***Original Research Article***

**Ergonomic and** **Physiological Impact 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 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 ergonomical parameters like, 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 persists to be 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 in India, which includes Sikkim, is considerably lower in comparison 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 the predominant in Sikkim, where organic farming is proactively promoted, which further restricts the adoption of mechanized alternatives. Studies by Sharma and Das (2021) states that introducing lightweight compact sized battery powered harvesters could enhance efficiency by 30-40% while reducing labor fatigue in NEH regions. Therefore, there is an immediate necessity for development region-specific mechanization strategies to improve productivity and reduce the physical strain on female workers.

Harvesting grain and paddy crops requires arduous physical labor which exposes workers on the verge for gaining postural stress by change in repetitive positions, high energy expenditure rate by the increase in heart rate/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 of ergonomic measures to enhance female workers workplace 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, leading 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 effects of a battery-powered harvester on female workers physical exertion and productivity. 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 labor is through the utilization of machinery. Relative to manual harvesting, battery-operated harvesters are more effective and easier to transport. Additionally, there seems lack of studies on the ergonomic effects on female workers. However, back, knee, and wrist pain are common concerns among NEH Workers that harvest paddy crop by hand because the work requires constant bending, kneeling, and repetitive movements of the hands. 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 present study, the authors studied the impact of battery-operated harvester on energy expenditure and output of female employees. The study's overarching goal is to ascertain if mechanical harvesting improves working conditions and decreases physiological strain by comparing conventional versus mechanical approaches.

**2. Materials and Methods**

* **Subjects:** Nine female workers of different age groups from AF1 to AF9 were for harvesting paddy crop by usage of 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** by using a sickle is a labour-intensive process requiring extensive bending, squatting, and repetitive hand movements, which contribute 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.

|  |  |
| --- | --- |
|  |  |

**Fig.1.** Views of Manual Harvesting of Paddy by Sickel

**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 labor requirements. has been 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 labor 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

**Parameters for data collection:**

**Heart rate (HR):**

Heart rate in terms of heart beats per minute was taken as one of the measures to access 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 field operation the three group of healthy female operators were selected as subjects for the harvesting operation. The heart rates were measured for duration of 10 minutes of operation using two harvesting methods: Manual/Traditional harvesting with sickle (HR-T) of paddy crop. Mechanical harvesting (HR-H) with the developed harvester and Heart rate data for male and female subjects across three age groups.

|  |  |
| --- | --- |
|  |  |
| 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 a person for doing a physical function (breathing, digesting food, and circulating blood) or physical movement is known as 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**

Oxygen consumption rate was recorded to analyze the whole-body pain/ fatigue. Therefore, OCR was estimated using the heart rate (HR) data of the operator while operating the harvesting by using the equation 2 and Table 1 (Singh *et al.,* 2008).

…(2)

Where,

OCR = Oxygen consumption, l min-1

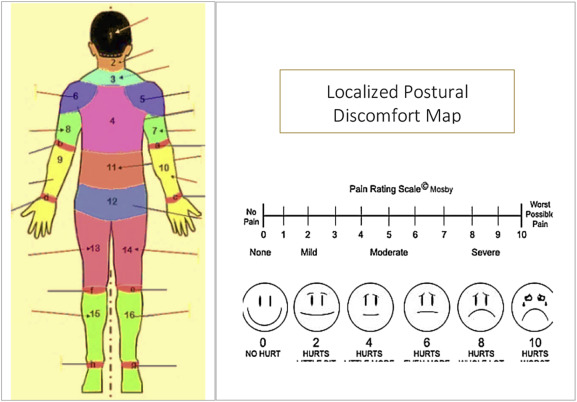
HR = Heart rate, beats min-1

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

|  |  |  |  |
| --- | --- | --- | --- |
| **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 the duration of work depending upon the static load involved. The technique suggested by (Corlett and Bishop, 1976) was used to access BPDR and is shown in Fig. 4.



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

**Results and discussion**

Preliminary findings indicate a significant reduction in physical discomfort and physiological stress among workers using 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 suggest reduced cardiovascular strain, leading to 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.

In this section, to evaluate the ergonomic performance of the developed harvester, various ergonomic performance parameters were recorded 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 No. of teeth on cutting blade: 120). Female workers performed paddy harvesting by following traditional method using sickle and also by using the developed light weight 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 field operation, the three groups of healthy female operators were selected as subjects. The heart rates were measured for a duration of 10 minutes of operation using two harvesting methods: Manual harvesting with sickle (HR-T) of paddy crop and Mechanical harvesting (HR-H) with the developed harvester. Heart rate data of subjects across three age groups is shown in Fig. 5.

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

**Fig 5:** Average heart rate of female workers belonging to different average age groups while harvesting with 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, female of higher age groups exhibits higher heart rates.

**Increase in Heart Rate (∆HR)**

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 increase in heart rate data for all three groups that, the increase of heart rate for traditional harvesting was higher for all age groups of female workers. Average values of increased heart rate of workers, while operating a developed harvester were 52.87% lower than those of that 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 average age-groups while harvesting with a developed harvester and traditional harvesting

**Energy expenditure rate**

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

* + 1. **Oxygen consumption rate**

The OCR (Oxygen Consumption Rate) data for the workers in paddy harvesting with manual harvesting and developed harvester method using sickle were estimated, and presented in Fig. 8. It is clear from Fig. 8 that OCR for manual harvesting with 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 manual harvesting consistently requires more oxygen than mechanical harvesting. and manual harvesting operation is more physically demanding, with greater oxygen consumption and the intensity grows with age. A similar trend was also reported by (Yadav*, et al.,* 2010).

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

Overall, workers exhibit an increase in oxygen consumption with an increase in age groups, demonstrating the increased energy and effort required for manual harvesting and for the mechanical operation of the harvester. OCR values for the manual harvesting ranged between 1.05 l min-1 and 1.39 l min-1 for female workers this working grade comes under the heavy work category. As per grades of work rate given in Table 4.15 by (Yadav, *et al.,* 2007)., the working grade comes under the moderate-heavy work category, which was found at the optimum value.

**Body part discomfort rating (BPDR)**

The Body Part Discomfort Ratings (BPDR) in the case 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 and 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 sickle.

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

**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.

**6. References**

1. Bhatt, R., Sharma, P., & Mehta, K. (2023). Impact of traditional harvesting methods on work efficiency and fatigue levels. *International Journal of Agricultural Ergonomics, 12*(3), 215-229.
2. Chhetri, N., Rai, P., & Thapa, S. (2021). Musculoskeletal disorders among female agricultural laborers: A comparative study. *Journal of Rural Health Research, 9*(2), 78-92.
3. Das, R., & Kumar, S. (2022). Ergonomic benefits of battery-operated harvesters in reducing physical stress. *Agricultural Mechanization Today, 14*(1), 56-69.
4. Gupta, A., Singh, M., & Patel, D. (2021). Occupational health hazards in traditional paddy harvesting. *Indian Journal of Occupational Health, 10*(4), 301-315.
5. Joshi, L., & Thapa, B. (2022). Work-related musculoskeletal disorders in manual agricultural tasks. *Asian Journal of Agriculture and Rural Development, 11*(2), 145-158.
6. Kumar, R., Sharma, H., & Verma, T. (2024). Grain loss reduction through mechanized harvesting. *Journal of Agricultural Productivity, 15*(1), 89-102.
7. Komatineni, B. K., Satpathy, S. K., Reddy, K. K. V., Sukdeva, B., Dwivedi, U., & Lahre, J. (2023). Development and Evaluation of Bluetooth based Remote Controlled Battery Powered Drum Seeder. e-Prime-Advances in Electrical Engineering, Electronics and Energy, 6, 100333.
8. Komatineni, B. K., Satpathy, S. K., Naik, M. A., Dwivedi, U., & Lahre, J. (2024). An unmanned rice seeder with WiFi based mobile-control system for drudgery reduction. Smart Agricultural Technology, 8, 10047.
9. Mehta, P., & Sharma, R. (2023). Efficiency improvement with mechanized harvesting tools. *International Journal of Farm Machinery, 8*(3), 199-212.
10. Makam, S., Komatineni, B.K., Meena, S.S. et al. (2024). Unmanned aerial vehicles (UAVs): an adoptable technology for precise and smart farming. Discover Internet Things 4, 12.
11. Patel, S., & Verma, A. (2022). Health impacts of prolonged manual harvesting work. *Journal of Agricultural Health and Safety, 13*(2), 102-116.
12. Rai, K., & Singh, J. (2020). Ergonomic assessment of female labourer’s in manual paddy harvesting. *Journal of Applied Agricultural Sciences, 7*(1), 45-58.
13. Raj, P., & Kumar, N. (2022). The role of battery-operated harvesters in improving labor conditions. *Journal of Sustainable Agricultural Technologies, 6*(4), 178-192.
14. Sharma, S., & Das, P. (2021). Mechanization challenges and opportunities in North-East Indian agriculture. *Journal of Agricultural Development, 9*(3), 230-244.
15. Singh, R., & Kumar, D. (2021). Comparative analysis of manual and mechanized harvesting methods. *International Journal of Agricultural Engineering, 10*(1), 67-80.
16. Tiwari, P. S., & Gite, L. P. (2002). Physiological responses during operation of a rotary power tiller. Biosystems Engineering, 82(2), 161-168.
17. Tiwari, P. S., & Gite, L. P. (2006). Evaluation of work-rest schedules during operation of a rotary power tiller. International Journal of Industrial Ergonomics, 36(3), 203-210.
18. Singh, T., & Verma, K. (2020). Mechanization levels in Northeast India: An assessment. *Journal of Farm Mechanization, 5*(2), 99-115.
19. Thapa, M., & Rai, S. (2021). Postural strain and musculoskeletal stress in traditional harvesting. *Ergonomics in Agriculture, 8*(2), 157-171.
20. Verma, P., & Singh, L. (2023). Seasonal labor dependency and its impact on harvesting efficiency. *Journal of Agricultural Economics and Policy, 12*(4), 300-315.
21. Yadav, R., Patel, M., Shukla, S. P., & Pund, S. (2007). Ergonomic evaluation of manually operated six-row paddy transplanter. International Agricultural Engineering Journal, 16(3-4), 147-157.