulting in an increased heart rate and oxygen consumption rate. Female workers are more likely to experience exhaustion and musculoskeletal diseases (MSDs) due to the usage of traditional tools like sickles and hand cutting. Research by Patel *et al.* (2021) indicated that 68% of female agricultural workers had moderate to severe lower back discomfort. Kumar *et al.* (2022) found that the implementation of automated equipment increased work efficiency by 35%. Therefore, there is a critical need for ergonomic measures to enhance female workers work conditions.

Mechanization has emerged as a potential solution to reduce labour-intensive activities. Battery-operated harvesters offer an efficient and lightweight alternative to manual harvesting. However, their ergonomic impact on female workers has not been extensively studied. Manual paddy harvesting in hilly regions involves sustained bending, squatting, and repetitive hand movements, which can lead to excessive strain on the lower back, knees, and wrists. Studies by Rai *et al. (2020) and Thapa et al.* (2021) indicate that prolonged exposure to these postures contributes to a high prevalence of musculoskeletal disorders (MSDs), including chronic lower back pain and knee osteoarthritis among female workers. This paper investigates the advantages of a battery-powered harvester on physical exertion and productivity of female workers. By comparing traditional and mechanized harvesting methods, the study aims to determine whether mechanization improves working conditions and reduces physiological strain.

A potential method to reduce the need for manual labour is through the utilization of machinery. Relative to manual harvesting, battery-operated harvesters are more effective and easier to transport. Additionally, there appears to be a lack of studies on the ergonomic effects on female workers. However, back, knee, and wrist pain are common concerns among NEH Workers who harvest paddy crops by hand, as the work requires constant bending, kneeling, and repetitive hand movements. Musculoskeletal diseases (MSDs), such as osteoarthritis of the knees and persistent lower back pain, are common among female workers, according to research by Rai *et al*. (2020) and Thapa et al. (2021). In this study, the authors investigated the impact of battery-operated harvesters on the energy expenditure and output of female employees. The study aims to determine whether mechanical harvesting improves working conditions and reduces physiological strain by comparing conventional and mechanical harvesting approaches.

**2. Materials and Methods**

* **Subjects:** Nine female workers of different age groups (AF1 to AF9 ) for harvesting paddy crop with hand tools and a developed harvester.
* **Experimental Design:** Comparative analysis of the physiological impact on female workers during manual and battery-operated harvester.

The traditional method of harvesting using a sickle is a labour-intensive process that requires extensive bending, squatting, and repetitive hand movements, contributing to high physical exertion levels. According to Patel *et al.* (2022), manual harvesting demands an average of 6-8 hours of continuous work per day, resulting in a 40% higher risk of musculoskeletal disorders compared to mechanized methods. Additionally, Singh and Kumar (2021) reported that manual harvesting yields an average output of 0.04 hectares per labourer per day, significantly lower than mechanized alternatives. The inefficiency of traditional methods is further exacerbated by the dependency on seasonal labour, which can lead to delays in harvesting and potential crop losses, as noted by Verma *et al.* (2023). According to Gupta *et al.* (2021), prolonged exposure to such postures results in a high prevalence of musculoskeletal disorders (MSDs), particularly lower back pain and knee osteoarthritis. Additionally, studies by Sharma and Verma (2020) indicate that manual harvesting is time-consuming and labour-intensive, with workers often experiencing fatigue-related productivity losses of up to 30%. These findings highlight the urgent need for ergonomic interventions to improve labour conditions in traditional harvesting practices.

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**Fig.1.** Manual Harvesting of Paddy with Sickle

**Mechanized harvesting** using a battery-operated harvester involves significantly reduced physical exertion and increased efficiency. According to Raj *et al.* (2022), battery-operated harvesters decrease the need for prolonged bending and squatting, lowering the risk of musculoskeletal disorders by 50% compared to manual methods. Studies by Mehta and Sharma (2023) highlight that mechanized harvesting improves productivity by up to 60%, with laborers covering 0.1 hectares per hour, as opposed to 0.04 hectares per day in manual harvesting. Furthermore, Kumar *et al.* (2024) reported that mechanization minimizes grain losses by 20%, ensuring better yield preservation and reducing post-harvest labour requirements. Also shown to significantly reduce the physical strain associated with traditional methods. According to Singh *et al.* (2021), battery-operated harvesters lower musculoskeletal stress by 45% compared to manual harvesting. Additionally, research by Das and Kumar (2022) highlights a 50% reduction in harvesting time, improving overall labour efficiency. The adoption of mechanized harvesting tools also minimizes repetitive stress injuries, particularly in the lower back and shoulders, which are common among female agricultural workers (Sharma & Verma, 2023).



**Fig.2.** Harvesting with the developed harvester

**Ergonomic parameters**

**Heart rate (HR):**

Heart rate in terms of heart beats per minute was taken as one of the measures to assess the whole body's physiological workload on the subjects operating the self-propelled harvester. Workload was determined with the help of heart rate reading (Singh *et al*., 2008; Varghese *et al*., 1994).

During paddy harvesting, heart rate was measured using a Polar heart rate monitor, and the recorded data was transferred to a computer for further analysis. During the field operation, the three groups of healthy female operators were selected as subjects for the harvesting operation. The heart rates were measured for 10 minutes of operation using two harvesting methods: manual/Traditional harvesting with a sickle (HR-T) for the paddy crop. Mechanical harvesting (HR-M) with the developed harvester and Heart rate data for male and female subjects across three age groups.

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| 1. Belt for heart rate monitoring | 1. Polar heart rate monitor (watch) |
| **Fig. 3.** Heart rate monitor | |

**Increase in heart rate (∆HR)**

Increase in heart rate refers to the difference between the heart rate measured during or after a farm operation and the minimum heart rate (typically the resting heart rate) before the activity (Yadav *et al.,* 2007).

**Energy expenditure rate**

The amount of energy required by a subject or person for performing a physical function (such as breathing, digesting food, and circulating blood) or engaging in physical movement is known as the energy expenditure rate. It can be calculated by equation 1 (Yadav *et al.,* 2007).

…(1) Where,

EER = Energy expenditure rate, kJ min-1

**Oxygen consumption rate**

The oxygen consumption rate was recorded to analyse whole-body pain and fatigue. Therefore, OCR was estimated using the operator's heart rate (HR) data while operating the harvester, as per Equation 2 and Table 1 (Singh *et al.,* 2008).

…(2)

Where,

OCR = Oxygen consumption, l min-1

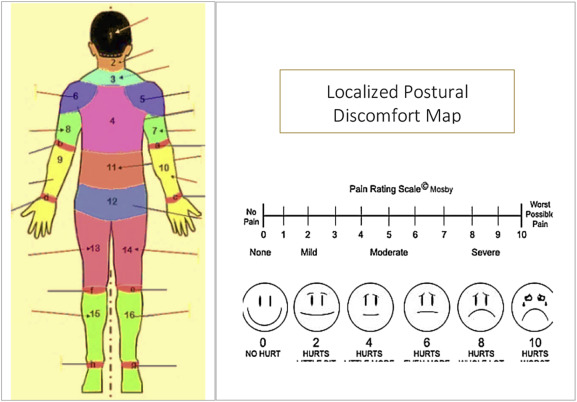
HR = Heart rate, beats min-1

**Table 1:** Oxygen consumption rate for workers

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| --- | --- | --- | --- |
| **Sr. No.** | **HR, beats min-1** | **OCR, l min-1** | **Grade of work** |
| 1 | <75 | <0.5 | Very light |
| 2 | 75-100 | 0.5-1.0 | Light |
| 3 | 100-125 | 1.0-1.5 | Moderately heavy |
| 4 | 125-150 | 1.5-2.0 | Heavy |
| 5 | 150-175 | 2.0-2.5 | Very heavy |
| 6 | >175 | >2.5 | Unduly heavy |

**Body part discomfort rating (BPDR):**

Body part discomfort rating is a measure of localized discomfort that may restrict work duration depending on the static load involved. The technique suggested by Corlett and Bishop (1976) was used to assess BPDR, as shown in Fig. 4.



**Fig.4.** Body part discomfort rating

**Results and discussion**

Preliminary findings suggest a significant reduction in physical discomfort and physiological stress among workers who use the battery-operated harvester. BPDR scores were notably lower for the mechanized method, particularly for the lower back, shoulders, and wrists. HR and OCR values indicate reduced cardiovascular strain, resulting in prolonged work efficiency without excessive fatigue. Productivity analysis showed a substantial increase in harvested area per unit time, demonstrating the economic and labour-saving benefits of mechanization.

The ergonomic performance of the developed harvester was evaluated by recording various ergonomic performance parameters for female workers. The paddy crop (variety PR-126) was selected for the testing of the developed harvester when the developed harvester was operated at optimized levels of different independent parameters (Forward speed: 1 km h-1, Blade speed: 2400 rpm, and Number of teeth on cutting blade: 120). Female workers performed paddy harvesting using both traditional methods with sickles and a newly developed lightweight, battery-operated cereal crop harvester. The female workers were grouped into three age groups [AF-20-24, BF-25-29 and CF-30-34 Years]. The heart rate (HR), increase in heart rate (∆HR), oxygen consumption rate (OCR), energy expenditure rate (EER), body part discomfort rate (BPDR), and field capacity (area harvested per hr) for each group were compared and presented in the following sections.

**Heart rate**

During paddy harvestings, heart rate was measured by a Polar heart rate monitor. The data was then transferred to the computer for further analysis (Singh et al., 2008; Varghese *et al*., 1994).

During the field operation, the three groups of healthy female operators were selected as subjects. The heart rates were measured for 10 minutes of operation using two harvesting methods: manual harvesting with a sickle (HR-T) and Mechanical harvesting (HR-H) with the developed harvester. Heart rate data of subjects across three age groups are shown in Fig. 5.

It is evident from the average values of heart rate data that heart rate values for manual harvesting were higher for all age groups of female workers. The average heart rates for female workers during the traditional method and with the developed harvester were 114 bpm and 98 bpm, respectively, which is 14.03% lower than those for traditional harvesting using a sickle.

**Fig 5:** Average heart rate of female workers in different age groups while harvesting with a developed harvester and traditional harvesting

The heart rate data shows an increase with age, having higher heart rates, particularly in manual harvesting.

HR-T consistently shows higher values than HR-H ones, highlighting potential physiological differences and the sensitivity of the manual method. Overall, females in older age groups exhibit higher heart rates.

**Increase in Heart Rate (∆HR)**

The change in heart rate during manual harvesting and mechanical harvesting operations across different age groups for female workers shows distinct patterns, as shown in Fig. 6.

It is evident from the average values of the heart rate increase data for all three groups that the increase in heart rate for traditional harvesting was higher for all age groups of female workers. The average values of increased heart rate for workers operating a developed harvester were 52.87% lower than those for traditional harvesting using a sickle. These results suggest that manual harvesting consistently places more strain on the cardiovascular system compared to mechanical harvesting, with the impact becoming more pronounced in older age groups (Komatineni *et al.,* 2023; Komatineni *et al.,* 2024)

**Fig 6:** Increase in average heart rates (∆HR) for females of different age-groups while harvesting with a developed harvester and traditional harvesting

**Energy expenditure rate**

The Energy Expenditure Rate (EER) data of workers, calculated using the methodology discussed above in Equation 2 and shown in Fig. 7, demonstrate that the EER for manual harvesting was higher for female workers across all age groups. The average values of EER for female workers, while operating a developed harvester, were 32.17% lower than those for manual harvesting using a sickle, as shown in Fig. 7.

The findings of the analysis were that manual harvesting operations demand a higher energy expenditure rate than mechanical harvesting operations by the developed harvester, with younger females showing lower EER values than older females. Overall, it shows an increased energy expenditure rate with an increase in age groups. (Tiwari and Gite, 2002; Yadav *et al.,* 2007).

**Fig 7:** Energy expenditure rate (EER) for females of different age-groups while harvesting with developed harvester and traditional harvesting

* + 1. **Oxygen consumption rate**

The OCR (Oxygen Consumption Rate) data for workers in paddy harvesting, both for manual harvesting and the developed harvester method using a sickle, were estimated and presented in Fig. 8. It is clear from Fig. 8 that the OCR for manual harvesting with a sickle was higher for all age groups of female workers. The average OCR for female workers, while operating the developed harvester for paddy harvesting, was 14.63% lower than that for manual harvesting using a sickle.

This trend indicates that manual harvesting consistently requires more oxygen than mechanical harvesting. Also, manual harvesting is a more physically demanding operation, with increased oxygen consumption, and the intensity of the task increases with age. A similar trend was also reported by Yadav *et al. (*2010).

**Fig 8:** Average oxygen consumption rate (OCR) for females of different average age-groups while harvesting with developed harvester and traditional harvesting

Overall, workers exhibit an increase in oxygen consumption with advancing age groups, demonstrating the increased energy and effort required for manual harvesting and the mechanical operation of the harvester. OCR values for manual harvesting ranged between 1.05 l/min and 1.39 l/min for female workers. This working grade comes under the heavy work category. According to the grades of work rate provided in Table 4.15 by Yadav et al. (2007), the working grade falls under the moderate-to-heavy work category, which was found to be at the optimum value.

**Body part discomfort rating (BPDR)**

The Body Part Discomfort Ratings (BPDR) of female workers for paddy harvesting by traditional methods (BPDR-T) using the developed harvester and (BPDR-H) were estimated by the technique discussed above (Corlett & Bishop, 1976). It is evident from Fig. 9 that females generally experience higher discomfort levels across most body parts. In particular, the back, shoulders, and wrists were the areas where females reported significantly higher discomfort, especially during traditional harvesting. For instance, back discomfort was rated at 6.5 for females during traditional methods. BPDR values for all three groups of female workers during manual harvesting with sickle were higher for all age groups. Average values of BPDR female workers, while operating the developed harvester for paddy harvesting, were 27.2% lower than those for manual harvesting using a sickle.

This suggests that traditional harvesting methods were more physically demanding, with females experiencing greater strain, likely due to differences in physical strength between different genders.

**Fig. 9:** Effect of body part discomfort score for females

**Conclusion and Future Scope** The study confirms that battery-operated harvesters offer substantial ergonomic and productivity advantages for female workers. The reduction in physical exertion, coupled with increased efficiency, highlights the need for wider adoption of mechanized harvesting solutions. Future research should focus on optimizing harvester design to further enhance user comfort and accessibility, particularly for small-scale farmers.

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