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The Physiological Cost of Manual Farming: An Integrated Assessment of Occupational Workload, Biomechanical Exposure, and Musculoskeletal Vulnerability Among Female Agricultural Workers

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ABSTRACT

Background: Female employees make a significant contribution to manual farming activities in India; they perform manual labor with frequent movements, awkward posture, and load lifting. Task-specific analysis of the postural strain and musculoskeletal disorders in these employees is required for their ergonomics improvement.

Methods: Cross-sectional study involving 180 female employees in the field in West Bengal, India was done, where 90 field cultivation workers (FCW) and 90 agricultural load handling workers (ALHW) participated in the study. Five tasks were recorded for each group; work time was measured. The postural strain was assessed using OWAS, RULA, REBA and LUBA. The musculoskeletal disorder and BPD scale were used to assess musculoskeletal symptoms.

Results: The workers were young (23.6 years) and underweight on average (BMI 18.43 kg/m^2). ALHW handled 15.21 ± 1.55 kg per cycle, whereas FCW handled at most 5.37 ± 0.51 kg but performed highly repetitive operations (up to 827.59 cycles per hour in transplantation). The highest postural risk was observed during manual weeding in FCW (RULA 7, REBA 11, LUBA 19) and during positioning of loads on the head or shoulders in ALHW (RULA 7, REBA 11, LUBA 18). Across the ten tasks, RULA, REBA and LUBA scores were strongly correlated with the maximum discomfort rating (Spearman $\rho = 0.91–0.95$). ALHW reported greater discomfort in the head, neck and shoulders (BPD 9.01, 8.09 and 7.39 vs 4.22, 5.06 and 5.61), whereas FCW reported greater discomfort in the knees, calves, ankles and legs (Holm-adjusted $p< 0.01$). Pain was more frequent among ALHW than FCW (86.7% vs 51.1%; odds ratio 6.22, 95% CI 2.98–13.0).

Conclusions: Field cultivation and load handling impose distinct, task-specific biomechanical burdens on women workers. Interventions should target lower-back and lower-limb strain in field cultivation (improved tools, posture modification, rest breaks) and neck–shoulder and spinal loading in load handling (load reduction, load-carrying aids and safe handling practices).

Keywords: *Female agricultural workers; ergonomic assessment; work-related musculoskeletal disorders (WMSDs); physiological workload; biomechanical risk factors; working posture analysis.*

1. Introduction

The occupation sector of agriculture is one of the most significant sectors in India and serves as a means of earning for many people in rural India, especially women. The women employed in agriculture help in activities such as planting, transplanting, weeding, harvesting, threshing and also the manual transportation of the crop yield. Although they engage in these activities, there still exist many instances where these processes are carried out using traditional tools and manual processes due to the lack of mechanized and ergonomically designed equipment in rural India. This exposes the female employees to repetitiveness, long periods of work, awkward postures and also manual handling which could cause biomechanical stress. [1–3].

Manual farming is characterized by exertion of the muscles, repetitive use of instruments and materials, and long-term postures. The tasks of planting rice, weeding, and harvesting crops often necessitate forward bending of the trunk, squatting, kneeling and repetition of limb motions; transporting crops, fertilizers, and instruments puts a burden on the back vertebrae, shoulder, and lower limbs of the body. The above mentioned tasks are exacerbated by poor rest, exposure to hot weather, and lack of ergonomics. In the study on the female laborers engaged in rice-wheat cultivation, planting, threshing, harvesting, and manual loading are the primary tasks causing physical stress and drudgery [2]. Occupational ergonomics for traditional farmers have also been attributed to long working hours, lack of adequate rest, and awkward postures [4].

WMSDs involve the muscles, joints, tendons, ligaments, and other supportive tissues and manifest themselves in the form of pain, discomfort, stiffness, and limitation in motion. They develop due to repetitive motions, excessive force, static contraction for long periods of time, manual handling of

materials, and constant adoption of non-neutral posture. The systematic review and meta-analysis found that musculoskeletal pain was prevalent among agricultural workers in low- and middle-income countries and that the most affected body region was the lower back [3]. Research involving Indian agricultural workers identified the lower back, knees, shoulders, and neck as common sites of complaints, which were attributed to squatting for prolonged periods, constant bending, and repetition [1].

The women agricultural workers have to cope with an extra strain because the agricultural work involves unpaid household work too. The prevalence of WMSDs was studied among the women farmers in the Kashmir Valley and there were some cases of WMSD, mainly in the lower back and neck shoulder region, and significant correlations with socio-economic factors [5]. The women workers who were engaged in harvesting peas manually suffered from severe postural strains, mostly in the hand, finger, shoulder, and neck regions [6].

Working posture is a major component of biomechanical exposure and depends on the task, the design of implements, worker anthropometry, exposure duration and movement frequency. Systematic posture assessment is therefore essential for identifying hazardous activities and setting priorities for intervention, and recent studies increasingly rely on direct field observation, photography and video recording under actual working conditions. A comparative ergonomic assessment of rubber tapping in India demonstrated that the Ovako Working Posture Analysis System (OWAS), Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) can identify task-specific postural stress, and that the methods address different aspects of exposure and should be selected according to the work evaluated [7].

OWAS classifies combinations of back, arm and leg postures together with load handling. RULA focuses on postural loading of the upper limbs, neck and trunk and is suited to repetitive hand movements and sustained upper-body postures. REBA evaluates whole-body posture by incorporating body-segment positions, force or load, coupling and activity. Loading on the Upper Body Assessment (LUBA) evaluates upper-body postural loading from joint-position discomfort and, unlike the other techniques, was developed from experimental measurements of perceived joint discomfort and maximum holding time [8]. RULA and REBA have been applied successfully to agricultural postures and to identify activities requiring corrective action [4, 7]. Because their scores represent different constructs, a combined application can broaden the characterization of postural exposure, provided the scores are interpreted independently.

Symptomatic evaluation can be performed using the standardized Nordic Musculoskeletal Questionnaire (NMQ) developed by Kuorinka et al. [9]. This has been widely used to record self reported musculoskeletal symptoms of various areas of the body. Variations of the questionnaire have been used within both agricultural and occupational health research. The Body Part Discomfort (BPD) scale can be used to record discomfort felt in certain parts of the body. Research has shown that women working within the agricultural sector show increased ergonomic awareness after receiving appropriate posture management training [10].

Although musculoskeletal complaints and ergonomic hazards in agriculture are well documented, biomechanical exposure and symptom patterns may differ markedly between individual farming activities. An integrated field assessment combining symptom evaluation with several observational posture methods may therefore characterize occupational risk more completely. The present study aimed to (i) describe the work–time characteristics of field cultivation and load handling in female agricultural workers, (ii) assess task-specific postural loading with OWAS, RULA, REBA and LUBA, and (iii) compare the prevalence, distribution and intensity of musculoskeletal symptoms between female field cultivation workers (FCW) and agricultural load handling workers (ALHW) in West Bengal, India, using the Modified Nordic Musculoskeletal Questionnaire and the BPD scale.

2. Methods

2.1 Study participants

The experiment was carried out on 180 female workers in agricultural fields in West Bengal, India. These 180 workers were selected randomly and they have had more than five years of experience in their jobs. These workers were then classified into two groups of equal size. Group I consists of 90 field cultivation workers (FCW). These workers were primarily involved in planting, transplantation, weeding, harvesting, and bundling of the harvested crops. Group II consists of 90 agricultural load handling workers (ALHW). These workers were primarily involved in lifting and loading of the products, positioning of the load on head/shoulders, carrying the product to collection or storage points, unloading, and arranging the harvested products.

2.2 Anthropometric measurements

Standing stature (cm) and body weight (kg) were measured with an anthropometric rod and a weighing scale, respectively. Body mass index (BMI) was calculated as body weight (kg) divided by the square of stature (m^2), following the standard formula described by the World Health Organization [11].

2.3 Work study and time–motion analysis

A work study was carried out under actual field conditions according to the principles of the International Labour Organization (ILO) [12]. Sowing, transplantation, weeding, harvesting and manual transportation of produce were examined by direct observation. Multiple-activity charts documented the sequence and coordination of activities, and activity sampling estimated the proportion of working time devoted to each task. A calibrated

stopwatch was used to time individual work cycles, and the load handled, the duration of each cycle and the number of cycles per hour were evaluated to characterize repetitive workload and ergonomic demand.

2.4 Assessment of working postures and ergonomic risk

Working postures were evaluated under field conditions by direct observation and by indirect analysis of photographs and video recordings taken during sowing, transplantation, weeding, harvesting and manual handling of produce. The recorded postures were analyzed with four established techniques: OWAS [13], RULA [14], REBA [15] and LUBA [8]. Particular attention was paid to trunk flexion, neck inclination, upper-limb movements, squatting, kneeling and manual load handling. Risk was classified using each method's own categories: OWAS action categories 1–4 (reported as low, moderate, high and very high risk), RULA action levels 1–4, REBA risk levels (negligible to very high) and LUBA categories I–IV.

2.5 Assessment of work-related musculoskeletal disorders (WMSDs)

Musculoskeletal symptoms and their prevalence and distribution were examined using Modified Nordic Musculoskeletal Questionnaire based on the standard questionnaire used by Kuorinka et al. [9]. The questionnaire was drafted in English and was explained in either of the two languages chosen by the participants, that is, Bengali or Hindi. Details collected included demographic details of the study participants, occupational history of the participants, the type and duration of farming activities involved and presence or absence of pain/discomfort in 16 body areas (head, neck, shoulder, elbow, upper arm, lower arm, wrist, hand, trunk, low back, thigh, knee, foot, ankle, calf and leg).

2.6 Assessment of body part discomfort (BPD)

The degree of discomfort experienced in different body parts while engaged in agricultural tasks was determined by a modified BPD numerical rating scale (0–10), based on existing methods of measuring discomfort [16, 17]. Zero (0) represented absence of any discomfort, one (1) minimal discomfort, five (5) medium discomforts and ten (10) intolerable discomforts. The most uncomfortable body parts for each activity were identified and scored (Tables 3 & 4).

2.7 Statistical analysis

Continuous data are presented as mean ± standard error of the mean (SEM) and categorical data as number (percentage). BPD scores of FCW and ALHW were compared for each body region with the independent-samples Student's t-test (df = 178), applied where the assumptions of parametric testing were satisfied [18, 19]; effect sizes are given as Cohen's d with 95% confidence intervals (CI) for the mean difference. The prevalence of complaints in each body region and of each symptom type was compared with Pearson's χ^2 test, and effect sizes are given as odds ratios (ALHW vs FCW) with Woolf 95% CI; proportions are accompanied by Wilson 95% CI and between-group differences by Newcombe 95% CI. Because 16 body regions (and four symptom types) were compared, p values were adjusted with the Holm–Bonferroni procedure, and an adjusted $p< 0.01$ was considered statistically significant. The relationship between postural scores (OWAS risk class, RULA, REBA, LUBA) and the maximum discomfort rating across the ten assessed tasks was explored with Spearman's rank correlation. Because these task-level scores are single values per task, they were described but not tested between groups.

3. Results and Discussion

3.1 Occupational context

Indian women in agriculture are predominantly involved in seasonal employment where the occurrence of their employment is determined by the pattern of cultivation, the amount of rainfall, and demand for laborers, recruiting periods coincide with intensive activities such as sowing, transplanting, weeding, harvesting and post-harvest operations. They begin their day early with household chores such as cooking and cleaning before leaving for work in the fields. Some of them come from the same or neighboring villages, while some of them are seasonal migrant laborers coming from other districts or states of India. At non-peak periods, apart from domestic chores, some of them may indulge in livestock management, subsistence farming and informal sector employment activities or remain temporarily unemployed. The wage payment can be on a daily basis, but also by the performance and piece rates system in transplanting, weeding, harvesting and manual transport activities, where wages may be dependent upon the amount of work done, the area covered or the quantity of crops handled. Sometimes there are advance payments or informal arrangements that are subsequently settled in terms of wage payment during the season.

3.2 Anthropometric and occupational profile

Anthropometric parameters and work experience of the 180 workers have been presented in Table 1. Mean BMI (18.43 ± 1.33 kg/m2) was just slightly below the value of 18.5 kg/m2, which is categorized as underweight and corresponds to chronic energy deficiency (CED) [11, 20]. There is evidence of the relation between nutritional status and work capacity in Indian rural women, and poor nutritional status may negatively influence tolerance of prolonged workload [21]. Workers had a young age (mean 23.6 ± 3.25 years), relatively short occupational experience (5-9 years). In previous studies

of female workers in West Bengal, considerable prevalence of musculoskeletal discomfort in the lumbar region, hips, wrists, shoulders and knees was noted [22]. The combination of poor nutritional status, physically demanding work and repetitive biomechanical load can result in increased physiological strain, fatigue and proneness to WMSDs.

Table 1. Anthropometric characteristics and occupational experience of female agricultural workers engaged in field cultivation and agricultural load handling (n = 180, groups combined).

Parameter	Mean ± SEM	Range
Height (cm)	142.23 ± 4.71	140–148
Body weight (kg)	42.95 ± 3.60	34–53
Body mass index (kg/m^2)	18.43 ± 1.33	16.24–22.41
Age (years)	23.6 ± 3.25	18–26
Work experience (years)	5.2 ± 0.25	5–9

Values are mean ± SEM; ranges are shown in the last column.

3.3 Work–time study

The two groups differed in the nature of their physical exposure (Table 2, Fig. 1). In FCW, the activities involved repetitive upper-limb movements, prolonged forward trunk bending, squatting and sustained constrained postures. Manual sowing required 10.15 ± 2.67 s per cycle (354.68 cycles per hour) and transplantation 4.35 ± 1.21 s per cycle (827.59 cycles per hour), implying a very high cumulative exposure of the wrists, hands, shoulders and lower back to repetitive loading. Weeding and soil preparation (180.16 ± 15.12 s per cycle), harvesting with hand tools (122.25 ± 11.02 s) and gathering and bundling of harvested crops (220.95 ± 14.67 s; the longest FCW cycle) were performed at 16–29 cycles per hour. The mean load handled by FCW ranged from 0.3 ± 0.2 kg in transplantation to 5.37 ± 0.51 kg in gathering and bundling. Although external loads were low, repeated trunk flexion, squatting and sustained muscular contraction may impose considerable cumulative postural stress, in agreement with Pal and Dhara [22], who identified prolonged forward bending and squatting as important contributors to musculoskeletal discomfort among female rice cultivators in West Bengal.

Table 2. Work–time study of female field cultivation workers (FCW) and agricultural load handling workers (ALHW) engaged in manual farming activities.

Activity	Load carried (kg)	Time per cycle (s)	Cycles per hour
Group I – Field cultivation workers (FCW)			
Manual sowing of seeds	0.5 ± 0.1	10.15 ± 2.67	354.68 ± 2.67
Transplantation of seedlings	0.3 ± 0.2	4.35 ± 1.21	827.59 ± 6.45
Manual weeding and soil preparation	0.4 ± 0.2	180.16 ± 15.12	19.98 ± 1.96
Harvesting crops using hand tool	0.6 ± 0.1	122.25 ± 11.02	29.45 ± 5.37
Gathering and bundling harvested crops	5.37 ± 0.51	220.95 ± 14.67	16.29 ± 1.33
Group II – Agricultural load handling workers (ALHW)			
Lifting produce and loading into baskets	15.21 ± 1.55	180.52 ± 52.20	19.94 ± 1.17
Positioning loads on head or shoulders	15.21 ± 1.55	210.21 ± 33.12	17.13 ± 1.79
Carrying produce to collection/storage points	15.21 ± 1.55	98.23 ± 13.67	36.65 ± 2.21
Unloading produce	15.21 ± 1.55	11.12 ± 1.36	323.74 ± 21.55

Activity	Load carried (kg)	Time per cycle (s)	Cycles per hour
Stacking and arranging harvested produce	15.21 ± 1.55	160.25 ± 26.31	22.46 ± 2.55

Values are mean ± SEM. Cycles per hour were calculated from the mean cycle time (3600 s/time per cycle).

On the contrary, ALHW had a mean load of 15.21 ± 1.55 kg. Lifting and loading of the basket were performed in 180.52 ± 52.20 s per cycle (19.94 cycles per hour), while positioning of the loads on the head and shoulders required 210.21 ± 33.12 s (17.13 cycles per hour). Produce transportation from the field to the collection or storage point required 98.23 ± 13.67 s per cycle (36.65 cycles per hour) and included the postural stabilization of the neck, shoulders, trunk, and lower limbs under a sustained external load. Unloading was the fastest ALHW task (11.12 ± 1.36 s; 323.74 cycles per hour), while stacking and arrangement took 160.25 ± 26.31 s (22.46 cycles per hour). Taking into account that the above-mentioned five activities can be considered as subsequent stages of one load-handling cycle, their mean total time is about 660.33 s (11.01 min); thus, theoretically, there could be up to 5.45 full load-handling cycles per hour. It does not include the return to the collecting point, pauses, etc., so it is likely to be lower and needs to be determined through direct observation.

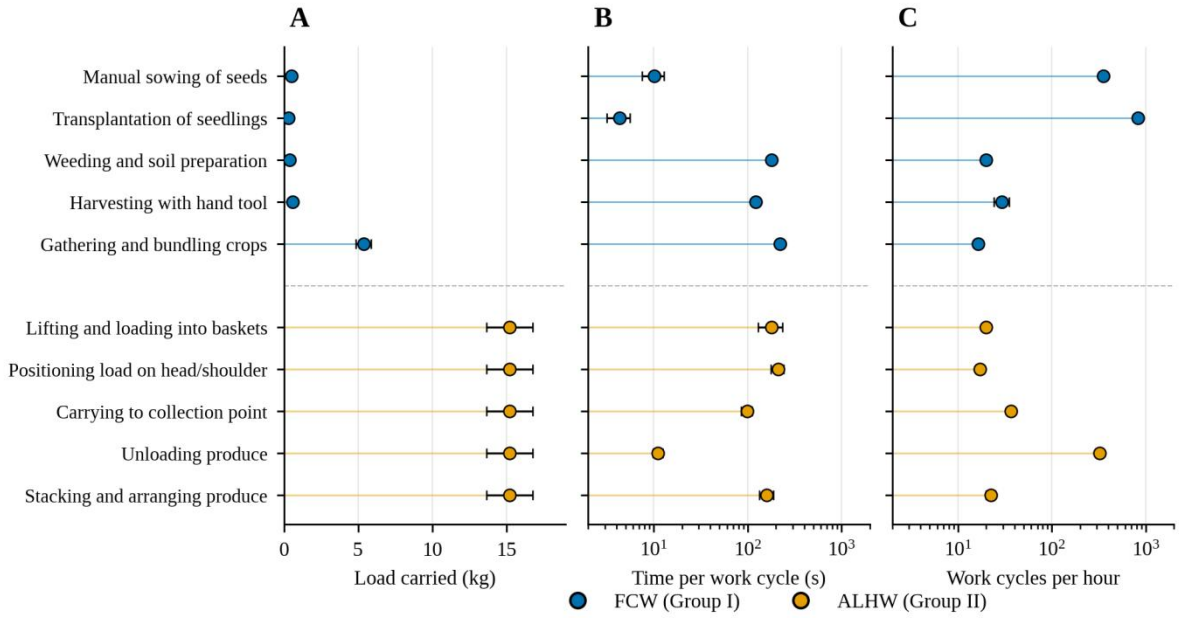


Fig. 1. Work–time characteristics of female field cultivation workers (FCW) and agricultural load handling workers (ALHW): (A) load carried per cycle (kg); (B) time per work cycle (s, logarithmic scale); (C) work cycles per hour (logarithmic scale). Points are means and bars are ± SEM.

Thus, FCW were exposed mainly to high-frequency movements, low external loads and prolonged awkward postures, whereas ALHW handled considerably heavier loads in repeated lifting, carrying, unloading and stacking operations. These patterns are consistent with reports that repetitive activity, prolonged stooping and squatting, and manual material handling are important ergonomic risk factors among Indian farmers [1], and that transplantation, harvesting and load carrying are physically demanding operations associated with considerable drudgery among female workers [2]. The relative severity of risk in the two groups is examined below using the postural and discomfort results.

3.4 Postural risk and discomfort among field cultivation workers

The postural assessment for the five FCW practices, along with the regions of maximum body discomforts, is provided in Table 3. The practice of manual sowing was categorized under moderate risk (OWAS 2,1,2,1; RULA 4; REBA 5; LUBA 8), with maximum discomfort in the lower back and shoulder region (6.2 ± 0.52). Transplanting (OWAS 2,1,4,1; RULA 6; REBA 9; LUBA 16), harvesting with hand tools (RULA 6; REBA 9; LUBA 15), and gathering and bundling (RULA 5; REBA 8; LUBA 14) showed that they all had high-risk postures, with the maximum discomfort levels being 8.8 ± 0.24 (lower back and knees), 8.2 ± 0.37 (lower back and shoulders), and 7.1 ± 0.11 (lower back and wrists), respectively. Manual weeding and soil preparation posed high risks using all methods (OWAS 4,1,4,1; RULA 7; REBA 11; LUBA 19), and thus there was an urgent need for ergonomic interventions, with maximum discomfort level being 9.1 ± 1.24 (lower back and knees).

Table 3. Ergonomic assessment of working postures using OWAS, RULA, REBA and LUBA among female field cultivation workers (FCW).

Activity	OWAS	RULA	REBA	LUBA	Maximum discomfort

	Code	Risk	Score	Action level	Score	Risk level	Load	Category	Body parts	Rating
Manual sowing of seeds	2,1,2,1	Moderate	4	2	5	Medium	8	II	Lower back, shoulders	6.2 ± 0.52
Transplantation of seedlings	2,1,4,1	High	6	3	9	High	16	IV	Lower back, knees	8.8 ± 0.24
Manual weeding and soil preparation	4,1,4,1	Very High	7	4	11	Very High	19	IV	Lower back, knees	9.1 ± 1.24
Harvesting crops using hand tool	2,1,4,1	High	6	3	9	High	15	III	Lower back, shoulders	8.2 ± 0.37
Gathering and bundling harvested crops	2,1,4,1	High	5	3	8	High	14	III	Lower back, wrists	7.1 ± 0.11

OWAS code = back, arms, legs, load categories; OWAS risk corresponds to action categories 1–4 (low to very high). RULA action levels: 1 acceptable, 2 further investigation, 3 investigate and change soon, 4 investigate and change immediately. REBA risk levels: 4–7 medium, 8–10 high, 11–15 very high. LUBA categories I–IV indicates increasing postural load. Cell shading denotes risk class (green, low; yellow, moderate/medium; orange, high; red, very high). Discomfort rating is the mean ± SEM on the 0–10 BPD scale for the body parts named.

In summary, the lumbar region was the body part that most frequently experienced problems, while knees, shoulders, and wrists were the other body parts mostly affected by FCW (all five activities). The activity that carried the highest risk in terms of postural problems was weeding and soil preparation, followed by transplantation and harvesting. Long periods of bent posture, repetitive movements of the upper limbs, squatting, and other factors could be some of the reasons behind this finding.

3.5 Postural risk and discomfort among load handling workers

The associated evaluation for the five ALHW tasks is given in Table 4. Lifting and loading produce into baskets has high risk (OWAS 2,1,4,2; RULA 6; REBA 10; LUBA 17), causing maximal discomfort in lower back region (8.4 ± 1.09). Loading of cargo onto heads or shoulders was found to be at the highest posture risk (OWAS 4,3,4,2; RULA 7; REBA 11; LUBA 18) and thus requires immediate action and is the task causing maximum discomfort (9.2 ± 0.25; neck and shoulders). Unloading was also assessed as high risk (OWAS 2,1,4,2; RULA 6; REBA 9; LUBA 13) causing maximal discomfort in lower back region (8.2 ± 0.63). Arranging of produce has very high risk according to OWAS (4,1,4,2) and is considered substantial concern according to RULA, REBA and LUBA (5; 8; 12). Discomfort occurred in lower back and knees (7.8 ± 1.29).

Table 4. Ergonomic assessment of working postures using OWAS, RULA, REBA and LUBA among female agricultural load handling workers (ALHW).

Activity	OWAS		RULA		REBA		LUBA		Maximum discomfort	
	Code	Risk	Score	Action level	Score	Risk level	Load	Category	Body parts	Rating
Lifting produce and loading into baskets	2,1,4,2	High	6	3	10	High	17	IV	Lower back	8.4 ± 1.09
Positioning loads on head or shoulders	4,3,4,2	Very High	7	4	11	Very High	18	IV	Neck and shoulders	9.2 ± 0.25
Carrying produce to collection/storage points	1,2,7,2	Low	4	2	7	Medium	9	II	Neck and shoulders	7.1 ± 0.15
Unloading produce	2,1,4,2	High	6	3	9	High	13	III	Lower back	8.2 ± 0.63

Activity	OWAS		RULA		REBA		LUBA		Maximum discomfort	
	Code	Risk	Score	Action level	Score	Risk level	Load	Category	Body parts	Rating
Stacking and arranging harvested produce	4,1,4,2	Very High	5	3	8	High	12	III	Lower back and knees	7.8 ± 1.29

Abbreviations, risk classes and shading as in Table 3.

The transportation of produce to the collecting/ storage site was described as low risk exposure by OWAS (1,2,7,2), while moderate risk exposure with need for further evaluation was reported by RULA (4), REBA (7) and LUBA (9), and maximum pain (neck & shoulder region, 7.1 ± 0.15) was due to sustained external load during transportation. This difference is explained by the differential sensitivities of the methods to the biomechanical exposure elements. In case of ALHW, the maximum pain was due to positioning of load on head and shoulders (9.2), followed by lifting & loading (8.4), unloading (8.2), stacking (7.8) and transporting (7.1). The regions which were most commonly affected were neck, shoulders & lower back.

3.6 Comparison of postural indices across the ten tasks

The risk matrix shown in Fig. 2 integrates the postural and discomfort data from all ten tasks in one figure. In FCW, weeding and soil preparation were the only two tasks classified in the highest class according to the OWAS, RULA and REBA method, while in ALHW positioning of loads on the head or shoulders was the only task in the highest class according to these three methods. Discomfort ratings were also the highest in these three tasks (9.1 and 9.2, respectively). In total, across the ten tasks the highest discomfort rating increased significantly with the RULA score (Spearman's $\rho = 0.95$), REBA score ($\rho = 0.95$) and LUBA postural load ($\rho = 0.91$; all $p < 0.001$; Fig. 3) and the correlation with the OWAS risk class was lower ($\rho = 0.68$, $p = 0.031$). The scores of the RULA, REBA and LUBA were very well correlated ($\rho = 0.92$-0.98). The presented correlations were calculated using ten tasks, which are not independent observations, and should thus be considered exploratory. Despite this, they show that the observational scores correlate with the discomfort ratings by the workers.

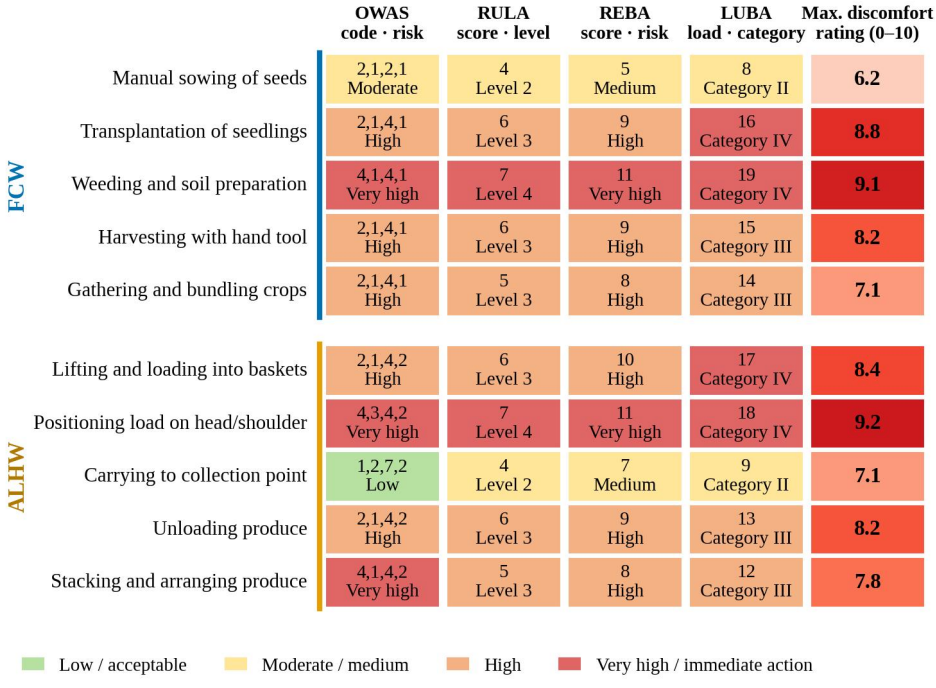


Fig. 2. Ergonomic risk matrix of the ten assessed tasks (FCW, five tasks; ALHW, five tasks). Cells show the OWAS code and risk class, the RULA score and action level, the REBA score and risk level, the LUBA postural load and category, and the maximum discomfort rating (0–10). Colour indicates risk class (green, low; yellow, moderate/medium; orange, high; red, very high); the shading of the discomfort column increases with the rating.

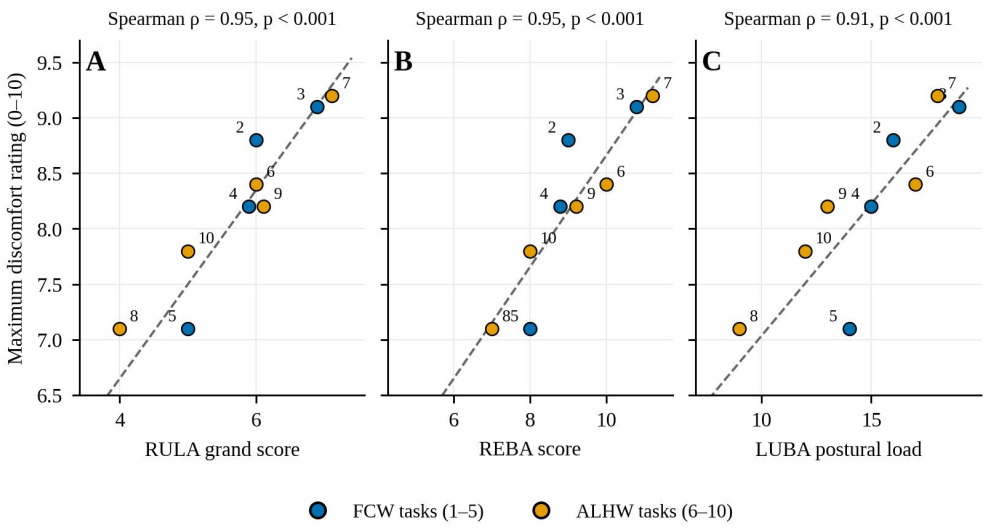


Fig. 3. Association between postural indices and the maximum discomfort rating across the ten tasks: (A) RULA score, (B) REBA score and (C) LUBA postural load. Tasks: 1, manual sowing; 2, transplantation; 3, weeding and soil preparation; 4, harvesting with hand tool; 5, gathering and bundling; 6, lifting and loading; 7, positioning loads on head/shoulders; 8, carrying; 9, unloading; 10, stacking and arranging. Dashed lines are least-squares fits for visual reference; Spearman's ρ is shown above each panel. Points with coinciding coordinates are offset slightly for legibility.

3.7 Distribution of musculoskeletal complaints by body region

Fig. 4 and Table 5 compare the prevalence of complaints in 16 body regions between the two groups. Complaints were common in most regions in both groups. Complaints in the head (96.7% vs 27.8%; odds ratio 75.4), neck (93.3% vs 72.2%), shoulder (71.1% vs 42.2%) and upper arm (72.2% vs 42.2%) were significantly more frequent in ALHW (all Holm-adjusted $p < 0.01$), consistent with repetitive lifting and the carrying of heavy loads on the head and shoulders. In contrast, complaints in the thigh (78.9% vs 55.6%), foot (93.3% vs 67.8%) and ankle (93.3% vs 70.0%) were significantly more frequent in FCW, who work for long periods in forward-bent, squatting and kneeling postures. Complaints in the lower back (93.3% vs 81.1%) and knee (92.2% vs 76.7%) were also numerically more frequent in FCW, and elbow complaints were numerically more frequent in ALHW (83.3% vs 65.6%), but these differences did not remain significant after adjustment for multiple comparisons (adjusted $p = 0.098$, 0.036 and 0.050, respectively). Wrist, hand, lower-arm, trunk, calf and leg complaints did not differ significantly. Both groups therefore bear a high burden of musculoskeletal complaints, but the distribution differs: upper-body and head–neck complaints predominated in load handling and lower-limb complaints in field cultivation.

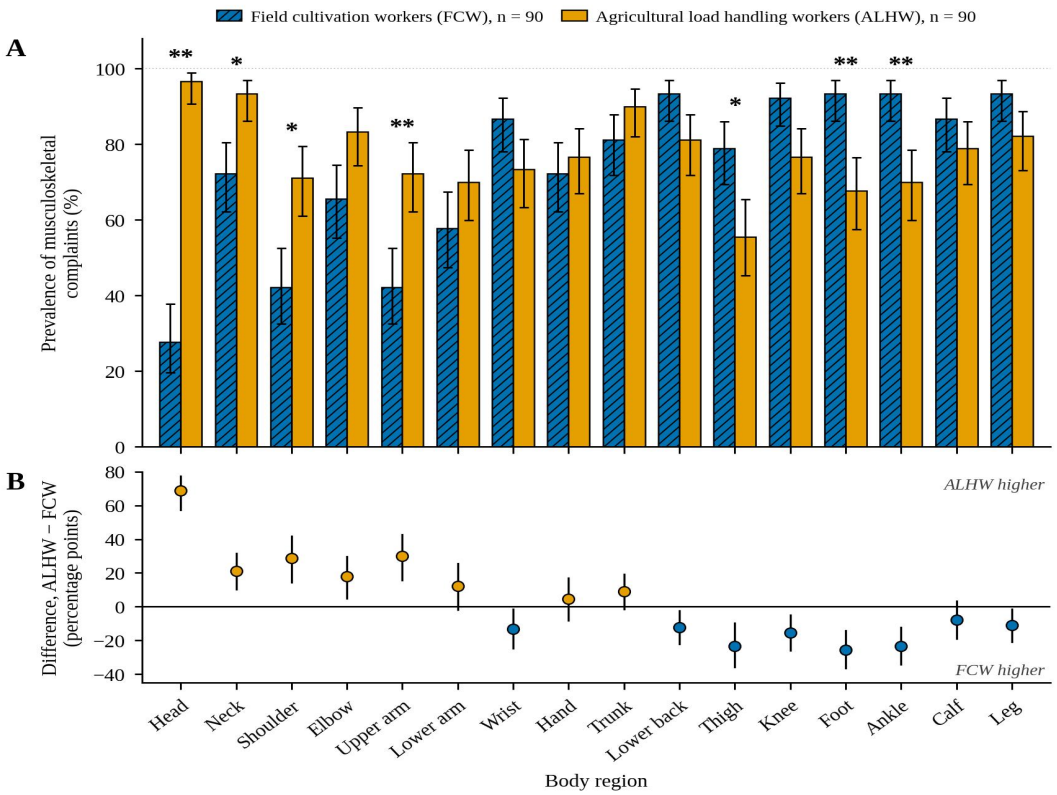


Fig. 4. Prevalence of musculoskeletal complaints (Modified Nordic Musculoskeletal Questionnaire) in 16 body regions among female field cultivation workers (FCW, n = 90) and agricultural load handling workers (ALHW, n = 90). (A) Prevalence (%) with Wilson 95% confidence intervals. (B) Difference in prevalence (ALHW − FCW) with Newcombe 95% confidence intervals; intervals that exclude zero indicate unadjusted differences. Asterisks denote Holm-adjusted $p < 0.01$ (*) and $p < 0.001$ (**) from Pearson's χ^2 tests.

Table 5. Between-group comparison of the prevalence of musculoskeletal complaints in 16 body regions (Modified Nordic Musculoskeletal Questionnaire).

Body region	FCW, n (%)	ALHW, n (%)	Difference, percentage points (95% CI)	Odds ratio, ALHW vs FCW (95% CI)	p (Holm-adjusted)
Head	**25 (27.8)**	**87 (96.7)**	**68.9 (57.2 to 77.4)**	**75.4 (21.8–260.5)**	**<0.001**
Neck	**65 (72.2)**	**84 (93.3)**	**21.1 (10.3 to 31.7)**	**5.38 (2.09–13.9)**	**0.002**
Shoulder	**38 (42.2)**	**64 (71.1)**	**28.9 (14.5 to 41.7)**	**3.37 (1.81–6.25)**	**0.001**
Elbow	59 (65.6)	75 (83.3)	17.8 (5.0 to 29.8)	2.63 (1.30–5.31)	0.050
Upper arm	**38 (42.2)**	**65 (72.2)**	**30.0 (15.6 to 42.7)**	**3.56 (1.91–6.63)**	**<0.001**
Lower arm	52 (57.8)	63 (70.0)	12.2 (−1.8 to 25.6)	1.71 (0.92–3.15)	0.351
Wrist	78 (86.7)	66 (73.3)	−13.3 (−24.7 to −1.6)	0.42 (0.20–0.91)	0.137
Hand	65 (72.2)	69 (76.7)	4.4 (−8.3 to 17.0)	1.26 (0.65–2.47)	0.494
Trunk	73 (81.1)	81 (90.0)	8.9 (−1.5 to 19.3)	2.10 (0.88–4.99)	0.351
Lower back	84 (93.3)	73 (81.1)	−12.2 (−22.2 to −2.4)	0.31 (0.11–0.82)	0.098
Thigh	**71 (78.9)**	**50 (55.6)**	**−23.3 (−35.9 to −9.6)**	**0.33 (0.17–0.64)**	**0.009**

Body region	FCW, n (%)	ALHW, n (%)	Difference, percentage points (95% CI)	Odds ratio, ALHW vs FCW (95% CI)	p (Holm-adjusted)
Knee	83 (92.2)	69 (76.7)	−15.6 (−26.0 to −5.0)	0.28 (0.11–0.69)	0.036
Foot	**84 (93.3)**	**61 (67.8)**	**−25.6 (−36.4 to −14.3)**	**0.15 (0.06–0.38)**	**<0.001**
Ankle	**84 (93.3)**	**63 (70.0)**	**−23.3 (−34.1 to −12.3)**	**0.17 (0.06–0.43)**	**<0.001**
Calf	78 (86.7)	71 (78.9)	−7.8 (−18.8 to 3.4)	0.57 (0.26–1.27)	0.351
Leg	84 (93.3)	74 (82.2)	−11.1 (−20.9 to −1.4)	0.33 (0.12–0.89)	0.137

n (%) of 90 workers per group. FCW, field cultivation workers; ALHW, agricultural load handling workers. Difference = ALHW − FCW (Newcombe 95% CI). Odds ratio >1 indicates higher odds in ALHW (Woolf 95% CI). *p* values are from Pearson's χ^2 test, adjusted across 16 regions by the Holm–Bonferroni method; bold rows are significant at adjusted $p < 0.01$.

3.8 Intensity of discomfort by body region

The intensity of discomfort assessed by the BPD scale (Fig. 5, Table 6) showed a similar pattern. ALHW reported significantly greater discomfort in the head (9.01 ± 0.33 vs 4.22 ± 0.23; mean difference 4.79, 95% CI 4.00 to 5.58; Cohen's $d = 1.78$), neck (8.09 ± 0.38 vs 5.06 ± 0.33; $d = 0.90$) and shoulders (7.39 ± 0.35 vs 5.61 ± 0.30; $d = 0.58$). FCW reported significantly greater discomfort in the knees (8.67 ± 0.35 vs 6.25 ± 0.35; $d = 0.73$), legs (8.58 vs 6.40), calves (8.09 vs 6.02) and ankles (7.29 vs 5.46) (all Holm-adjusted $p < 0.01$). The lower back received the highest discomfort rating of any region in FCW (8.95 ± 0.45) and was rated higher than in ALHW (7.58 ± 0.35), but this difference, like those for the trunk and foot, did not meet the significance threshold after adjustment (unadjusted $p \approx 0.014$–0.017). Discomfort in the elbow, upper arm, lower arm, wrist and hand did not differ between groups (adjusted $p > 0.9$), so the group difference in the upper limb was confined to the proximal regions (neck and shoulders) and the head. These differences probably reflect the contrasting biomechanical demands of the two occupations: sustained loading of the cervical spine, shoulders and upper extremities during repetitive lifting and carrying in ALHW (carrying distance 0.7 ± 0.09 km), and prolonged forward bending, squatting and kneeling with repetitive operations such as transplantation, weeding and harvesting in FCW, which load the lumbar region and lower limbs. The findings thus highlight the task-specific nature of biomechanical exposure and of work-related musculoskeletal disorders among female agricultural workers.

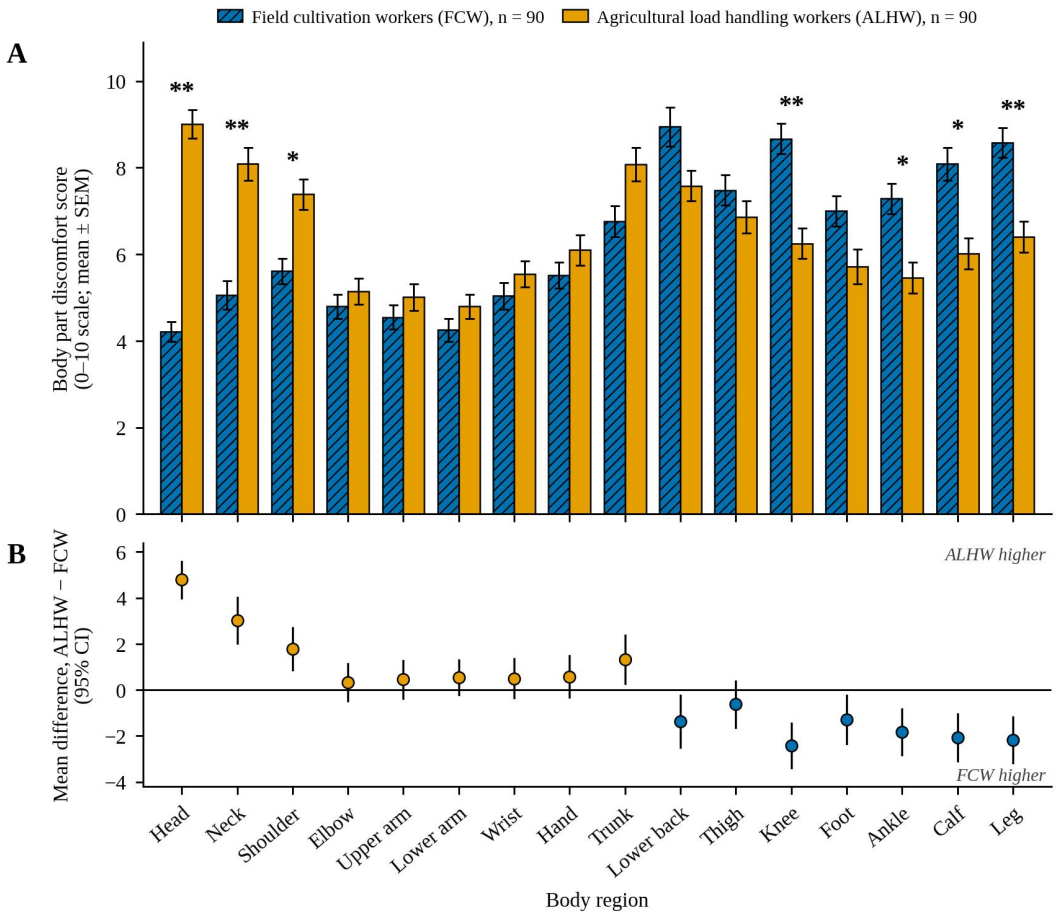


Fig. 5. Body part discomfort (BPD) scores (0–10 scale) in 16 body regions among female field cultivation workers (FCW, n = 90) and agricultural load handling workers (ALHW, n = 90). (A) Mean ± SEM. (B) Mean difference (ALHW − FCW) with 95% confidence intervals. Asterisks denote Holm-adjusted $p < 0.01$ (*) and $p < 0.001$ (**) from independent-samples *t*-tests.

Table 6. Between-group comparison of Body Part Discomfort (BPD) scores (0–10 scale) in 16 body regions.

Body region	FCW, mean ± SEM	ALHW, mean ± SEM	Mean difference, ALHW − FCW (95% CI)	t (df = 178)	Cohen's d	p (Holm-adjusted)
Head	**4.22 ± 0.23**	**9.01 ± 0.33**	**4.79 (4.00 to 5.58)**	**11.91**	**1.78**	**<0.001**
Neck	**5.06 ± 0.33**	**8.09 ± 0.38**	**3.03 (2.04 to 4.02)**	**6.02**	**0.90**	**<0.001**
Shoulder	**5.61 ± 0.30**	**7.39 ± 0.35**	**1.78 (0.87 to 2.69)**	**3.86**	**0.58**	**0.002**
Elbow	4.80 ± 0.28	5.14 ± 0.30	0.34 (−0.47 to 1.15)	0.83	0.12	>0.99
Upper arm	4.55 ± 0.28	5.01 ± 0.31	0.46 (−0.36 to 1.28)	1.10	0.16	>0.99
Lower arm	4.25 ± 0.26	4.80 ± 0.28	0.55 (−0.20 to 1.30)	1.44	0.21	0.911
Wrist	5.04 ± 0.31	5.54 ± 0.30	0.50 (−0.35 to 1.35)	1.16	0.17	>0.99
Hand	5.52 ± 0.30	6.10 ± 0.35	0.58 (−0.33 to 1.49)	1.26	0.19	>0.99
Trunk	6.76 ± 0.36	8.08 ± 0.39	1.32 (0.27 to 2.37)	2.49	0.37	0.124
Lower back	8.95 ± 0.45	7.58 ± 0.35	−1.37 (−2.50 to −0.24)	−2.40	−0.36	0.136

Body region	FCW, mean ± SEM	ALHW, mean ± SEM	Mean difference, ALHW − FCW (95% CI)	t (df = 178)	Cohen's d	p (Holm-adjusted)
Thigh	7.48 ± 0.35	6.86 ± 0.37	−0.62 (−1.63 to 0.39)	−1.22	−0.18	>0.99
Knee	**8.67 ± 0.35**	**6.25 ± 0.35**	**−2.42 (−3.40 to −1.44)**	**−4.89**	**−0.73**	**<0.001**
Foot	7.00 ± 0.35	5.72 ± 0.40	−1.28 (−2.33 to −0.23)	−2.41	−0.36	0.136
Ankle	**7.29 ± 0.35**	**5.46 ± 0.36**	**−1.83 (−2.82 to −0.84)**	**−3.64**	**−0.54**	**0.004**
Calf	**8.09 ± 0.38**	**6.02 ± 0.36**	**−2.07 (−3.10 to −1.04)**	**−3.95**	**−0.59**	**0.001**
Leg	**8.58 ± 0.35**	**6.40 ± 0.36**	**−2.18 (−3.17 to −1.19)**	**−4.34**	**−0.65**	**<0.001**

FCW, field cultivation workers; ALHW, agricultural load handling workers (n = 90 per group). Independent-samples *t*-test; *p* values adjusted across 16 regions by the Holm–Bonferroni method; bold rows are significant at adjusted $p< 0.01$. A positive difference and *d* indicate higher discomfort in ALHW.

3.9 Types of musculoskeletal discomfort

The types of discomforts that have been reported using the Modified Nordic Musculoskeletal Questionnaire have been shown in table 7. In this case, workers might have more than one type of discomfort; hence, the percentages do not add up to 100. Pain was the most common discomfort reported by both FCWs (51.11%) and ALHWs (86.67%), with an odds ratio of 6.22 (95% CI: 2.98-13.0). There were also significantly more instances of numbness, swelling and stiffness among ALHWs than among FCWs (56.67% vs 36.67%, 43.33% vs 13.33% and 28.89% vs 6.67%); all Holm adjusted p<0.01. The higher levels of symptoms experienced by ALHWs can be due to the repetitiveness of lifting heavy loads and carrying loads for long durations. Discomforts in FCWs are due to repetitiveness and awkward postures.

Table 7. Comparative distribution of different types of musculoskeletal discomfort among FCW and ALHW.

Type of discomfort	FCW, n (%)	ALHW, n (%)	Odds ratio, ALHW vs FCW (95% CI)	χ^2 (df = 1)	p (Holm-adjusted)
Pain	46 (51.11)	78 (86.67)	6.22 (2.98–13.0)	26.54	<0.001
Numbness	33 (36.67)	51 (56.67)	2.26 (1.24–4.11)	7.23	0.007
Swelling	12 (13.33)	39 (43.33)	4.97 (2.38–10.4)	19.95	<0.001
Stiffness	6 (6.67)	26 (28.89)	5.69 (2.21–14.6)	15.20	<0.001

n (%) of 90 workers per group; more than one type could be reported. Odds ratio >1 indicates higher odds in ALHW. Pearson's χ^2 test; *p* values adjusted across four symptom types by the Holm–Bonferroni method.

4. Conclusion

Female agricultural workers engaged in manual farming in West Bengal experienced substantial ergonomic strain, and the pattern of exposure and symptoms depended strongly on the task performed. Field cultivation (particularly weeding, transplantation and harvesting) combined highly repetitive movements with prolonged forward bending, squatting and kneeling, and was associated with greater discomfort in the knees, legs, calves and ankles. Load handling, in which workers carried a mean of 15.21 kg, was associated with greater head, neck and shoulder discomfort and a higher prevalence of pain, numbness, swelling and stiffness; positioning loads on the head or shoulders was the most hazardous task in this group. RULA, REBA and LUBA scores closely tracked the workers' discomfort ratings, which support the use of multiple assessment techniques to identify hazardous tasks and to set priorities for prevention. Task-specific ergonomic interventions, improved agricultural implements, safe load-handling practices and appropriate work–rest schedules may help to reduce musculoskeletal strain. Greater attention to ergonomic awareness, worker training and gender-sensitive occupational health policies is also needed to make agricultural work safer and more sustainable for women.

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