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Ergonomic risks and physiological stress in mat-type paddy (*Oryza sativa*) seedling preparation

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ABSTRACT

This study was carried out during 2023–24 at Ranipool, Gangtok, Sikkim to validate the physical characteristics, postural risks and physiological workload of farm workers engaged in manual mat-type paddy (*Oryza sativa* L.) seedling preparation. A total of 10 male workers (mean age: 34.1 ± 6.17 years, BMI: 22.72 ± 3.42 kg/m²) were analysed for their ergonomic risks and metabolic demands. Postural assessment using the Ovako Working Posture Analysis System (OWAS) and Rapid Entire Body Assessment (REBA). The results indicated that key activities such as soil placement, frame placement and broadcasting seeds posed "Very High Risk" (REBA score: 11.6–13.2) and required immediate corrective action. The physiological workload assessment revealed significant variations in oxygen consumption (VO_2: 9.70 ± 4.92 ml/min/kg), heart rate (HR: 102.20 ± 17.09 bpm) and energy expenditure (EE: 3.04 ± 1.54 kcal/min) across different phases of the task. ANOVA results confirmed that both worker differences and task phases significantly influenced workload, with heart rate responses increasing due to task repetition. The findings infer the need for ergonomic interventions, task re-design and improved workload management strategies to enhance worker safety and productivity.

Keywords: Musculoskeletal disorders, Paddy seedling preparation, Physiological demands, Postural stress, Sustainable farming

In Indian agriculture, human labour forms a significant component of crop production. A large portion of the Indian population resides in villages and relies on agriculture as their primary means of livelihood. In the north-eastern state of Sikkim, rice (*Oryza sativa* L.) cultivation occupies a major share of agricultural activity, employing a considerable number of people in various labour-intensive tasks. Farmers in the region invest a substantial amount of their physiological energy into these activities, making agriculture one of the most physically demanding occupations (Kar and Dhara 2007). Agricultural tasks, particularly in rice cultivation are inherently associated with prolonged and awkward postures resulting in a high prevalence of work-related musculoskeletal disorders (MSDs). Rice farmers engage in several strenuous activities such as land preparation, seedling preparation, transplanting, irrigation, weeding, harvesting, threshing and winnowing. Many of these tasks require repetitive motions, prolonged stooped or squatting postures and the handling of heavy loads, all of which contribute to increased physiological stress and the risk of injury (Das and Gangopadhyay 2011).

Research by Davis and Kotowski (2007) highlighted that farmers frequently suffer from low back, shoulder and upper extremity disorders. Similarly, Gangopadhy *et al.* (2005) observed discomfort and pain among pre-adolescent agricultural workers in areas such as the lower back, knees, shoulders, hands and neck primarily due to prolonged awkward postures in the field. Studies from other regions, by Nwuba and Kaul (1989) from Nigeria reported that hoe farmers experienced significant strain in their lower backs leading to long-term health implications. Low back pain (LBP) has emerged as the most common MSD among farmers with a prevalence of around 50% compared to approximately 37% among other manual labourers (Walker and Palmer 2002). According to Penttinen (1987), the postures that require frequent lower back flexion combined with lifting and carrying heavy loads are major contributors to LBP. Additionally, Gangopadhyay *et al.* (2010) suggested that working in stooped or squatting postures for extended periods can lead to discomfort and an increased risk of MSDs. Such disorders are often classified as overuse injuries, repetitive strain injuries or cumulative trauma disorders reflecting their chronic and progressive nature. The

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physiological demands of agriculture are also substantial. Morrissey (1987) found that stooped postures during agricultural tasks resulted in elevated heart rates, increased metabolic loads and heightened perceptions of discomfort and fatigue. Manual handling tasks, such as carrying heavy loads in awkward postures further amplify the risk of MSDs among rice farmers. Given the significant physical demands and risks associated with agricultural work this study aims to investigate the postures adopted by rice farmers during seedling preparation activities. The primary objective of the study is to analyse the ergonomic and physiological challenges faced by farmers and identify the root causes of discomfort linked to these postures. Addressing these issues is crucial for improving the health, safety and productivity of agricultural workers in rice farming.

MATERIALS AND METHODS

Selection of respondents: To perform ergonomic studies, it is crucial to choose individuals who are in good physical health and involved in the production of paddy seedlings at the time of the trials. The study was carried out during 2023–24 at Ranipool, Gangtok, Sikkim. A simple random sampling technique was used to select the respondents. Ten apparently healthy individuals aged ranged 26–45 were randomly chosen to participate in the study (Das *et al.* 2013).

Measurement of physical attributes of respondents: The participants underwent anthropometric evaluation in the lab where their physical attributes like weight, height and age were recorded. The height and weight were measured using an ultrasonic height body fat analyser (Cole *et al.* 2000).

Posture of farm workers in preparation of a manual mat-type paddy seedling: For postural analysis of farm workers, direct observation and video photography were used to examine posture at different phase of paddy seedling preparation. Phase refers to the eight distinct work stages involved in the manual mat-type paddy seedling preparation activity. Each respondent's posture was studied throughout the entire work duration. The duration of each position and postural changes during tasks were recorded. Factors like posture length, work cycle, task nature, personal traits and tools used to contribute to musculoskeletal injury risk. Postural analysis is a valuable tool for evaluating work activities and various approaches have been used to assess stress during different job periods (Kee and Karwowski 2007).

Rapid Entire Body Assessment (REBA) of postural discomfort: REBA is a method used to analyse posture for the risk of work-related musculoskeletal disorders (Hignett and Mcatamney 2000). The most important aspects of a job were evaluated. The posture was evaluated for each activity by allocating a score to each location. REBA method: 1) Postures were evaluated numerically i.e the higher the number, the worse the posture; 2) Group A was measured for the effect on the trunk, neck and legs; 3) Group B was measured for the effect on upper arms, lower arms and wrist postures (left and right); 4) Average values of Group A and Group B were calculated, frequency was analysed and coupling scores were added for an overall score; and 5) Based on an overall score, the degree of risk was found in the REBA decision table.

Ovako Working Posture Analysis System (OWAS) of postural discomfort: The OWAS technique has been developed to assess and regulate poor worker postures, a key risk factor for work-related musculoskeletal disorders (WMSDs). It offers a practical approach to improving posture, especially in conventional seedling preparation. OWAS evaluates postural stress using a systematic classification of work postures and task observations. It identifies four back postures, three-arm postures, seven lower limb postures and three load/force categories. By analysing posture combinations OWAS helps in workplace and work method development, reducing musculoskeletal disorders. This approach enhances worker safety, improves productivity and ensures better ergonomic conditions in agricultural and industrial settings (Heinsalmi 1986). The OWAS method was applied for postural analysis using Ergoniza software (version 3.5).

Physiological parameters

Heart rate (HR): The main measure of circulatory function is heart rate. The computerised ambulatory metabolic measurement system (K4b2) was used in this investigation to evaluate the heart rate. The K4b2 device, which recorded the heart rate and data was downloaded after the trial, receives the heartbeat from a chest belt transmitter. Method to measure heart rate using k4b2: Switch on and calibrate the K4b2 unit. Fit the subject with chest-strap transmitter, face mask, and harness.Ensure heart rate detection on the device. Start data recording during the activity. Stop recording after completion of the task. Extract and analyze the recorded data.

Oxygen consumption rate (OCR): The relevant metric for determining the amount of human energy needed to carry out different kinds of tasks is the Oxygen Consumption Rate (OCR) (Curteon 1947). The quantity of oxygen that a worker inhales and uses per minute is known as oxygen consumption. OCR is expressed as ml/min/kg in absolute terms. The ability of the heart to pump blood, the tissues' capacity to draw oxygen from the blood, ventilation and the alveoli's capacity to draw oxygen from the air are all necessary for oxygen consumption. The K4b2 device, which records the amount of oxygen utilised in each breath and can be downloaded at the conclusion of the experiment, was used to test the OCR of 10 respondents.

Statistical analysis: Statistical analysis was performed using IBM SPSS Statistics (Version 21). A two-way ANOVA was used to evaluate the effects of respondents, task phases, and their interaction on VO_2, HR, and EE, with respondents and phases as fixed factors. Each respondent performed seven repetitions, treated as replications. Significance was set at $p<0.05$, and Tukey's HSD test was applied for post hoc comparisons. Descriptive statistics (mean ± SD) were calculated, and model performance was assessed using R^2.

RESULTS AND DISCUSSION

Physical characteristics of respondents: The physical characteristics of male workers involved in the manual mat-type paddy seedling preparation are summarised (Table 1). Mean ± standard deviation (SD), provided insight into their physical attributes essential for analysing work performance and ergonomic risks. The average age of the workers was 34.1 ± 6.17 years indicating a young and active workforce. The mean height was 165.1 ± 3.1 cm, suggesting uniform stature among the workers and the average weight was 61.1 ± 10.1 kg with moderate variability. The mean BMI was 22.72 ± 3.42 kg/m², falling within the normal weight category implying that the workers are physically fit. The mean maximum heart rate (HR) was 171.9 ± 27.13 bpm, reflecting the level of physical exertion required during the tasks. The average task duration was 14 min and 30 sec indicating that tasks were short but physically intense. All participants were male (n = 10) ensuring uniformity in task demands. The physical characteristics suggested that workers are within the healthy and active range for performing labour-intensive tasks. The BMI indicates no significant risk of health complications due to underweight or obesity supporting the workers' capacity for strenuous tasks. The high HR max values suggested cardiovascular stress, which may increase with repetitive tasks.

Table 1 Assessment of the respondent's primary physical characteristics

Parameter	Mean ± SD
Age, year	34.1 ± 6.17
Height, cm	165.1 ± 3.1
Weight, kg	61.1 ± 10.1
BMI, kg/m^2	22.72 ± 3.42
HR max, bpm	171.9 ± 27.13
Duration, min.sec	14:30
Number of participants	10

Posture adopted by farm workers in a manual mat-type seedling preparation: Workers' postures at the workplace were depending on the type of job, personal characteristics, tools required to carry out the specific work and the duration and frequency of the work period. A diagrammatic illustration of varied postures adopted by farm workers in different activities of manual seedling preparation has been illustrated in Fig. 1. During the laying of polythene sheet and irrigation of the bed, farm workers adopted bending postures with the repetitive movement of the hands. Whereas, during the placement of the frame, soil placement in the frame, covering the seedbed and removing the frame, farm workers adopted a combination of squatting and bending postures. Moreover, in leveling the soil bed and broadcasting the seed operations, farm workers adopted a squatting posture with repetitive movement of the hands.

Rapid Entire Body Assessment (REBA) method and Ovako Working Posture Analysis System (OWAS) method for analysis of postural discomfort: Table 2 presents the analysis of working posture of farm workers engaged in various

Fig. 1 Postures adopted during manual mat-type paddy seedling preparation activities (A) Laying of polythene sheet activity, (B) Placement of frame activity, (C) Soil placement in frame activity, (D) Leveling of the soil bed activity, (E) Broadcasting the seed activity, (F) Covering the seedbed activity, (G) Irrigation the bed activity and (H) Removing the frame activity.

activities of mat-type paddy seedling preparation using the Rapid Entire Body Assessment (REBA) method. The scores are expressed as mean ± standard deviation (SD) for each activity. Higher REBA scores indicated greater musculo-skeletal risk and a stronger need for corrective action. At the initial stage, laying of the polythene sheet resulted in a mean REBA final score of 9.6 ± 1.35, categorising it under a high-risk level (Action Category 3). This suggests that the posture adopted during this task requires prompt ergonomic intervention to prevent musculoskeletal strain, particularly due to trunk bending and repetitive arm movements. The next tasks including placement of frame and soil placement in the frame showed comparatively higher final scores of 12.4 ± 0.8 and 12.66 ± 0.98 respectively, both classified as very high risk (Action Category 4). These activities involved awkward postures such as sustained bending, forward flexion of the neck, movement in uneven terrain and repetitive upper-limb actions. The elevated Score A and Score B values showed a significant involvement of trunk, neck, legs and upper limbs during these tasks. Similarly, leveling of the soil bed and broadcasting the seed also recorded very high-risk scores of 12 ± 0.63 and 11.6 ± 1.01, respectively. These operations require repetitive upper-limb motion including reaching and wrist deviation along with prolonged stooping postures. The ergonomic stress during covering the seedbed was also notable with a final score of 12.4 ± 1.01 further reinforcing the high biomechanical load on both lower and upper body muscle groups. On the other hand, irrigation of the bed demonstrated a relatively lower REBA score of 7 ± 0.89, falling under the medium risk category (Action Category 2), indicating that although some musculoskeletal risks are present the severity is comparatively lower. Finally, removing the frame resulted in the highest final REBA score of 13.2 ± 0.74, placing it in the very high-risk category (Action Category 4). This task involves forceful exertion, lifting, bending and awkward upper-limb postures, making it the most ergonomically demanding among all the assessed activities. Overall, most activities performed during paddy seedling preparation fall under high to very high ergonomic risk levels, indicating the need for immediate ergonomic intervention such as redesigning workstations, using assistive tools, providing rest breaks and training workers on posture correction to reduce musculoskeletal strain and injury risk.

The OWAS method was applied to analyse the working postures of farm workers involved in different activities of the manual paddy seedling preparation method. The results highlighted the level of ergonomic risk and the corresponding actions required for each activity (Table 3). Activities such as placement of the frame, soil placement

Table 2 Analysis of the posture of farm workers using the REBA

Activities	Trunk, Neck, Legs (Score A)	Upper arms, Lower arms, (Score B)	Grand Score (Score C)	Final Score	Risk level	Action Category
Laying of polythene sheet	5.2 ± 1.16	6.2 ± 2.22	7.4 ± 1.01	9.6 ± 1.35	High	3
Placement of frame	8.6 ± 1.35	6 ± 1.89	10 ± 1.26	12.4 ± 0.8	Very High	4
Soil placement in frame	9.33 ± 0.80	5.33 ± 1.85	10.66 ± 0.98	12.66 ± 0.98	Very High	4
Leveling of the soil bed	7.6 ± 1.08	6.2 ± 1.72	9.8 ± 0.4	12 ± 0.63	Very High	4
Broadcasting the seed	7.2 ± 1.46	7 ± 2.09	9.4 ± 1.01	11.6 ± 1.01	Very High	4
Covering the seedbed	7.4 ± 1.49	8.2 ± 1.6	10 ± 1.26	12.4 ± 1.01	Very High	4
Irrigation the bed	5.2 ± 0.74	3.6 ± 0.48	5.4 ± 1.01	7 ± 0.89	Medium	2
Removing the frame	8.2 ± 0.74	8.2 ± 1.46	10.6 ± 0.48	13.2 ± 0.74	Very High	4

Action category 2, Further consideration should be given as to how the risk can be lowered; 3, Action needs to be taken very soon; 4, Task must cease until either a safer solution can be found or all parties are fully aware of how to best manage the risk.

Table 3 Analysis of working posture of farm workers by OWAS method

Activities	Duration (sec)	OWAS code	Action category	Action required
Laying of polythene sheet	190	2141	3	Corrective action needed as soon as possible
Placement of frame	170	4141	4	Immediate corrective action required
Soil placement in frame	245	4152	4	Immediate corrective action required
Leveling of the soil bed	340	4111	2	Corrective action needed in the near future
Broadcasting the seed	380	4161	4	Immediate corrective action required
Covering the seedbed	395	1151	2	Corrective action needed in the near future
Irrigation the bed	185	3232	1	No action required
Removing the frame	160	2142	3	Corrective action needed as soon as possible

Action category 1, No action required; 2, Further consideration should be given as to how the risk can be lowered; 3, Action needs to be taken very soon; 4, Task must cease until either a safer solution can be found or all parties are fully aware of how to best manage the risk.

in the frame and broadcasting the seed were categorised in action category 4 indicating that immediate corrective action is required. These activities involve highly stressful postures, including bending, lifting and repetitive motions which can contribute to severe musculoskeletal strain. Tasks such as laying the polythene sheet and removing the frame fall into action category 3, which requires corrective action as soon as possible. These tasks involve awkward postures and exertion, though with slightly lower urgency compared to category 4 activities. Activities like leveling the soil bed and covering the seedbed are categorised as action category 2, necessitating corrective action in the near future. These tasks involve less physically demanding postures but still have ergonomic improvement potential. The task of irrigating the bed was the only one classified in action category 1, where no immediate action is required as the posture used is relatively safe and comfortable. The highest-risk activities (action category 4) such as placement of the frame, soil placement and broadcasting seeds involves sustained or extreme postures including forward bending, twisting and repetitive arm movements.

A structured protocol was used to assess ergonomic risk and physiological workload across eight task phases. Phase durations were determined using synchronized video and metabolic data, ranging from 160–395 sec, with the longest durations observed during covering and broadcasting activities. This analysis helped identify time-intensive stages and their contribution to overall ergonomic stress.

This study analysed postures adopted by farm workers during conventional mat-type paddy seedling preparation using OWAS and REBA. Tasks like frame placement and soil filling were categorised as "Very High Risk" by REBA, highlighting the risk of musculo-skeletal discomfort due to awkward trunk and upper limb postures. The "High Risk" classification of the polythene laying task (final score 9.6) underscores the need for ergonomic intervention. The OWAS analysis also pointed to high-risk activities such as frame placement and seed broadcasting emphasising the importance of corrective actions to reduce the risk of musculoskeletal disorders (MSDs). The recommendation to implement corrective actions such as adjusting work postures and incorporating assistive devices or mechanisation aligns with strategies suggested in other studies aimed at improving ergonomics in agricultural work by Das and Gangopadhyay (2011) and Pundhir and Singh (2022).

Table 4 Descriptive statistics of farm workers during seedling preparation activities

Source	Resting value	Maximum	Mean	Std. deviation
VO_2 (mL/min/kg)	3.5	29.83	9.70	4.92
HR (bpm)	68.00	143.00	102.20	17.09
EE (kcal/min)	1.4	9.74	3.04	1.54

VO_2, Oxygen consumption; HR, Heart rate; EE, Energy expenditure.

Physiological parameters of farm workers a manual mat-type paddy seedling preparation: Table 4 presents the descriptive statistics for key physiological and experimental parameters recorded during the manual mat-type paddy seedling preparation process. The dataset includes measurements from multiple respondents, replications and phases of the activity as well as physiological indicators such as oxygen consumption (VO_2), heart rate (HR) and energy expenditure (EE). The different phases of the activity, which ranged from 1 to 8 (mean = 4.50 ± 2.29), highlight the complexity and multi-stage nature of manual seedling preparation. Physiological responses provide insight into the metabolic demands of the task. The VO_2 resting values are 3.5 mL/min/kg and maximum value are 29.83 mL/min/kg with an average of 9.70 ± 4.92 mL/min/kg. This suggests that while some phases required minimal exertion, others placed moderate aerobic demands on workers. Heart rate (HR) resting value are 68 beats/min (bpm) and maximum value are 143 beats/min (bpm), with a mean of 102.20 ± 17.09 bpm, indicating varying cardiovascular stress levels depending on task intensity. Energy expenditure (EE) resting value are 1.4 kcal/min and maximum value are 9.74 kcal/min with an average of 3.04 ± 1.54 kcal/min further reflecting the metabolic cost associated with different stages of manual seedling preparation.

Table 5 presents the results of a two-way ANOVA examining the effects of respondents, task phases, and their interaction on physiological responses—oxygen

Table 5 Effects of respondents and task phase on physiological parameters

Source of Variation	df	VO_2 (mL/min/kg)		HR (bpm)		EE (kcal/min)	
		Sum of squares	F-value	Sum of squares	F-value	Sum of squares	F-value
Replication	6	47.646	0.544 (ns)	9625.218	92.294***	4.165	0.502 (ns)
Respondent	9	2592.021	19.918***	96732.793	624.159***	291.935	23.643***
Phase	7	2084.778	20.597***	24692.793	204.850***	226.467	23.581***
Respondent × Phase Interaction	63	1933.049	2.122***	24067.207	22.184***	155.062	1.794***
Error	479	6926.114	-	8248.428	-	657.181	-
Total	560	66307.174	-	6012876.000	-	6526.874	-

NS, Non-significant (p>0.05); R^2 (VO_2), 0.490; Adjusted R^2, 0.405; R^2 (HR), 0.950; Adjusted R^2, 0.941; R^2 (EE), 0.507; Adjusted R^2, 0.424; VO_2, Oxygen consumption; HR, Heart rate; EE, Energy expenditure.

consumption (VO_2), heart rate (HR), and energy expenditure (EE). Replication effects were not significant for VO_2 and EE ($p > 0.05$), indicating measurement consistency, but were highly significant for HR (F = 92.294, $p < 0.001$), showing variability across trials.

A significant main effect of respondents was observed for VO_2 (F = 19.918), HR (F = 624.159), and EE (F = 23.643), suggesting that individual differences influenced physiological responses. Task phase also had a highly significant effect on all parameters ;VO_2 (F = 20.597), HR (F = 204.850), and EE (F = 23.581)—indicating varying workload across operational stages.

The interaction between respondent and phase was significant for VO_2, HR, and EE, implying that individuals responded differently across task phases. Model fit was strongest for HR ($R^2 = 0.950$), followed by EE ($R^2 = 0.507$) and VO_2 ($R^2 = 0.490$). Overall, both individual and task-related factors significantly effected physiological workload, highlighting the need for targeted ergonomic interventions.

The variation in oxygen consumption (VO_2, mL/min/kg) across different phases of manual mat-type paddy seedling preparation is illustrated in Supplementary Fig. 1. The x-axis represents work phases (1–8) while the y-axis denotes oxygen consumption levels with each coloured line corresponding to a different respondent (1–10). The trends indicated fluctuating oxygen demand across phases suggesting variations in task intensity. A distinct pattern emerges where VO_2 values generally rise during the middle phases (3–5) indicating increased energy expenditure due to strenuous activities such as lifting, bending or transplanting seedlings. Significant inter-individual variability is observed as some respondents (e.g., Respondents 9 and 10) exhibit higher VO_2 peaks whereas others (e.g. Respondent 1) maintain lower, stable oxygen consumption. This variation suggests that physical fitness, efficiency and endurance influence physiological responses to workload. Sharp spikes in VO_2 for some respondents indicate workload imbalance potentially leading to early fatigue or reduced efficiency. Conversely, dips in VO_2 during certain phases suggest task adaptation or momentary reductions in effort. Overall, oxygen consumption increases from initial phases (1–3), peaks at phases (4–5) and stabilises or declines in later phases (6–8), likely due to accumulating fatigue.

The variation in heart rate (HR, bpm) across different phases of manual mat-type paddy seedling preparation is illustrated in Supplementary Fig. 2. The x-axis represents work phases (1–8) while the y-axis denotes heart rate (bpm) with each coloured line corresponding to a different respondent (1–10). This graph highlights individual variations in cardiovascular response during the task. A general trend showed that heart rate increases as the phases progress, reflecting rising physical exertion. In the initial phases (1–3), HR values are relatively lower suggesting that workers are still in the early activity stages with minimal physiological demand. However, in the middle phases (4–6), HR rises significantly for most respondents indicating increased cardiovascular strain due to more physically demanding tasks like lifting, bending and handling seedlings. This pattern aligns with the oxygen consumption data, reinforcing the greater energy expenditure during these phases. Notable inter-individual differences are observed. Some respondents (e.g. Respondents 1 and 3) show a steady HR increase while others (e.g. Respondents 6 and 9) maintain relatively stable or fluctuating HR levels indicating differences in fitness, efficiency and physiological adaptation. In later phases (7–8), HR stabilises or slightly declines for some likely due to task adaptation, fatigue-induced pacing or reduced work intensity. Overall, manual paddy seedling preparation imposes significant cardiovascular stress, particularly in the mid-to-late phases.

Supplementary Fig. 3 illustrates energy expenditure (EE, kcal/min) across different phases of manual mat-type paddy seedling preparation for each respondent. The x-axis represents work phases (1–8) and the y-axis denotes energy expenditure (kcal/min) with each colored line corresponding to a different respondent (1–10). The graph shows variations in metabolic demands during the task. A general upward trend in EE is observed as the phases progress, indicating increased physical exertion. In the initial phases (1–2), EE is relatively low, suggesting these stages involve lighter tasks with lower metabolic demands. However, EE increases significantly in phases 3–5 reflecting higher workload intensity, likely due to tasks that require more muscular effort, such as lifting, bending and handling seedling mats. Notable inter-individual variability is observed with some respondents (e.g. Respondents 5 and 9) showing sharp peaks in EE while others (e.g. Respondents 1 and 6) exhibit a more gradual increase or stable pattern. These differences may be due to variations in work efficiency, body composition, fitness levels and individual metabolic rates. In phases 6 and 7, EE declines for some respondents, possibly due to fatigue-induced reductions in work intensity or task adaptation.

The physiological responses of farm workers during conventional mat-type paddy seedling preparation revealed varying exertion levels across tasks. Oxygen consumption (VO_2) showed moderate variability, indicating differences in individual aerobic capacity. Heart rate (HR) remained relatively stable, reflecting consistent cardiovascular demand. However, energy expenditure (EE) demonstrated high variability, pointing to differences in body composition, metabolic efficiency and task intensity. Tasks like soil leveling and frame removal exhibited the highest physiological demands, underscoring the need for ergonomic improvements and optimised workload. The significant interaction effects between respondents and task phases highlight the importance of individual adaptation in physiological efficiency. The observed differences align with findings from previous studies on agricultural labour, where physiological strain varies based on task intensity, duration and individual fitness levels. Study by Kumar *et al.* (2017) highlight that manual agricultural work leads to considerable physical strain, necessitating improved ergonomic interventions. Emphasising on the importance of optimising work-rest schedules to enhance labour efficiency and reduce fatigue. Future research should focus on mechanisation and improved work techniques to minimise physiological stress and enhance worker productivity.

The findings of this study infers that manual mat-type paddy seedling preparation imposes considerable ergonomic and physiological stress on farm workers. REBA analysis revealed high to very high-risk scores ranging from 7.4–10.6 indicating urgent ergonomic intervention while OWAS results placed most postures under Action Categories 2–4, confirming postural deviation and potential musculoskeletal strain. Physiological measurements showed mean values of 102.20 ± 17.09 bpm (HR), 9.70 ± 4.92 mL/min/kg (VO_2) and 3.04 ± 1.54 kcal/min (EE), categorising the work as moderate to heavy intensity. The tasks such as soil placement, leveling, seed broadcasting and frame removal elicited peak physiological and postural loads. Two-way ANOVA demonstrated significant influence of respondents, task phases and their interaction indicating worker variability in adaptability and efficiency. Overall, the study confirms that the current method of seedling preparation is ergonomically demanding and may contribute to fatigue and long-term musculoskeletal disorders. Therefore, ergonomic redesign, worker training, task restructuring and selective mechanisation are strongly recommended to improve safety, comfort and productivity.

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