Ergonomic Risk Factors Associated with Musculoskeletal Disorders and Fatigue among Horticultural Farmers in Agrotourism Settings

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Abstract. Combining crop production with visitor-service responsibilities may intensify the physical demands placed on horticultural farmers in agrotourism enterprises. This field-based cross-sectional investigation quantified postural exposure, musculoskeletal discomfort, fatigue, and cardiovascular workload in 110 farmers. MSD complaints were recorded with the Nordic Body Map; the Rapid Upper Limb Assessment (RULA) was used to rate working posture; subjective fatigue was obtained through a structured questionnaire; and heart rate represented physiological demand. Pre- and post-work outcomes were tested with paired t tests, associations were examined using Pearson coefficients, and post-work MSD scores were modeled with hierarchical multiple regression. Across the principal tasks, mean RULA values were 5.45-6.02, consistent with moderate-to-high action requirements. MSD scores rose from 10.64 ± 1.26 to 26.90 ± 5.54 and fatigue from 34.06 ± 1.45 to 59.34 ± 12.56 (both $p < 0.001$). RULA had a very strong association with post-work MSDs ($r = 0.955$, $p < 0.001$) and a moderate association with fatigue ($r = 0.563$, $p < 0.001$). After age, work experience, BMI, and working hours were entered as covariates, the final model accounted for 92.1% of MSD variance (adjusted $R^2 = 0.917$). Postural risk was the dominant independent predictor ($\beta = 0.905$, $p < 0.001$), whereas ΔHR contributed modestly ($\beta = 0.076$, $p = 0.023$). The results point to task-level redesign, improved material handling, work-rest organization, and safer access paths as priorities for risk reduction.

Keywords: Agrotourism, Ergonomic Risk, Horticultural Farmers, Musculoskeletal Disorders, RULA, Work Fatigue

1 Introduction

Manual agriculture places substantial mechanical demands on workers, and musculoskeletal disorders (MSDs) remain common among farming populations (Barneo-Alcántara et al., 2021; Shivakumar et al., 2024). Evidence from agricultural ergonomics consistently implicates repeated exertion, non-neutral body positions, repetitive actions, and manual material handling as major exposure pathways (Benos et

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al., 2020; Das, 2023). Horticultural and greenhouse production may be especially demanding because many operations are performed in stooped, squatting, or load-carrying postures (De-Benavides-Jiménez et al., 2025; Srinidhi et al., 2025). Where mechanization is limited, these exposures can persist for longer periods and may compromise worker well-being, performance, and long-term workforce sustainability (Ndirangu & Zoltan, 2025; Zhang & Kim, 2025).

Among the mechanical hazards reported in farming, repetition, high external loads, and deviation from neutral joint positions are recurrent contributors to MSD risk (Ananda et al., 2025; Kaewdok et al., 2021). Observational posture tools offer a practical way to prioritize tasks for corrective action. RULA emphasizes the upper extremities, neck, and trunk together with muscle use and load, whereas REBA gives greater attention to whole-body postural instability and dynamic demands (Corlett, 1993; Hignett & McAtamney, 2000). Consequently, instrument selection should reflect the movement pattern and biomechanical features of the tasks under study.

Physical workload and fatigue may modify the effects of biomechanical exposure. Greater effort is typically accompanied by higher heart rate and perceived tiredness, potentially affecting recovery and performance (De-Benavides-Jiménez et al., 2025; Oakman et al., 2023). The added contribution of cardiovascular demand beyond posture remains less clear in manual horticulture. Age, work experience, BMI, and workday duration were therefore considered potential confounders.

Agrotourism adds visitor-service responsibilities to crop production. Farmers may cultivate and handle produce while also assisting guests, maintaining presentation areas, or demonstrating farm processes. Slopes and irregular outdoor surfaces can further increase the mechanical demands of movement and load handling (Bairwa et al., 2026).

Ergonomics evidence is dominated by conventional agricultural settings, so the occupational consequences of combining horticulture with tourism remain insufficiently characterized. The present study therefore quantified postural exposure and cardiovascular workload, measured short-term changes in MSD complaints and fatigue over a work period, and tested their independent relationships while controlling for age, work experience, BMI, and daily working hours. By integrating observational, physiological, repeated-outcome, and covariate data within one field model, the study addresses an important evidence gap in agrotourism work systems.

2 Methods

2.1 Study Design and Setting

A field-based cross-sectional design was used to examine relationships between ergonomic exposures and two worker outcomes—MSDs and fatigue—in horticultural agrotourism. All observations and measurements were obtained while participants carried out their usual duties so that the exposure profile reflected real farming and visitor-related work (Beetel et al., 2023; Ndirangu & Zoltan, 2025; Yusuf et al., 2025).

2.2 Participants and Sampling

Purposive sampling identified farmers who were currently engaged in horticultural tasks, had at least one year of work experience, and also participated in agrotourism activities. The final sample comprised 110 participants. Farmers unable to perform their usual duties because of acute injury or severe illness were excluded to avoid measuring atypical exposure conditions.

2.3 Field Data Collection

Field procedures combined direct task observation, work documentation, heart-rate recording, and questionnaires. Figure 1 links participant selection and exposure measurement with outcome assessment, data-quality checks, adjusted analysis, and ergonomic recommendations.

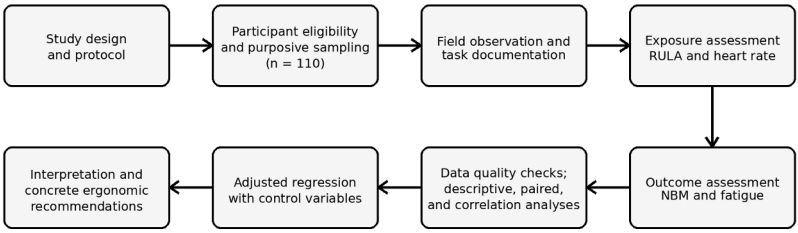


Figure 1. Sequence of Study Procedures and Analysis

Postural Exposure Assessment. RULA was used to rate upper-limb, neck, and trunk posture together with muscle use, force, and repetition (McAtamney & Corlett, 1993). It was selected because planting, weeding, harvesting, and produce handling frequently required trunk and neck flexion, repeated arm-hand actions, and sustained upper-body positions. Each farmer's predominant task was scored on the conventional 1-7 scale, with larger values indicating greater need for intervention. REBA can complement RULA when lower-limb loading, squatting, carrying, or unstable whole-body posture is prominent (Hignett & McAtamney, 2000).

Musculoskeletal Symptom Measurement. Musculoskeletal discomfort was recorded immediately before and after the work period using the Nordic Body Map. Participants scored discomfort separately for each anatomical region, allowing both regional patterns and an overall MSD score to be derived for the two measurement times (Benos et al., 2020).

Fatigue Measurement. Perceived fatigue was obtained at the same pre-work and post-work points with a structured instrument covering physical tiredness, reduced motivation, and difficulty maintaining concentration. Higher totals represented greater fatigue. Administration procedures and timing were standardized across participants.

Heart-Rate Measurement. Heart rate served as the physiological workload indicator. A resting value was obtained before activity and a working value during the observed task; cardiovascular response (ΔHR) was calculated as working HR minus resting HR (De-Benavides-Jiménez et al., 2025).

2.4 Statistical Analysis

Variables were summarized descriptively. Paired-samples t tests quantified pre- to post-work changes in total MSD and fatigue scores, while Pearson coefficients described associations among RULA, ΔHR, post-work MSDs, and fatigue. Hierarchical linear regression used post-work MSD score as the dependent variable. Age, work experience, BMI, and daily working hours entered Block 1; RULA and ΔHR entered Block 2. Standardized β, p, R^2, adjusted R^2, ΔR^2, and VIF were reported, with $p < 0.05$ defining statistical significance.

2.5 Research Ethics

Participation was voluntary and began only after informed consent was obtained. Participant anonymity and study-data protection were maintained throughout the research process.

3 Results and Discussion

3.1 Results

Participant Characteristics. The analytic sample consisted of 110 horticultural farmers. Mean age was 36.48 ± 7.15 years, participants had worked in the occupation for an average of 9.04 ± 4.38 years, and mean daily work duration was 7.13 ± 1.83 hours. Average BMI was 20.54 ± 3.30 kg/m².

Table 1. Participant Demographic and Work Characteristics

Variable	Mean ± SD
Age (years)	36.48 ± 7.15
Work experience (years)	9.04 ± 4.38
Working hours/day	7.13 ± 1.83
BMI (kg/m²)	20.54 ± 3.30

The distribution of age, occupational experience, BMI, and daily work duration shown in Table 1 provided the covariate variation required for the adjusted regression analysis.

Postural Risk by Task. Mean RULA scores for the four principal activities ranged from 5.45 to 6.02, indicating that each task warranted ergonomic attention. Planting had the highest mean; harvesting and carrying were equal, while weeding was lowest but remained elevated.

Table 2. RULA Scores Across Principal Horticultural Tasks

Activity	Mean ± SD	Risk Level
Planting	6.02 ± 0.94	High
Weeding	5.45 ± 1.00	Medium–High
Harvesting	5.70 ± 0.92	High
Carrying loads	5.70 ± 0.86	High

Planting combined sustained forward bending, trunk flexion, squatting, and static positioning. Harvesting and carrying, both averaging 5.70, also required frequent non-neutral upper-body and trunk postures.

Pre- to Post-Work Musculoskeletal Symptoms. Across the work period, total MSD score rose from 10.64 ± 1.26 to 26.90 ± 5.54, a statistically significant change, $t(109) = 29.51$, $p < 0.001$. Post-work values were higher in every body region assessed. The greatest mean discomfort was reported for the lower back, followed in descending order by the upper back, shoulders, arms, neck, knees, and legs.

Table 3. Regional MSD Scores Before and After Work

Body Region	Pre-Work	Post-Work	Δ Score
Neck	1.53	3.78	2.25
Shoulders	1.45	3.84	2.39
Upper back	1.54	3.87	2.33
Lower back	1.55	4.05	2.50
Arms	1.51	3.83	2.32
Knees	1.55	3.77	2.22
Legs	1.51	3.75	2.24

Post-work discomfort was higher in every anatomical region. The lower back had the largest mean (4.05), consistent with repeated bending, lifting, carrying, and trunk-flexion demands.

Fatigue and Cardiovascular Workload. Perceived fatigue increased from 34.06 ± 1.45 before work to 59.34 ± 12.56 after work, $t(109) = 21.21$, $p < 0.001$. Cardiovascular demand also rose during activity: mean heart rate was 72.11 ± 5.26 bpm at rest and 120.27 ± 4.69 bpm while working, corresponding to a mean ΔHR of 48.16 ± 6.63 bpm.

Table 4. Fatigue and Heart-Rate Measures

Variable	Mean ± SD
Pre-work fatigue	34.06 ± 1.45
Post-work fatigue	59.34 ± 12.56
Resting HR (bpm)	72.11 ± 5.26
Working HR (bpm)	120.27 ± 4.69
ΔHR (bpm)	48.16 ± 6.63

Together, higher fatigue scores and working heart rate indicate a marked acute response to physical work demands.

Bivariate Associations. Post-work MSD score showed a very strong positive association with RULA ($r = 0.955$, $p < 0.001$), while the relationship between RULA and post-work fatigue was moderate ($r = 0.563$, $p < 0.001$). ΔHR was also positively related to post-work MSDs ($r = 0.541$, $p < 0.001$), but its association with fatigue was weaker ($r = 0.321$, $p = 0.001$).

Table 5. Bivariate Correlations Among Exposure and Outcome Variables

Variable Pair	r	p
RULA – MSDs	0.955	<0.001
RULA – Fatigue	0.563	<0.001
ΔHR – MSDs	0.541	<0.001
ΔHR – Fatigue	0.321	0.001

The strongest bivariate association occurred between RULA and post-work MSDs. ΔHR was related to both outcomes, but its coefficients were smaller than those for postural risk.

Adjusted Hierarchical Regression. The four control variables explained 9.5% of post-work MSD variance in Block 1 ($R^2 = 0.095$; adjusted $R^2 = 0.060$; $F(4,105) = 2.75$, $p = 0.032$), with BMI significant ($\beta = 0.234$, $p = 0.013$). Adding RULA and ΔHR increased explained variance by 82.6% ($\Delta R^2 = 0.826$), giving $R^2 = 0.921$ and adjusted $R^2 = 0.917$, $F(6,103) = 200.41$, $p < 0.001$. In the final model, RULA was dominant ($\beta = 0.905$, $p < 0.001$), ΔHR remained significant ($\beta = 0.076$, $p = 0.023$), and all controls were nonsignificant.

Table 6. Hierarchical Regression Model for Post-Work MSD Score

Variable	Model 1 β	p	Model 2 β	p
Age (years)	- 0.150	0.136	- 0.025	0.400
Work experience	- 0.084	0.405	0.015	0.632
BMI (kg/m²)	0.234	0.013	0.051	0.072
Working hours/day	- 0.050	0.598	- 0.043	0.131
RULA	—	—	0.905	<0.001
ΔHR	—	—	0.076	0.023
R^2	0.095	—	0.921	—
Adjusted R^2	0.060	—	0.917	—

Variance inflation factors ranged from 1.02 to 1.43, indicating that multicollinearity was not a concern in the final adjusted model.

3.2 Discussion

Overall, the findings indicate concurrent postural loading, acute musculoskeletal discomfort, and fatigue. Entering age, work experience, BMI, and daily work duration

before RULA and ΔHR allowed the adjusted model to separate ergonomic exposure from background worker characteristics.

Planting was the most posture-intensive of the activities observed, although all four tasks produced RULA levels that warranted ergonomic attention. The work pattern was characterized by combinations of trunk and neck flexion, repeated upper-extremity motion, squatting, and manual handling. These features align with the domains emphasized in RULA, which rates upper-limb, neck, and trunk position together with muscle use and external load (Corlett, 1993). Because some agricultural operations also place substantial demands on the legs and on balance, however, RULA should not be interpreted as an exhaustive measure of biomechanical exposure. REBA could extend the assessment for tasks involving deep squatting, load transport, or movement on unstable ground (Hignett & McAtamney, 2000; Yusuf et al., 2024).

The pre-post pattern provides evidence of acute symptom accumulation during the work period. Discomfort after work was greatest in the lower back, followed by the upper back and shoulders. Repeated flexion, lifting, carrying, and stabilization on sloped or uneven ground plausibly concentrate loads in these regions. Previous agricultural studies report a similar anatomical distribution, with the lower back and shoulder girdle frequently affected by repeated bending, manual load handling, and sustained postures (Ananda et al., 2025; Barneo-Alcántara et al., 2021; Damayanti et al., 2026). Persistent exposure of this type could contribute to longer-term musculoskeletal problems if suitable controls are not introduced.

The parallel rise in subjective fatigue and heart rate during work shows that biomechanical demands were accompanied by meaningful physiological effort. ΔHR was related to MSDs more strongly than to fatigue, but neither correlation approached the strength observed for RULA and MSDs. This suggests that cardiovascular workload contributes to overall occupational strain while not fully accounting for the observed symptom pattern. The safety relevance of fatigue remains important because impaired recovery and attentional capacity can adversely affect work performance (De-Benavides-Jiménez et al., 2025; Oakman et al., 2023; Sudiajeng et al., 2022).

The correlations emphasize the importance of posture. RULA had an exceptionally strong association with post-work MSDs and a moderate relationship with fatigue. By comparison, the smaller ΔHR coefficients suggest that cardiovascular effort contributes to occupational strain but is not the primary explanation for variation in musculoskeletal symptoms.

The hierarchical model provides the clearest test of independent effects. Worker characteristics explained 9.5% of MSD variance at the first step. When RULA and ΔHR were added, R^2 increased to 0.921, corresponding to an 82.6-percentage-point increment in explained variance. RULA retained by far the largest standardized effect after adjustment, while ΔHR contributed a small but statistically significant effect. Age, work experience, BMI, and workday length did not remain significant in the final equation. Thus, within this sample, reducing biomechanical exposure appears to offer the greatest opportunity for modifying post-work MSD burden, although physiological workload should not be ignored.

The agrotourism context is relevant when interpreting these findings because agricultural tasks are interleaved with service and presentation responsibilities. A farmer may move between crop work, visitor guidance, landscape upkeep, and demonstrations within the same day. Such task switching can alter work sequence and

recovery opportunities, while slopes, irregular surfaces, and outdoor conditions add further demands during movement and material handling. The exposure profile is therefore best viewed as part of an interacting socio-technical work system rather than as posture alone (Damayanti et al., 2026; Ndirangu & Zoltan, 2025).

Intervention priorities should be matched to the task. For planting and weeding, reducing the duration and angle of forward trunk flexion could be addressed through longer-handled implements, raised or terraced work zones where feasible, and planned changes between kneeling, sitting, and standing. Produce handling may benefit from lightweight carts, two-sided handles or backpack-style load distribution, shorter transport distances, and shared handling for bulky items. Organizational controls should combine task rotation with scheduled active-recovery periods and avoid placing peak visitor duties directly alongside the most physically demanding farm operations. Improving traction and stability on uneven paths and using participatory posture training would support implementation under local farming conditions.

4 Conclusion

The study identified a consistent pattern of meaningful postural exposure accompanied by sharp within-shift increases in MSD complaints and fatigue among horticultural farmers working in agrotourism. Of the observed activities, planting had the highest RULA value, while lower-back, upper-back, and shoulder discomfort was most pronounced after work.

Adjustment for age, work experience, BMI, and daily work duration did not diminish the importance of posture. The full model explained 92.1% of post-work MSD variance (adjusted $R^2 = 0.917$); RULA had the largest independent effect ($\beta = 0.905$, $p < 0.001$), while ΔHR contributed a smaller significant effect ($\beta = 0.076$, $p = 0.023$).

Accordingly, risk reduction should combine engineering and organizational measures: longer-handled tools and higher work surfaces for low-level crop tasks; carts and improved load-sharing approaches for harvesting and transport; shorter carrying distances; rotation and active recovery; improved path stability on sloped ground; and participatory training on posture and material handling. Scheduling should also reduce overlap between the heaviest agricultural tasks and periods of high visitor demand.

Further research should test these recommendations prospectively using longitudinal or controlled intervention designs. Concurrent application of RULA and REBA would broaden postural coverage, while repeated or multilevel models could incorporate psychosocial load, visitor intensity, terrain, and environmental conditions. Adding objective motion measures and serial symptom tracking would improve causal inference and the evaluation of intervention effectiveness.

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