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Ergonomic Assessment of Farm Tools to Reduce Musculoskeletal Disorders among Farm Workers

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Abstract

Musculoskeletal disorders (MSDs) constitute the leading occupational health burden in global agriculture, with prevalence ranging from 15.5% to 92% and a pooled estimate of 65.6%. This comprehensive review synthesizes evidence on the ergonomic assessment of traditional farm tools and the effectiveness of targeted redesign interventions to mitigate work-related MSDs among farm workers. Key risk factors prolonged awkward postures, repetitive motions, heavy lifting, and anthropometric mismatches drive excessive spinal compression (often exceeding the 770 lb NIOSH limit), rapid muscle fatigue (measured by sEMG shifts in mean frequency and RMS amplitude), and elevated physiological strain. Standardized observational tools (RULA for upper-limb tasks, REBA for whole-body dynamic work, and OWAS for field observations) are compared for their suitability in agricultural settings. Case studies of redesigned tools demonstrate substantial benefits: adjustable-handle hoes and chisel weeders reduce postural discomfort by 28–54%, spinal compression by 28%, and increase work capacity by 60–80%; ergonomic bucket carriers lower low-back disorder risk by 41–69%; and smaller harvest tubs cut pain by 20% with minimal productivity loss. Anthropometric data highlight the need for population-specific designs, particularly for smallholder and ethnic-minority farmers. Despite clear health and productivity gains, adoption barriers include high upfront costs, infrastructural limitations, low literacy, and cultural resistance. Policy support through ILO's WIND participatory methodology, combined with emerging AI/machine-vision posture detection and frugal 3D-printed innovations, offers scalable solutions. Ergonomic tool redesign is therefore a high-impact, evidence-based strategy for reducing MSDs, enhancing worker well-being, and supporting sustainable agricultural productivity.

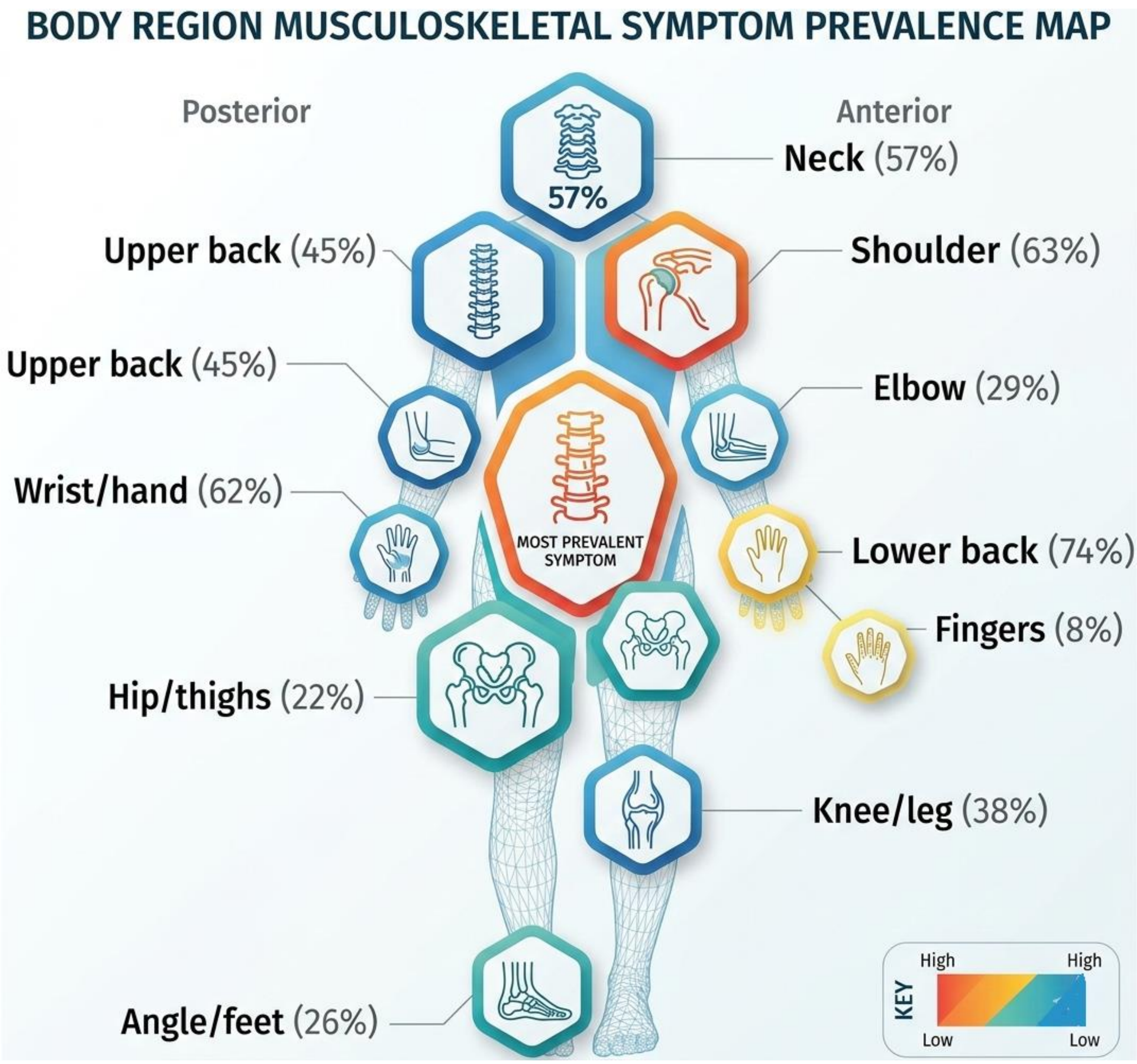
Keywords: Musculoskeletal Disorders (MSDs), Agricultural Ergonomics, Farm Tool Redesign, Rula, Reba, Owas, Anthropometry, Surface Electromyography (sEMG), Manual Material Handling, Smallholder Farmers, Occupational Health, Precision Ergonomics

1. Introduction

The global agricultural landscape, despite being a primary driver of food security and economic stability, remains one of the most hazardous industrial sectors regarding occupational health and safety (Ramankutty et al., 2018). The prevalence of work-related musculoskeletal disorders (WRMSDs) serves as a critical indicator of the physical toll extracted by manual labor-intensive farming practices (Borah et al., 2024). WRMSDs are defined as disabling injuries or impairments to the muscles, tendons, nerves, and supporting structures of the body, primarily caused by repetitive tasks, heavy lifting, and maintained awkward postures (Mishenin et al., 2023). These disorders are a leading cause of absenteeism and long-term disability, indicating that current risk management strategies in many agricultural environments are profoundly inadequate (BMJ Open, 2025).

Metanalytical data provides a stark overview of this crisis. Across a wide range of studies, the mean prevalence of musculoskeletal disorders among farm workers has been found to range from 15.5% to as high as 92%, with a pooled prevalence estimate of approximately 65.6% (Govaerts et al., 2021). For instance, longitudinal data suggest that the lifetime prevalence of MSDs among farmers may reach as high as 90.6%, with a one-year prevalence rate of 76.9% (Greggi et al., 2024). These figures underscore a fundamental reality: farming is a physically demanding occupation where the work tasks including the lifting of heavy objects, moving and carrying equipment, and maintaining sustained postures are inherently pathogenic to the human musculoskeletal system (Thomas et al., 2024).

Figure 1: Distribution and Prevalence of Work-Related Musculoskeletal Symptoms by Body Region among Agricultural Workers.



Regional disparities further illuminate the influence of socio-economic status and mechanization levels on worker health. In Bangladesh, cross-sectional analyses revealed a 78% prevalence rate of MSDs, with more than half of the respondents reporting chronic low back pain (Rahman et al., 2025). In Swedish farming communities, the odds of reporting musculoskeletal problems were 51% higher compared to non-farming populations (Kumaraveloo et al., 2018).

Table 1: Comparative Global Prevalence and Site-Specific Distribution of MSDs

Region/Cohort	Overall Prevalence (%)	Most Frequent Site	Secondary Sites of Pain	Statistical Significance Factor
Global Meta-Analysis	65.6%	Low Back	Neck, Shoulders	Repetitive duration ($p < 0.05$)
Bangladesh Farmers	78.0%	Low Back (50%+)	Upper Back (18.5%), Shoulder (20%)	Age, Working years ($p < 0.05$)
US Agricultural Workers	40.0% - 73.0%	Low Back (24.3%)	Hips/Knees (17.0%), Shoulders (9.8%)	PR = 1.28 for shoulder pain
Korean Greenhouse Workers	84.6%	Low Back (47.3%)	Knee (27.3%), Shoulder (6.9%)	Task frequency ($p < 0.01$)
Iranian Greenhouse Workers	50.9% (Self-report)	Back (36.2%)	Shoulder (19.5%), Knee (17%)	Inactivity ($p <= 0.05$)

The economic ramifications of these health trends are immense. In the United States alone, poor ergonomics and the resulting injuries account for roughly 33% of all worker injury and illness cases, translating to an estimated 13.3 billion dollars in annual workers' compensation claims (Temitope & Emmanuel, 2025). Awkward postures alone are responsible for approximately 4.7 billion dollars in annual claims, highlighting the urgent need for ergonomic intervention (Solus Group, 2025).

2. Pathophysiology of Agricultural Injury: Mechanisms and Physiological Strain

The development of musculoskeletal disorders in agriculture is a complex interaction of biomechanical loading and physiological exhaustion. Workers are frequently exposed to a triad of risk factors: excessive force, high repetition, and non-neutral postures (Barneo-Alcántara et al., 2021). These factors act cumulatively, causing micro-traumas to the soft tissues that, over time, exceed the body's reparative capacity (Benos et al., 2020).

2.1 Biomechanics of Spinal Compression and Trunk Flexion

The lumbar spine, specifically the L4/L5 intervertebral disc, is the most vulnerable site for instability and injury in agricultural workers. Tasks such as weeding and harvesting low-growing crops require prolonged trunk flexion, often exceeding 60 degrees (ResearchGate, 2024). Mathematical modeling using 3D Static Strength Prediction Program (3DSSPP) software allows for the estimation of these forces. The back compression design limit is generally set at 770 lb (3425 N) (Beyrami et al., 2021). In traditional manual lifting tasks, the compression forces often approach or exceed this threshold. Research indicates that reducing the horizontal distance of a load from the spine and adopting more upright postures through redesigned tool handles can alleviate these forces by up to 28.15% (Robert-Lachaine et al., 2021).

2.2 Surface Electromyography and the Quantification of Muscle Fatigue

Surface electromyography (sEMG) serves as a vital tool to measure the electrical activity and fatigue levels of muscles during dynamic agricultural tasks. Local muscle fatigue occurs when metabolic demands exceed oxygen and nutrient supply (Agrawal et al., 2025). Fatigue is characterized by specific shifts in the sEMG signal, such as a downward shift in the Mean Frequency (MNF) and an increase in the Root Mean Square (RMS) amplitude (Yousif et al., 2019). Redesigning tools to optimize handle angles can reduce these muscle activation levels by over 30%, delaying the onset of fatigue (Gokcesu et al., 2018).

Figure 2: Experimental Framework for Comparing Manual and Mechanized Farm Tools through Surface Electromyography (sEMG) and Muscle Activity Quantification (nRMS).

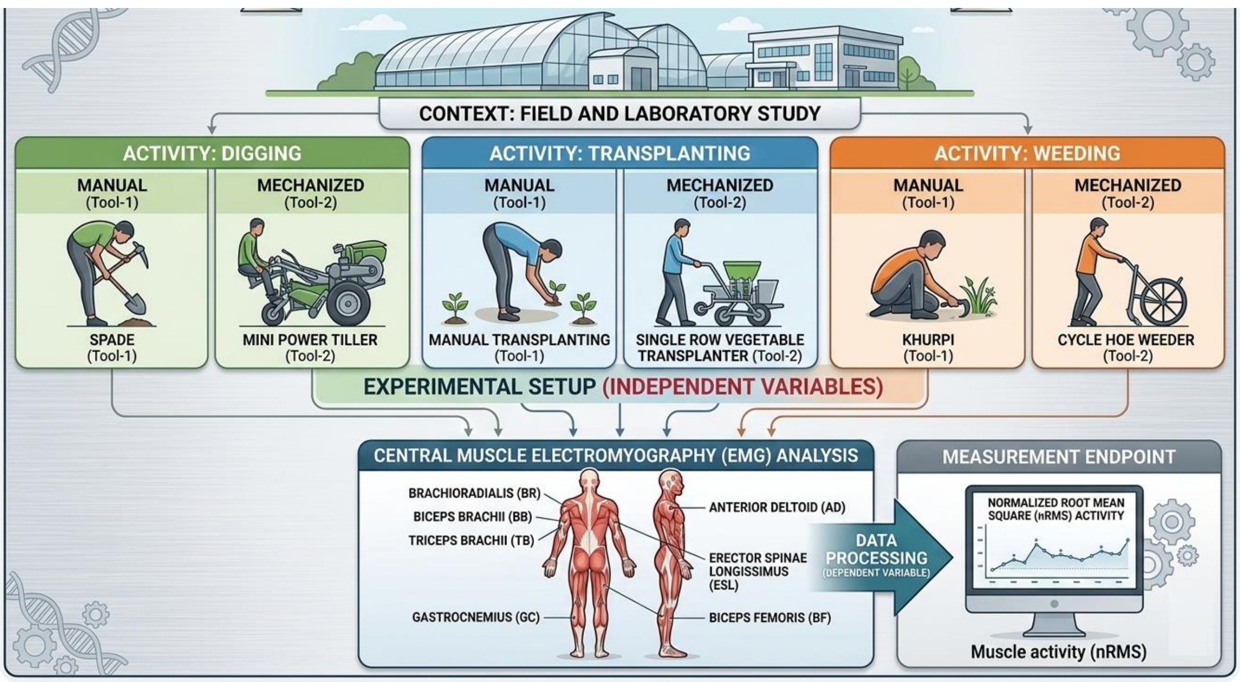


Table 2: Physiological and Biomechanical Metrics of Traditional vs. Ergonomic Tools

Metric Category	**Traditional Tools (Sickle/Hoe)**	**Redesigned Ergonomic Tools**	**Percentage Improvement**	**Statistical Evidence**
sEMG Activity	High activation/Rapid fatigue	Reduced activation (>30%)	~33% Reduction	$p < 0.01$ (Kantchede et al., 2022)
Spinal Compression	Near/Above 770 lb limit	28.15% Lower compression	28.15% Reduction	3DSSPP Analysis
Lifting Index (LI)	> 1.0 (High Risk)	~0.5 (Safe Range)	52.77% Reduction	NIOSH Equation
Heart Rate (HR)	134 - 135 bpm	90 - 134 bpm	Significant decrease	$p < 0.05$ (Agriculture Journal, 2024)

Energy Expenditure	7.4 - 17.91 kJ/min	6.5 - 17.6 kJ/min	~12% Lower	Physiological study

3. Methodological Frameworks for Ergonomic Assessment in the Field

To identify risks, ergonomic assessments utilize observational methods that categorize postural stress through "Action Classes" or "Action Levels." (Hussain, 2023).

3.1 Comparison of RULA, REBA, and OWAS

The choice of assessment tool is determined by the nature of the task. The three most utilized systems are the Rapid Upper Limb Assessment (RULA), the Rapid Entire Body Assessment (REBA), and the Ovako Working Posture Analysis System (OWAS) (Kee, 2020).

- **RULA:** Highly sensitive to upper limb postures, making it suited for tasks like fruit picking or rubber tapping.
- **REBA:** Developed to handle the unpredictable postures found in agriculture, evaluating the entire body including coupling and dynamic loading
- **OWAS:** Characterized by speed and simplicity, identifying four back postures and seven leg positions. It is effective even when the operator is partially obscured (Ndirangu & Zoltan, 2025).
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Table 3: Summary of Observational Assessment Features and Suitability

Feature	OWAS	RULA	REBA
Number of Variables	4	9	9 - 16
Body Focus	Whole-body (general)	Upper limb/Trunk/Neck	Entire body (complex)
Load Factors	Weight category (3 levels)	Strength/Muscle activity	Coupling/Dynamic load/Strength
Leg Assessment	Detailed (7 categories)	Weak (unstable vs. supported)	Detailed (unstable vs. walking)
Best Agricultural Use	Obscured field observations	Repetitive harvesting/Pruning	General tillage/Manual lifting
Ease of Application	Very High	High	Moderate

4. Anthropometric Foundations of Ergonomic Tool Design

Ergonomics is fundamentally the science of fitting the task to the human. In agriculture, this requires understanding anthropometry the measurement of physical body. A significant contributor to MSDs is the mismatch between mass-produced tools and the physical characteristics of the local population (Unegbu & Yawasa, 2025).

4.1 Regional and Ethnic Variance

Anthropometric indicators are not constant across geography. Studies in India identified significant variations between different ethnic groups within the same state. In Uttarakhand, hill farmers exhibited hand grip strengths significantly lower than the national average, necessitating adjustments to tool handle diameters (Negi et al., 2025).

Table 4: Key Anthropometric Dimensions for Farm Tool Redesign

Body Dimension	Application in Tool Design	Potential MSD if Mismatched
Stature (Standing)	Cab height, workstation height	Chronic neck and back pain
Eye Height	Visual field in machinery cabins	Neck strain, safety hazards
Grip Diameter	Handle thickness (hoes, sickles)	Carpal tunnel, hand fatigue
Acromial (Shoulder) Ht	Height of controls and handles	Shoulder tendonitis
Reach (Forward)	Bin depth, control layout	Lumbar strain from overreaching
Popliteal Height	Seat height on tractors/stools	Lower limb numbness, leg pain

5. Case Studies in Ergonomic Intervention and Redesign

The application of ergonomic principles has consistently demonstrated gains in worker well-being and productivity (Adiga, 2023).

5.1 Redesign of Manual Weeders and Hoes

Traditional hoes often have short handles requiring deep stooping. Redesigned weeders, such as chisel weeders, have integrated adjustable handle angles (45 to 65 degrees), lightweight mild steel frames (4.5 kg), and optimized cutter blades (175 mm) (Lee et al., 2014). Field experiments showed these modifications result in 28% lower postural discomfort scores. In Indonesia, farmers using ergonomically designed hoes demonstrated work capacities 60% to 80% higher than those using conventional hoes (Wardany et al., 2025).

5.2 Manual Material Handling (MMH) Innovations

The "Ergo Bucket Carrier" (EBC) redistributes loads, reducing low back disorder (LBD) risk during carrying by 41% and dumping by 69%. Additionally, reducing the weight of harvest tubs by just 11 lbs (from 57 to 46 lbs) can reduce pain by 20% with only a 2.5% decrease in productivity (Ray et al., 2021).

Table 5: Productivity and Safety Gains from Ergonomic Interventions

Intervention Type	Primary Change	Safety Outcome	Productivity Outcome
Hoe Redesign	Handle length/angle	54% Reduction in discomfort	60-80% Capacity increase
Chisel Weeder	Adjustable grips	28% Lower postural stress	36% Improvement in speed
Bucket Carrier	Load redistribution	41-69% LBD risk reduction	Reduced fatigue over time
Battery Pruners	Motorized shear	Eliminated carpal tunnel risk	Increased productivity
Scooter Wagon	Seated mobile unit	Reduced knee/back strain	Improved time management
Harvest Tubs	Smaller unit size	20% Pain reduction	97.5% Efficiency retention

6. Socio-Economic and Technical Barriers to Adoption

Widespread adoption of ergonomic technologies is often hindered by socio-technical and infrastructural factors, particularly in smallholder contexts (Thomas et al., 2024).

6.1 Economic Barriers and Infrastructural Gaps

For many smallholder farmers 60% of whom live below the poverty line even low-cost tools represent a significant financial risk. Furthermore, many regions struggle with unreliable electricity and unstable internet, making it difficult to utilize digital tools (Food Secure Canada, 2025). Adoption is more likely when technologies are offered through shared-use models or cooperatives (Kumaraveloo et al., 2018).

Table 6: Major Barriers to the Adoption of Ergonomic Technologies

Barrier Category	Specific Factors	Impact on Adoption	Mitigation Strategy
Economic	Lack of credit, high costs	Unattainable for smallholders	Shared-use models/Cooperatives
Infrastructural	No internet, unstable power	Excludes remote enterprises	Frugal, low-power innovation
Literacy	Low education levels	Difficulty using digital apps	Local language, visual UIs
Gender	Cultural norms, assets	Women lack decision-power	Participatory design groups
Cultural	Resistance to change	Reliance on "proven" hoes	Local material fabrication

7. Policy Frameworks and Global Guidelines for Agricultural Ergonomics

To address the epidemic of MSDs, global policy must shift from reactive healthcare to proactive ergonomic intervention (Pedrosa et al., 2021).

7.1 ILO Centennial Declaration and WIND Methodology

The International Labour Organization (ILO) emphasizes a human-centered approach to safety. Practical applications often include "Ergonomic Checkpoints" manuals detailing practical, low-cost interventions. The Work Improvement in Neighbourhood Development (WIND) methodology is a participatory approach that empowers farmers to identify risks and implement immediate changes (International Labour Organization, 2020).

8. Future Frontiers: AI, Machine Vision, and Precision Ergonomics

The next decade of agricultural ergonomics will be defined by the integration of artificial intelligence and machine vision (MDPI Sustainability, 2025).

8.1 AI-Enabled Posture Detection and Biomechanical Phenotyping

New AI models, such as Movenet, analyze video data to automatically classify postures into risk categories, providing immediate data for intervention (Roggio et al., 2024). Additionally, research is linking biomechanical crop properties to ergonomic loads. By quantifying the shear modulus of plant stalks, researchers can optimize tool geometry to minimize the effort required by the operator (Aswin et al., 2024).

Table 7: Summary of Future Research Directions in Agricultural Ergonomics

Future Frontier	Technical Mechanism	Expected Outcome
Machine Vision	Deep learning skeletal tracking	Automated, real-time risk scoring

Precision Tools	CAD/Biomechanical modeling	Tools optimized for specific crops
Digital Inclusion	Microcredentials and ICT platforms	Equitable access for women farmers
Frugal Innovation	3D printing and local fabrication	High-quality, low-cost local tools
Biomechanical Phenotyping	Stalk mechanical property analysis	Reduced force during harvesting

9. Conclusion

Ergonomic assessment and redesign of farm tools provide a practical, cost-effective, and immediately implementable solution to the pervasive epidemic of work-related musculoskeletal disorders that afflict the global agricultural workforce. By addressing the root biomechanical and physiological causes awkward postures, excessive spinal loading, and muscle fatigue redesigned tools (adjustable hoes, ergonomic weeders, load-redistributing carriers, and optimized harvest aids) have consistently demonstrated reductions in postural stress of 28–54%, spinal compression forces of up to 28%, and low-back disorder risk of 41–69%, while simultaneously increasing work capacity by 60–80% and preserving or enhancing productivity. These gains are achievable even in resource-constrained smallholder systems when interventions are grounded in local anthropometric data and developed through participatory approaches such as the ILO's WIND methodology. However, widespread adoption requires overcoming persistent barriers of cost, infrastructure, literacy, and cultural inertia through targeted policies, subsidized tool programs, cooperative models, and locally fabricated solutions. Looking forward, the integration of artificial intelligence, machine vision for real-time posture monitoring, and precision biomechanical phenotyping of crops will further accelerate the transition to truly worker-centered farm tools. Investing in agricultural ergonomics is therefore not only an investment in worker health and dignity but a strategic imperative for building resilient, sustainable, and equitable food systems worldwide. Governments, extension services, manufacturers, and researchers must collaborate to scale these proven interventions and ensure that the physical price of feeding the world is no longer paid in chronic pain and disability.

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