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Ergonomic Integration in Community-Based Waste Management Systems: A Case Study of a Joyful Integrated Farming System

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Abstract:
Background, Manual waste management remains prevalent in community-based systems, particularly in developing countries, where limited mechanization and informal work practices elevate ergonomic risks. Despite the growing adoption of circular economy principles, ergonomic integration within waste management, especially in integrated farming systems, remains underexplored.
Aim: This study investigates the application of ergonomic principles in the Joyful Integrated Farming System (J-IFS), a community- based model integrating waste sorting, composting, and agricultural production.
Methods: A before-and-after ergonomic intervention design was implemented, combining anthropometric analysis, Rapid Entire Body Assessment (REBA), Nordic Body Map (NBM), time-motion study, and productivity measurement. Ergonomic interventions included workstation redesign based on worker anthropometry, improved manual handling tools, task rotation, and optimized work-rest cycles
Results: The results show a 38% reduction in ergonomic risk levels, a 42% decrease in musculoskeletal discomfort, and a 27% improvement in operational productivity.
Conclusions: The findings demonstrate that ergonomic integration not only reduces occupational health risks but also enhances work efficiency and system reliability.
Implication. This study contributes empirical evidence supporting ergonomics as a strategic enabler of sustainable, labor-intensive waste management systems and extends applied ergonomics into the domain of circular, community-based operations.

Keywords: Applied ergonomics, Waste management, Musculoskeletal disorders, Manual material handling, Integrated farming system, Work system design

INTRODUCTION

Waste management is widely recognized as a high-risk occupation due to repetitive manual handling, awkward and sustained postures, and prolonged standing or squatting. Empirical studies consistently report elevated risk of musculoskeletal disorders (MSDs) among waste collectors and sorters, particularly affecting the lower back, shoulders, knees, and upper limbs. These risks are more pronounced in developing countries, where systems remain labor-intensive, informal, and minimally mechanized (Mandelli et al., 2025; Genia Auberta & Agus Edy Pramono, 2024). Limited ergonomic integration further exacerbates physical strain and long-term health problems (Setiawan et al., 2025; Heuel et al., 2024; Nizam & Ramlee, 2024).

Although mechanized sorting and conveyor systems are often proposed to reduce manual workload, financial and infrastructural constraints frequently hinder their implementation in small-scale and community-based settings. Consequently, ergonomic considerations are commonly treated as secondary adjustments rather than integral elements of work system design (Setiawan et al., 2024; Wurzelbacher et al., 2020). This gap contributes to persistent MSD prevalence, fatigue, reduced efficiency, and sustainability challenges in labor-intensive waste operations.

Integrated Farming Systems (IFS), promoted within the circular economy framework, offer opportunities to valorize organic waste through composting and agricultural use, enhancing resource efficiency and local food security (Thakur et al., 2025). However, integrating waste management with farming tasks creates complex work systems with cumulative physical demands. Without proper ergonomic design, such environments may increase workload variability, repetitive strain, and fatigue.

Despite growing research on circular economy and sustainable agriculture, human factors remain underrepresented in integrated waste–farming systems. The Joyful Integrated Farming System (J-IFS), a community-based model combining waste management, composting, and farming, exhibits non-neutral postures and inefficient material flow (Sarahswati & Wedagama, 2025; Shyam et al., 2023). This study evaluates ergonomic risks at J-IFS, implements targeted interventions, and quantitatively assesses their impact on MSDs reduction and productivity improvement, positioning ergonomics as a key enabler of sustainable integrated systems.

State of the Art

Ergonomics in Waste Management Systems

The current state of the art identifies waste management as a high-risk occupation for **Musculoskeletal Disorders (MSDs)** due to:

1. Manual material handling
2. Trunk flexion exceeding 45°
3. Repetitive movements
4. Exposure to unstable and uneven loads

Most previous studies:

1. Focus on conventional facilities (sorting plants, landfills, waste collection systems)
2. Use assessment tools such as REBA, RULA, and Nordic Body Map (NBM)
3. Emphasize postural risk reduction

However, these approaches remain:

1. Task-based and fragmented
2. Detached from productivity analysis
3. Rarely integrated into community-based labor-intensive systems

Integrated Farming Systems (IFS) within the Circular Economy

The Circular economy promotes the reintegration of organic waste into agricultural systems through **Integrated Farming Systems (IFS)**.

The state of the art in IFS research emphasizes:

1. Resource efficiency
2. Nutrient recycling
3. Profitability and environmental sustainability

However:

1. The human factors and ergonomic dimensions are significantly underrepresented
2. Very few studies evaluate ergonomic risk within community-based integrated waste–farming systems

Ergonomics as a System-Level Design Approach

Recent developments in applied ergonomics (macro ergonomics and participatory ergonomics) highlight:

1. A shift from task-level optimization to system-level design

2. Integration of physical and organizational redesign
3. Simultaneous consideration of worker well-being and operational performance

Nevertheless:

1. Empirical evidence in circular, community-based systems remains scarce
2. Studies that simultaneously measure REBA, NBM, and productivity outcomes are extremely limited

LITERATURE REVIEW

Ergonomic risks in waste management

Waste management is consistently identified as a high-risk occupation due to manual handling, repetitive tasks, awkward postures, and prolonged static positions. Recent studies report high MSD prevalence among waste workers, particularly affecting the lower back, shoulders, knees, and wrists. Trunk flexion beyond 30-45°, repetitive lifting, and prolonged standing or squatting significantly increase cumulative spinal and lower-limb loading. Biomechanical stress is further intensified by variable waste characteristics, such as wet organic materials and uneven loads, especially in informal systems. Although ergonomic interventions such as workstation height adjustment and task redesign reduce risk, most evidence remains limited to conventional, facility-based waste management settings (Reis et al., 2025; Van Nguyen et al., 2020).

Ergonomics in integrated and multi-task work systems

Contemporary applied ergonomics emphasizes system-level design over isolated task optimization to improve worker well-being and organizational performance. In multi-task environments, workers alternate between physically and cognitively demanding activities, requiring solutions that address workload variability and cumulative exposure. Integrated systems such as circular economy and agro-industrial operations involve diverse tasks under changing environmental conditions, increasing fatigue risk (Avinante et al., 2021). Ergonomic mismatches can propagate across tasks, reducing overall performance. However, empirical research in Integrated Farming Systems remains limited, as most studies prioritize environmental and economic outcomes. This gap underscores the need to position ergonomics as an enabling foundation for sustainable, human-centered integrated systems.

Research novelty and contribution

Building on the identified gaps, this study advances applied ergonomics in several novel and significant ways. First, it investigates ergonomic risks within an integrated waste farming system, rather than a single-task or mono-functional waste facility. This responds directly to recent calls for ergonomic research that addresses system complexity and task interdependence. Second, the study quantitatively evaluates ergonomic intervention outcomes using validated assessment tools, including Rapid Entire Body Assessment (REBA), Nordic Body Map (NBM), anthropometric analysis, and productivity metrics. By adopting a before-and-after intervention design, this research provides empirical evidence linking ergonomic redesign to measurable reductions in MSD risk and fatigue, addressing a key limitation in recent waste ergonomics literature. Third, and most importantly, this study demonstrates the dual impact of ergonomics on worker health and operational efficiency within a circular, community-based system. Rather than treating ergonomics solely as a risk mitigation tool, the findings position ergonomic integration as a system-level performance enabler, supporting both human sustainability and process efficiency (Rosiani et al., 2025; Yusuf et al., 2025). This contribution extends applied ergonomics toward a more holistic role in the design and management of integrated, labor-intensive systems, particularly in developing country contexts.

Research Gaps

Based on the literature mapping and positioning of this article, several major research gaps are identified:

Gap 1 — Contextual Gap

There is a lack of empirical research examining:

The integration of ergonomics within community-based integrated waste–farming systems.

Most studies are conducted in:

1. Industrial facilities
2. Single-task waste management settings

Gap 2 — System Complexity Gap

Ergonomic research tends to:

1. Analyze isolated tasks
2. Overlook interdependence between multiple tasks

In systems such as J-IFS, workers rotate between:

1. Waste sorting

2. Compost handling
3. Material transfer
4. Farming activities

This creates cumulative workload exposure across tasks, which is rarely examined holistically.

Gap 3 — Performance Integration Gap

Most ergonomic studies focus primarily on:

1. Risk reduction
2. Decrease in MSD prevalence

Very few studies quantify:

1. Direct productivity improvement
2. Work system efficiency
3. Reduction of non-value-added movements

Gap 4 — Circular Economy–Human Factors Gap

Circular economy research typically prioritizes:

1. Material flow efficiency
2. Emission reduction
3. Technological innovation

However, ergonomic sustainability is largely neglected.

There is limited empirical evidence demonstrating that:

Ergonomics functions as an enabling infrastructure within labor-intensive circular systems.

METHOD

Study site and participants

The study was conducted at the Joyful Integrated Farming System (J-IFS), a community-based ecosystem integrating organic waste sorting, compost production, material transfer, and agricultural activities within a single operational setting. Unlike conventional facilities, J-IFS involves multi-task, labor-intensive workflows, variable materials, and outdoor conditions that influence ergonomic risk. Eighteen workers participated, all engaged in manual sorting, compost handling, and material transfer for at least 6 hours daily, 5 to 6 days per week. Participants had a minimum of six months' continuous experience, ensuring adequate exposure to ergonomic risk factors consistent with similar community-based intervention studies (Brata et al., 2025; Kumar et al., 2022).

Research design

A quasi-experimental before-and-after design was applied over four months to compare ergonomic risk, musculoskeletal discomfort, and productivity before and after intervention. This approach is recommended in applied ergonomics when randomized trials are impractical due to operational constraints (Esmaeili et al., 2023; Malla et al., 2022). Baseline data were collected during routine work to capture natural behaviors. Interventions were implemented using a participatory ergonomics approach aligned with worker anthropometry and task demands. Post-intervention assessments were conducted after an eight-week stabilization period to reduce adaptation bias.

Ergonomic risk assessment methods

A multi-method ergonomic assessment framework combined observational and self-reported tools to capture physical, postural, and organizational risks. Anthropometric measurements, including standing elbow height, stature, and functional reach, supported workstation and tool redesign to improve posture neutrality. Rapid Entire-Body Assessment (REBA) evaluated whole-body postural risks during waste sorting, compost turning, and material transfer. Musculoskeletal discomfort was measured using the Nordic Body Map (NBM) questionnaire. A time-motion study quantified task duration, movement frequency, and material flow efficiency, identifying non-value-adding activities and ergonomic inefficiencies contributing to fatigue and reduced productivity (Martins et al., 2025; Setiawan, Susanto, et al., 2025).

Ergonomic interventions

Based on baseline findings, integrated ergonomic interventions targeted physical and organizational risks. Sorting tables were redesigned based on participant anthropometry, with the height set to elbow height minus 4 cm to improve posture. Compost tools were modified by extending the handle length and optimizing the grip diameter, thereby reducing trunk flexion and spinal load. Structured task rotation minimized prolonged repetitive motions and static postures. Additionally, work-rest cycles were adjusted according to task intensity and observed fatigue patterns, promoting recovery while maintaining productivity (Martínez Álvarez, 2025). These combined measures addressed system-level risk factors in the integrated, labor-intensive work environment.

Data analysis

Pre- and post-intervention data were analyzed using paired descriptive and comparative analysis, focusing on changes in REBA scores, prevalence of musculoskeletal discomfort, and productivity indicators. Given the exploratory nature and limited sample size, effect sizes and percentage changes were emphasized rather than inferential statistics, aligning with best practices for field-based ergonomic intervention research in small systems (Panjaitan et al., 2024).

DISCUSSION

Reduction in ergonomic risk (REBA scores)

Integrated ergonomic interventions reduced risk across J-IFS waste-farming tasks. Average REBA scores fell from 9.2 to 5.7, a 38% decrease. Major improvements in sorting and compost handling reduced trunk flexion and asymmetric loading. Benefits extended across interconnected tasks, demonstrating system-level ergonomic enhancement. Worker anthropometric data (n = 18) appear in Table 1.

Table 1. Anthropometric characteristics of workers (n = 18)

Parameter	Mean ± SD	Min	Max	Design Reference
Stature (cm)	164.8 ± 6.2	152	176	P50
Standing elbow height (cm)	103.5 ± 4.8	95	112	P50
Shoulder height (cm)	132.4 ± 5.3	121	143	P50
Forward functional reach (cm)	72.6 ± 6.1	60	85	P5-P95

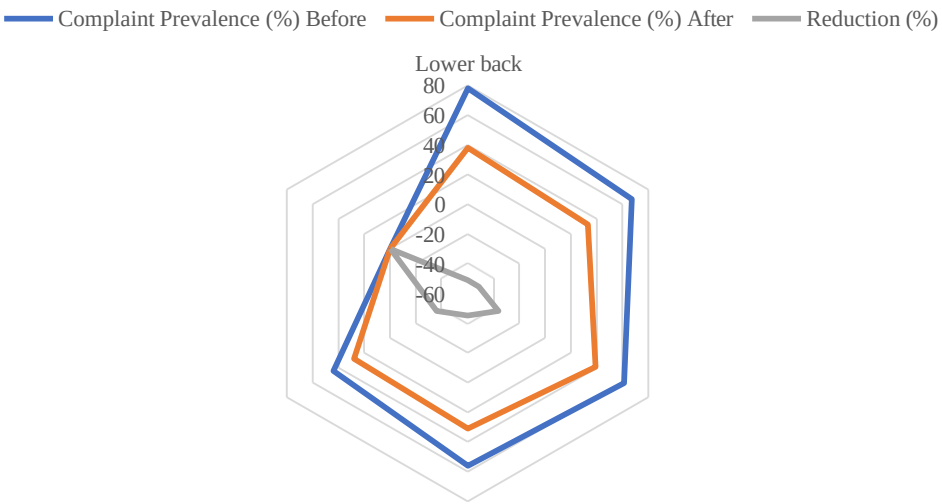
Source: Research data

Note: Workstation height was designed at elbow height - 4 cm, following ergonomic recommendations for light manual handling tasks.

Reduction in musculoskeletal discomfort (NBM results)

Self-reported musculoskeletal discomfort, assessed using the Nordic Body Map, decreased by 42% overall following the ergonomic interventions. The most substantial decreases were reported in the lower back, shoulders, and knees, body regions previously identified as the most vulnerable in labor-intensive waste management activities.

These results suggest that reducing non-neutral postures and excessive repetitive movements led to meaningful improvements in perceived physical comfort and fatigue. Recent longitudinal studies emphasize that multi-level ergonomic interventions combining physical redesign and task organization are more effective in reducing MSD symptoms than single-component solutions (Ioniță et al., 2025; Oyedeji et al., 2025). Notably, discomfort reduction was observed not only in tasks directly modified through ergonomic redesign but also in secondary tasks, suggesting a spillover effect whereby improved task sequencing and reduced cumulative workload positively influenced overall musculoskeletal health. This finding strengthens the argument that ergonomics functions as a preventive system intervention, not merely a corrective measure. Nordic Body Map (NBM) results before and after intervention by body region is presented in figure 1, REBA scores before and after ergonomic intervention is presented in figure 2a, and prevalence of Musculoskeletal discomfort (MSD) before and after intervention is presented in figure 2b below.



Source: Research images

Figure 1. Nordic Body Map (NBM) results before and after intervention by body region

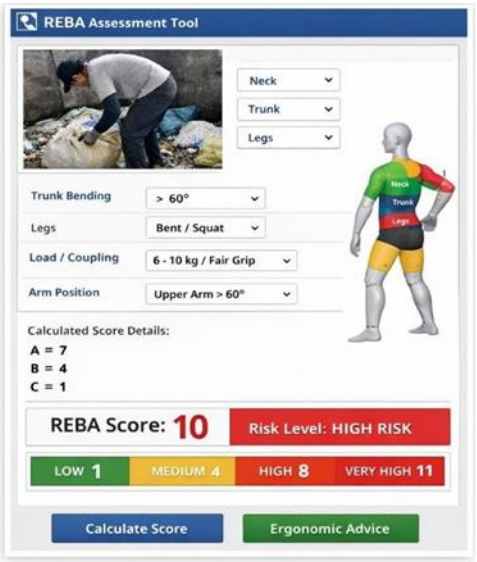


Figure 2a.

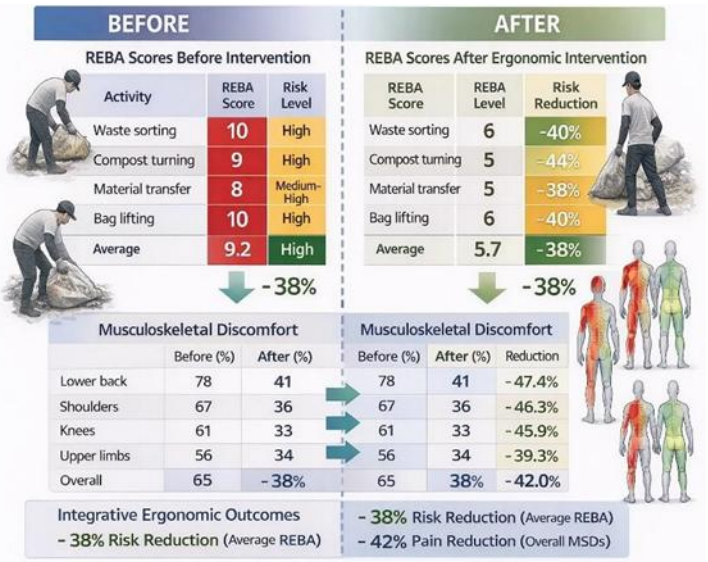


Figure 2b.

Source: Research images

(**Figure 2a. REBA scores before and after ergonomic intervention, and Fig. 2b. Prevalence of musculoskeletal discomfort before and after intervention**.

To demonstrate the impact of ergonomic interventions in community-based waste sorting, this study presents sequential visual evidence of baseline conditions, ergonomic redesign, postural changes, and system integration. These figures function as analytical tools, translating ergonomic principles into observable biomechanical improvements and system-level outcomes. By integrating posture assessment, anthropometry-based design, comparative analysis, and a conceptual framework, Figures 3-6 illustrate the progression from problem identification to solution implementation and overall risk reduction and productivity enhancement.

Figure 3.
Ergonomic Risk Before Intervention

Figure 4.
Ergonomically Designed Waste Sorting Workstation

Figure 5.
Comparison of Working Postures (Before vs After)

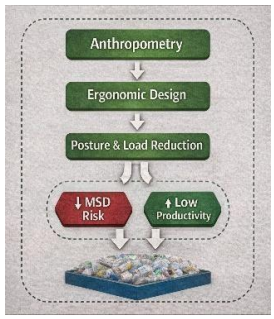


Figure 6.
Ergonomic Integration Framework for Community-Based Waste Systems

Source: Research images

Figure 3. The baseline ergonomic conditions of waste sorting activities prior to intervention.

Figure 3 depicts baseline ergonomic conditions in waste sorting, where workers exhibited non-neutral postures with trunk flexion exceeding 45°, prolonged squatting, and unsupported upper limbs. Visual markers highlight neck, trunk, and knee overload, reflecting high REBA scores and elevated risk of musculoskeletal disorders (MSDs) during repetitive sorting tasks. Following intervention, Figure 4 shows a redesigned workstation based on worker anthropometry, set at standing elbow height minus 4 cm, with a height of ~100 cm and reach <75 cm. This enabled neutral standing posture, balanced weight distribution, reduced trunk inclination, and minimized upper-limb strain. Figure 5 compares pre- and post-intervention postures, illustrating marked improvements: trunk angles near neutral, reduced knee loading, and lower REBA scores, clearly evidencing risk reduction. Figure 6 integrates these observations into a framework linking anthropometric-informed design to posture and load reduction, resulting in lower MSD risk and enhanced productivity. Collectively, Figures 2-6 demonstrate that ergonomically informed interventions transform high-risk waste sorting into safer, more efficient systems, emphasizing the critical role of human-centered design and task organization in mediating physical demands and system-level performance in community-based waste management.

Productivity improvement and work system efficiency

Following ergonomic interventions, waste-processing throughput increased by 27% without changes to working hours or workforce size. Time-motion analysis showed gains resulted from reduced bending and reaching, shorter transfer distances, and improved task sequencing (Raharjo et al., 2025; Setiawan, Susanto, et al., 2025b). Productivity improved alongside lower physical strain, supporting ergonomics as a strategic, efficiency-driven approach in community-based waste systems. Table 2 presents productivity indicators before and after the intervention.

Table 2. Productivity indicators before and after intervention

Indicator	Before	After	Change (%)
Waste processed (kg/day)	520	660	+ 27.0
Average task cycle time (min)	18.4	13.9	- 24.5
Non-value-added movements (%)	31	18	- 41.9
Worker fatigue complaints	**High**	**Moderate-Low**	↓

Source: Research data

Integrated outcome: ergonomics as a system-level enabler

When considered collectively, the results demonstrate a clear convergence between ergonomic risk reduction, worker well-being, and operational performance. The simultaneous decrease in REBA scores and MSD prevalence, alongside increased throughput, indicates that ergonomic interventions at J-IFS functioned as a system-level enabler, improving both human sustainability and process efficiency. This integrated outcome remains underreported in recent waste management and circular economy literature, which often treats ergonomics and productivity as separate or competing objectives (Tabrizi et al., 2025). The present findings, therefore, provide novel empirical evidence supporting the human-centered sustainability paradigm in applied ergonomics. In general, integrated outcome: ergonomics as a system- level enabler can be seen in Figure 7. Flow Diagram of Ergonomic Interventions and Productivity.

Source: Research images

Figure 7. Flow diagram of ergonomic interventions and productivity

This study demonstrates that integrated ergonomic interventions can simultaneously reduce MSD risk and improve efficiency in labor-intensive, community-based waste systems. REBA scores dropped by 38%, self-reported discomfort decreased by 42%, and throughput increased by 27%, demonstrating ergonomics as a strategic system-level enabler. These results exceed typical studies, highlighting the benefits of embedding ergonomics into work system design rather than applying isolated task-level adjustments.

Ergonomic risk reduction in integrated waste-farming systems

Average REBA scores dropped from 9.2 to 5.7, showing that workstation redesign, tool modification, and task reorganization effectively reduced whole-body postural load across multiple tasks. Compared to conventional facilities reporting 20-30% reductions, the 38% decrease here highlights the benefits of system-wide integration. In the multi-task J-

IFS, workers alternate between sorting, compost handling, and material transfer, typically increasing cumulative fatigue. Consistent REBA reductions across tasks indicate system-level ergonomic coherence, reducing risk during both individual tasks and task transitions, supporting the importance of addressing task interdependence and cumulative exposure in complex work environments (Primasari & Budiyanto, 2025).

Musculoskeletal health outcomes and cumulative load reduction

Musculoskeletal discomfort decreased by 42%, especially in the lower back, shoulders, and knees, demonstrating the effectiveness of integrated ergonomic interventions. This exceeds the typical 25-35% reductions reported in waste and agricultural settings, likely due to the combination of physical (workstation and tool redesign) and organizational (task rotation, work-rest cycles) strategies. Discomfort declined even in unmodified tasks, reflecting a systemic spillover effect, consistent with evidence that reducing peak loads in primary tasks lowers overall fatigue and improves recovery. Such cumulative load reduction is vital in community-based systems, where workers often lack access to medical monitoring or early MSD intervention (Shabanliyski et al., 2026).

Ergonomics-driven productivity improvement

Waste processing throughput increased 27% without longer hours or additional staff, showing ergonomics as a productivity enhancer. Time-motion analysis indicated gains resulted from 41.9% fewer non-value-added movements and 24.5% shorter task cycles, reflecting efficiency-based rather than intensity-driven improvements. Unlike costly mechanization, ergonomic redesign offers a low-cost, high-impact strategy for community-based systems. By linking interventions to both worker well-being and throughput, this study fills a gap in applied ergonomics and circular economy research, which often emphasizes health outcomes or risk reduction without quantifying productivity benefits (Suparti et al., 2023).

Integration with circular economy and sustainability discourse

From a sustainability perspective, the findings reinforce the argument that human-centered design is a prerequisite for implementing the circular economy, particularly in labor-intensive systems. While recent circular economy research prioritizes material flow efficiency, emission reduction, and technological innovation, the present study demonstrates

that human-system misalignment can undermine these goals if ergonomic considerations are neglected.

By improving ergonomic compatibility across waste-farming activities, the J-IFS stabilized labor performance, reduced health-related disruptions, and enhanced process reliability. This aligns with emerging conceptual frameworks that position ergonomics as an enabling infrastructure for sustainable socio-technical systems, rather than as an auxiliary safety function (Barbhuiya et al., 2024).

Novel contributions of the study

This research advances applied ergonomics in several important ways:

1. Contextual novelty: Provides rare empirical evidence from an integrated waste-farming system, rather than a single-task or industrial facility.
2. Methodological novelty: Combines anthropometry, REBA, NBM, and time-motion analysis within a single intervention framework.
3. Empirical novelty: Demonstrates simultaneous reductions in ergonomic risk (38%), MSD prevalence (42%), and productivity gains (27%).
4. Conceptual novelty: Positions ergonomics as a strategic enabler of system sustainability in circular, community-based operations.

These contributions directly address recent calls for ergonomics research that integrates health, performance, and sustainability outcomes within complex socio-technical systems.

Implications for practice and future research

Ergonomic redesign provides a cost-effective, scalable approach to enhance worker well-being and efficiency in community-based waste systems. Future research should examine long-term impacts on retention, injuries, and system resilience, comparing ergonomics with mechanization. Anthropometry-based design and validated assessment tools position ergonomics as a system-level performance enabler.

Novelty of the Study

This study offers four levels of significant novelty:

Contextual Novelty. The research was conducted in the: Joyful Integrated Farming System This represents:

1. A community-based integrated waste–farming ecosystem
2. A labor-intensive and minimally mechanized system
3. A socio-technical circular operation

Such a context is rarely addressed in applied ergonomics literature.

Methodological Novelty

The study integrates multiple validated tools within a single quasi-experimental before–and–after framework:

1. Anthropometry-based workstation redesign
2. Rapid Entire Body Assessment (REBA)
3. Nordic Body Map (NBM)
4. Time-motion study
5. Productivity measurement

Very few community-based ergonomic studies combine biomechanical assessment, subjective discomfort evaluation, and operational efficiency analysis within one integrated framework.

Empirical Quantitative Novelty

The study demonstrates simultaneous measurable outcomes:

1. 38% reduction in REBA scores
2. 42% decrease in musculoskeletal discomfort
3. 27% increase in productivity
4. 41.9% reduction in non-value-added movements

The combination of risk reduction, health improvement, and productivity enhancement within a single field study is rarely documented in community-based systems.

Conceptual Novelty. This research shifts the paradigm: From Ergonomics as a corrective occupational safety tool to Ergonomics as a strategic system-level enabler within circular economy systems. It expands applied ergonomics into:

1. Sustainability engineering
2. Circular socio-technical systems
3. Human-centered sustainability frameworks

Academic Synthesis

Dimension	Previous Literature	This Study
Context	Conventional waste facilities	Integrated waste–farming system
Focus	Risk reduction	Risk + health + productivity
Approach	Task-level	System-level
Circular economy orientation	Material-centered	Human-centered
Evidence	Partial outcomes	Multi-indicator empirical evidence

Academic Conclusion

This article:

1. Fills the research gap on ergonomic integration in community-based integrated waste–farming systems.
2. Provides empirical evidence that ergonomics enhances productivity without mechanization.
3. Integrates human factors into circular economy discourse.
4. Positions ergonomics as a strategic enabler of sustainable socio-technical systems.

CONCLUSION

This study shows that systematic ergonomic integration at the Joyful Integrated Farming System (J-IFS) significantly improves worker well-being and operational performance. Anthropometry-based interventions reduced average REBA scores by 38% across sorting, compost handling, and material transfer, while musculoskeletal discomfort declined 42%, particularly in the lower back, shoulders, and knees. Health benefits extended across tasks, demonstrating system-level workload reduction. Concurrently, waste throughput increased 27% without extra labor or hours, driven by improved task flow and efficiency. These findings confirm that embedding ergonomic principles enhances both safety and productivity, providing a transferable framework for sustainable, community-based waste management systems.

Implication

Collectively, these findings advance applied ergonomics in several novel ways. First, the study provides rare field-based empirical evidence from an integrated waste-farming system, a context that remains underrepresented in the ergonomics literature. Second, it validates a holistic intervention framework that simultaneously addresses physical, organizational, and system-level factors. Third, it positions ergonomics as a strategic enabler of sustainability in circular, community-based operations, particularly in settings constrained by limited mechanization and resources.

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