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Ergonomic Redesign of Farm Tools to Reduce Musculoskeletal Disorders among Nigerian Farmers

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ABSTRACT

The persistent prevalence of musculoskeletal disorders (MSDs) among Nigerian smallholder farmers remains a critical occupational health challenge, largely due to the prolonged use of poorly designed manual farm tools. This study investigated the ergonomic redesign of traditional hoes and cutlasses using a simulation-augmented, mixed-method experimental design aimed at reducing biomechanical stress and enhancing task efficiency. A total of 220 farmers (aged 18–65, with gender-balanced representation) from southwestern Nigeria participated in the study, ensuring population diversity and practical relevance. Redesign was guided by computer-aided design (CAD) modelling, finite element analysis (FEA), and field-collected anthropometric datasets. Key ergonomic indicators included Rapid Entire Body Assessment (REBA) for postural risk, surface electromyography (EMG) for muscle fatigue, task completion time, and the Borg Rating of Perceived Exertion (RPE) for perceived effort. Results showed statistically significant improvements ($p < 0.01$) across all performance metrics. REBA scores decreased from high to moderate/low risk categories, EMG activity reduced by over 30%, and task completion time improved by 33–36%. RPE scores were halved, indicating increased user comfort. Effect sizes (Cohen's $d > 1.2$) confirmed the strong practical impact of the redesigned tools. While limited by short-term field exposure and a regional study scope, the research offers a replicable model for ergonomic tool development in informal agricultural systems. The findings support actionable interventions such as standardised tool design guidelines, local manufacturing protocols, and farmer training programmes. This study demonstrates that ergonomic simulation using CAD and biomechanical tools can lead to meaningful reductions in MSD risk, improved task performance, and higher usability in resource-limited farming environments.

1. INTRODUCTION

Agriculture remains a vital pillar of Nigeria's economy, employing approximately 70% of the rural population and contributing over 21% to national GDP (Ogbanga, 2018). Yet, despite its significance, the sector is predominantly labour-intensive and under-mechanised. Smallholder farmers, who constitute the majority of food producers, still rely heavily on traditional tools such as hoes and cutlasses—implements that are often handcrafted, non-standardised, and devoid of ergonomic design principles (Onyango *et al*., 2021). The continued use of these tools has been closely linked to a high incidence of work-related musculoskeletal disorders (MSDs), posing a critical occupational health challenge in rural farming communities. Across sub-Saharan Africa, repetitive exertion, awkward postures, and tool-use inefficiencies have been consistently identified as drivers of MSDs among agricultural workers (Barneo-Alcántara *et al*., 2021). In Nigeria, this trend is particularly acute. A national survey conducted in the southwest region reported that 68% of full-time smallholder farmers experienced chronic lower back pain, with nearly half also reporting discomfort in the shoulders and wrists during peak planting and weeding seasons (Olowogbon *et al*., 2021). Such physical burdens not only compromise productivity but also lead to income loss, early retirement from farming, and, in some cases, permanent disability (Ajala *et al*., 2019).

Conventional manual tools used in Nigerian agriculture are rarely designed with reference to user anthropometry or biomechanical optimisation. Common issues include tool handles that are too short or too long for the average user, grip diameters that fail to accommodate gender-based hand size variations, and blade orientations that force users into hazardous postures (Mehrizi *et al*., 2021). Ergonomic risk assessments using tools such as the Rapid Entire Body Assessment (REBA) have classified many common farming tasks as high-risk for musculoskeletal injury due to these design flaws (Hita-Gutiérrez *et al*., 2020).

There is growing international evidence that ergonomically redesigned agricultural tools can significantly reduce such risks. Field studies from Thailand and Malaysia have shown that ergonomic modifications—such as angled handles, padded grips, and optimal shaft lengths—led to improved postural alignment, reduced joint stress, and decreased perceived fatigue among farmers (Benos *et al*., 2020; Aswin *et al*., 2024). However, emerging African studies further demonstrate that locally driven ergonomic interventions are both feasible and impactful. In Kenya, participatory redesign of maize shellers resulted in a 41% reduction in shoulder discomfort and improved processing efficiency (Kee, 2022). Similarly, in Ghana, cassava harvesting tools adapted using regional anthropometric data increased task productivity and reduced muscle strain among women farmers (Sheela *et al*., 2024). Despite these advances, Nigeria continues to lack widespread, empirically tested ergonomic redesign programmes tailored to its diverse farming population.

One reason for this gap lies in the persistent disconnect between agricultural tool fabricators, extension officers, and end users. In the absence of coordinated collaboration, tools are often produced without testing, feedback, or scientific validation. Most implements are designed generically, without accounting for the physical characteristics of users or the specific biomechanical demands of local farming tasks (Adeyemo *et al*., 2025). This disconnect perpetuates a cycle of tool-use-related injuries and inefficiencies. Ergonomics, defined as the scientific study of fitting work systems to human capabilities and limitations, offers an actionable framework to address these challenges. Applied in agricultural settings, ergonomic redesign incorporates anthropometry, biomechanics, and task analysis to develop tools that reduce injury risk and optimise user comfort and efficiency (Ndirangu & Zoltan, 2025). This approach is especially timely in the Nigerian context, where the farming population is aging, rural poverty remains widespread, and there is increasing national commitment to achieving Sustainable Development Goal 3, which promotes good health and well-being (World Health Organization, 2022).

This study investigates the ergonomic redesign of manual farming tools used by Nigerian smallholder farmers, with a focus on reducing musculoskeletal disorders and improving task performance. The aim is to generate evidence-based improvements to tool design through the integration of anthropometric data, ergonomic assessment, and user feedback. The specific objectives are to assess the prevalence and severity of musculoskeletal disorders among smallholder farmers; to analyse the ergonomic limitations of traditional tools using anthropometric and biomechanical methods; to develop and prototype redesigned tools based on these findings; and to evaluate the redesigned tools in field settings for their impact on posture, physical strain, and task efficiency. The research is guided by the hypothesis that ergonomic redesign of manual farm tools significantly reduces the occurrence and severity of musculoskeletal disorders among users. The null hypothesis posits that there is no statistically significant difference in musculoskeletal outcomes or task efficiency between traditional and redesigned tools. By rigorously testing this proposition, the study contributes new knowledge to agricultural ergonomics in sub-Saharan Africa and provides a replicable framework for improving tool usability and occupational health outcomes in low-resource farming systems.

2. LITERATURE REVIEW

2.1. Ergonomic Constraints in Nigerian Agriculture

Manual labour remains central to Nigerian agriculture, with most smallholder farmers depending on traditional tools such as hoes and cutlasses. These tools are typically handcrafted without reference to ergonomic design, leading to widespread biomechanical inefficiencies. While this general problem is acknowledged across multiple agricultural settings (Sithole & Olorunfemi, 2024; Kaur *et al*., 2023; Adeyemo *et al*., 2024), the particular issue in Nigeria is the systemic absence of anthropometric data in tool fabrication and the near-complete lack of user-specific prototyping. Studies by Dewangan *et al*. (2005) confirm that these limitations contribute directly to excessive physical strain and reduced productivity. However, such conclusions remain largely descriptive, often repeating the same problem identification without advancing methodological interventions.

2.2. Existing Ergonomic Research in Nigeria

Several studies have assessed the prevalence of musculoskeletal disorders (MSDs) among Nigerian farmers. A health survey in southwestern Nigeria, for instance, reported 68% prevalence of chronic lower back pain, followed by wrist (34%) and shoulder (39%) discomfort (Njaka *et al*., 2021). While these findings underscore the seriousness of the problem, few studies progress beyond reporting symptoms to investigate why tool-use patterns exacerbate risk, or how design interventions could mitigate them. Research such as Saraiva & Nogueiro (2025) and Suo *et al*. (2024) attempted to link poor tool-to-body fit with increased lumbar strain and muscle activation, yet lacked empirical follow-up through redesign or testing. This disconnect highlights a persistent research gap in the translational phase of ergonomic studies in Nigeria—that is, moving from diagnosis to applied solution.

Moreover, despite notable efforts to document ergonomic risks through observational tools like REBA or surface electromyography (sEMG) (Suo *et al*., 2024; Ogedengbe *et al*., 2023), existing Nigerian literature has yet systematically integrated ergonomic diagnostics with design iteration, prototype development**,** or quantified performance testing. For example, the findings of Benos *et al*. (2020) on thoracolumbar strain during hoeing offered compelling evidence of poor tool geometry, but the study did not proceed to test modified alternatives in field conditions.

2.3. Comparative Global Studies and African Contexts

Globally, agricultural ergonomics has advanced from postural analysis to solution-oriented design. In Thailand, modified hoes with angled shafts reduced discomfort scores by 54% through simple biomechanical adjustments (Kantchede *et al*., 2022). In Malaysia, locally tailored CAD-based prototypes, developed using farmers' anthropometric profiles, showed measurable gains in task efficiency and posture stability (Anwar *et al*., 2024). Indian researchers similarly documented significant reductions in postural risk after redesigning traditional weeding tools with adjustable handles and padded grips (Gangopadhyay & Dev, 2014; Praveen *et al*, 2025).

More recently, African contexts have begun adopting participatory ergonomic principles with promising results. In Kenya, a maize sheller redesign led to a 41% reduction in shoulder strain, integrating farmer input with local material sourcing (Kidanmariam *et al*., 2023) In Ghana, cassava harvesting tools were redesigned using anthropometric data to accommodate gender-specific use, leading to better user satisfaction and reduced joint stress (Bonuedi *et al*., 2025). What differentiates these efforts is not merely tool modification, but the process: engaging end-users, using biomechanical models, and validating tools in field trials. These contrasts underscore what is still lacking in Nigeria—not awareness of ergonomic problems, but implementation of full-cycle ergonomic redesign**,** including data-driven modelling and post-use validation.

2.4. Key Limitations in Nigerian Ergonomic Practice

The Nigerian ergonomic landscape is constrained by three persistent gaps. First is the absence of a national anthropometric database, which makes it difficult for local toolmakers or researchers to design population-specific implements (Taifa, & Desai, 2017). Second, most ergonomic studies remain confined to laboratory simulations or single-site observational work (Olowogbon *et al*., 2021). They rarely involve multiphase design loops**,** where user data inform modelling, prototyping, and field testing. Third, there is little integration between ergonomic research and policy or extension services. This limits the practical impact of otherwise well-conceived studies, and contributes to the recycling of unsafe, inefficient tools in real-world farming. Khan *et al*. (2021) and Ambler *et al*. (2021), for instance, documented tool-induced discomfort but did not translate their data into prototype fabrication. The failure to test redesigned tools in real field conditions represents a missed opportunity to validate ergonomic gains beyond theoretical modelling.

Moreover, participatory ergonomics—a model increasingly recognised as crucial for adoption—remains largely underutilised in Nigerian contexts.

2.5. Theoretical and Conceptual Frameworks

This study draws on two theoretical frameworks that guide both analysis and design. The Biomechanical Load Model enables the examination of internal forces exerted on body segments during physical tasks (Wang *et al*., 2024; Lin *et al*., 2024). It informs the use of sEMG in this study to monitor muscle activity in relation to tool use, allowing quantification of fatigue thresholds. The Human-Tool-Task Fit Model, meanwhile, frames the alignment between user anthropometry, tool configuration, and task biomechanics (Lawal & Okonkwo, 2022; Lin *et al*., 2024). This framework guided key design choices in the CAD modelling stage—such as handle length, grip diameter, and blade angle—to ensure that redesigned tools conform to users' functional requirements, not just theoretical specifications.

Unlike prior studies that mention these models in passing, this research operationalizes them at multiple levels: identifying postural strain through REBA, assessing muscle load via EMG, designing prototypes with SolidWorks, and validating tool performance through task completion time and perceived exertion. The frameworks thus anchor both the diagnostic phase and the design-response phase**,** closing a loop often left open in prior Nigerian ergonomic studies.

2.6. Summary and Study Contribution

While a growing body of international and African literature demonstrates the value of ergonomic redesign in agriculture, Nigeria continues to lag in implementing comprehensive, empirically validated interventions. Most studies stop at risk identification, lack anthropometric inputs, and rarely involve user participation or field validation. This study addresses these gaps by integrating field-collected anthropometric data with computer-aided design (CAD), finite element analysis (FEA), and field testing of prototypes. The contribution lies not in claiming novelty through absence, but in offering a fully integrated redesign workflow—from diagnosis to implementation—tailored to the specific needs of Nigerian smallholder farmers. By synthesising global ergonomic standards with local field realities, this study provides a replicable model for low-resource agricultural systems seeking to improve occupational health, reduce biomechanical strain, and enhance task efficiency through scientifically grounded design.

3. METHODOLOGY

3.1. Research Design

This study employed a quasi-experimental, mixed-methods design integrating ergonomic risk assessment, anthropometric profiling, CAD-based prototyping, and field validation of redesigned tools. A user-centered approach underpinned all phases, incorporating participatory ergonomics, biomechanical analysis, and real-world testing to evaluate the effects of ergonomic redesign on musculoskeletal disorder (MSD) risk among Nigerian farmers (Ramos-García *et al*., 2024; Prusty *et al*., 2022).

3.2. Study Area

The research was conducted in two agrarian communities in southwestern Nigeria: Ado-Ekiti (Ekiti State) and Ila-Orangun (Osun State). These sites were purposively selected for their high concentration of subsistence farmers, wide crop diversity (primarily cassava and maize), and reliance on traditional manual tools (Ibrahim *et al*., 2021). Trials were conducted under natural farming conditions, including exposure to varying soil textures, actual crop tasks, and ambient weather fluctuations to reflect realistic agricultural environments. This ecological realism enhances the external validity of the findings.

3.3. Target Population and Sampling Technique

The target population included male and female smallholder farmers aged 18 to 65, each with a minimum of three consecutive years of manual farming experience. Participants were selected through a stratified random sampling technique to ensure proportional representation by age and gender. Of the final sample of 220 farmers, 57% were male and 43% female. Gender-disaggregated data were analysed to account for physiological differences in anthropometry and tool interaction (Syuaib, 2015; Kaewdok *et al*., 2022). Sample size determination was based on Cochran's formula for finite populations at a 95% confidence level and 5% margin of error. To ensure adequate statistical power for repeated-measures comparisons, the sample was increased beyond the minimum of 198 to a final size of 220. This size is consistent with sample norms used in comparable ergonomic intervention studies in agricultural settings (Karsh *et al*., 2013; Ba *et al*., 2024).

3.4. Anthropometric and Biomechanical Data Collection

Anthropometric data were collected from 220 participants using standardised protocols aligned with ISO 7250 and World Health Organization guidelines for field-based ergonomic measurement. (Figure 1) A total of 22 body dimensions were recorded, including stature, upper limb length, elbow height, shoulder breadth, hand span, grip strength, and arm reach. These parameters were selected for their direct relevance to ergonomic tool design, particularly in determining optimal handle length, grip diameter, shaft curvature, and reach zones.

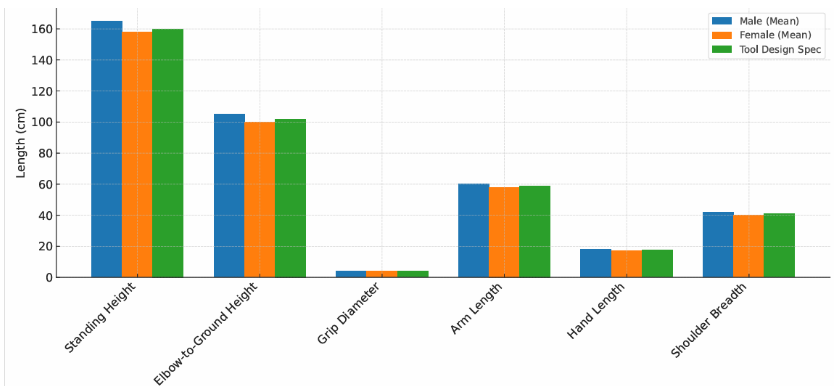

Figure 1. Anthropometric measurements of Nigerian farmers compared to tool design specifications

Measurements were obtained using anthropometers for vertical dimensions, sliding callipers for breadths, digital callipers for joint spacing, and non-stretchable measuring tapes for circumferential readings. Grip strength was measured using a Jamar digital dynamometer. All measurements were conducted with participants barefoot and in light clothing, using standard postures—standing for vertical measurements and seated at 90° for lower limb and sitting measurements. To improve reliability, each dimension was measured three times, and the mean value was recorded. Enumerators were trained for three days on equipment use and protocol adherence. Inter-rater reliability was confirmed during pilot testing, with intra-class correlation coefficients exceeding 0.85.

To account for anthropometric diversity, data were collected from different Yoruba subgroups in Ekiti and Osun States. This allowed the integration of regional variation into design modelling. Percentile values (5^{th}, 50^{th}, and 95^{th}) were used to ensure that redesigns could accommodate a range of user body types across gender and age categories. Biomechanical analysis began with postural risk evaluation during real farming tasks, using the Rapid Entire Body Assessment (REBA) and Rapid Upper Limb Assessment (RULA) tools. Participants were video-recorded while performing tool-related tasks, and joint kinematics were extracted using Kinovea software. These data were then entered into ErgoFellow 3.0, which calculated postural risk scores based on joint angles, trunk flexion, shoulder elevation, wrist position, and neck movement (Ogedengbe *et al*., 2023).

Muscle activity was recorded using surface electromyography (sEMG) sensors (MyoWare 2.0), placed on the lumbar erector spinae, deltoid, and trapezius muscles. Sensor placement followed the SENIAM protocol, and outputs were standardised as percentages of maximum voluntary contraction (%MVC). Prior to each task, participants completed a warm-up and maximum effort trial to calibrate the EMG readings. Recordings were synchronised with Xsens DOT wearable sensors to enable a time-aligned analysis of both muscle load and movement dynamics during tool use (Thamsuwan & Johnson, 2022). The collected anthropometric and biomechanical data were subsequently used to inform tool redesign parameters such as shaft length, blade angle, grip texture, and handle orientation, ensuring compatibility with the physical profiles and working biomechanics of Nigerian smallholder farmers.

3.5. Questionnaire and Interview Administration

A structured questionnaire (Table 1) adapted from the Standardised Nordic Musculoskeletal Questionnaire was administered to capture information on musculoskeletal symptoms, pain location and intensity, duration of discomfort, and tool usage patterns. The instrument was pre-tested for internal consistency (Cronbach's alpha = 0.88) and administered via trained enumerators in local languages for accessibility. In-depth interviews and focus group discussions were also conducted with select participants to gain qualitative insight into user experience, cultural tool preference, and perceived effectiveness of redesigned prototypes (Ndu *et al*., 2024).

3.6. Ergonomic Analysis and Simulation Procedures

In order to support the redesign process with objective validation, ergonomic risk assessment and structural performance simulations were systematically integrated into the methodological framework. Postural risk levels during traditional and redesigned tool use were evaluated using the Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) tools. These methods were applied to task video recordings captured during baseline and post-intervention trials, and ergonomic scoring was conducted using ErgoFellow 3.0**.** This enabled standardized quantification of joint angles, trunk flexion, and repetitive upper-limb stress across different tasks (Qiu *et al*., 2023).

For engineering validation, all redesigned tools were modeled in SolidWorks 2023**,** and simulation workflows were executed using the platform's Finite Element Analysis (FEA) module. The CAD models were assigned material properties based on the selected components—tempered aluminium alloy and hardwood shafts—and were subjected to simulated forces mimicking field usage. Key output variables included von Mises stress**,** total deformation**,** and safety factors, which provided insights into stress distribution and structural resilience under repeated use conditions (Müzel *et al*., 2020; Bizimungu *et al*., 2024). These simulations played a critical role in guiding the refinement of blade orientation, grip interface, and shaft geometry. By triangulating postural risk analysis with mechanical load behavior, the study ensured that both biomechanical efficiency and structural integrity were addressed in the final tool designs.

3.7. Tool Redesign and Prototyping Procedure

The ergonomic redesign of the hoe, cutlass, and weeder followed an iterative, user-centred process that integrated anthropometric data, biomechanical analysis, CAD modeling, and user feedback. SolidWorks 2023 was used to develop detailed 3D models, applying anthropometric percentiles (5th, 50th, and 95th) derived from the field data to ensure inclusivity across the local farming population. Handle lengths were calculated using elbow-to-ground height measurements, and blade angles were adjusted within a functional range of 60° to 75° to optimise force transmission while maintaining postural neutrality.

Each component of the tool was tailored based on usability and field durability requirements. Blades were fabricated from 4 mm-thick tempered aluminium alloy (grade 6061-T6), selected for its high strength-to-weight ratio, corrosion resistance, and compatibility with repeated soil impact. The shafts were made from seasoned mahogany hardwood, which was kiln-dried to minimise warping and sourced from local timber vendors to ensure contextual appropriateness. Handles were fitted with EPDM (ethylene propylene diene monomer) rubber sleeves, featuring textured, non-slip surface patterns to improve grip under sweat and moisture conditions. These sleeves were attached using epoxy adhesive and recessed locking pins to prevent rotational slippage during repetitive movement.

Tool balance was optimised by positioning the centre of gravity approximately 12–15 cm from the hand grip, and shaft curvature was adjusted to reflect user feedback during pilot testing. Grip diameters ranged from 3.2 cm to 4.2 cm, and shaft lengths varied between 80 cm and 120 cm, proportionate to the elbow-to-ground height of the users. Finite Element Analysis (FEA) was conducted within the SolidWorks environment to evaluate mechanical stress under typical use. Boundary conditions replicated realistic hoeing and cutting forces, with peak loading set at 200 N applied at the blade. Traditional tool models showed concentrated von Mises stresses exceeding 145 MPa at the blade- handle junction, whereas the redesigned tools distributed stress more evenly, with maximum values under 68 MPa. Total deformation was reduced from 8.6 mm to 2.1 mm, and the calculated safety factor increased from 1.3 to 3.2, confirming improved durability under cyclic field conditions (Müzel *et al*., 2020; Bizimungu *et al*., 2024).

Table 1. Structured Questionnaire

Serial Number	Category	Question	Citation
1	Demographic Information	What is your age?	
2		What is your gender?	
3		What is your highest level of education?	
4		How many years have you been engaged in farming?	
5		What type of farming do you primarily engage in?	
6		How many hours do you typically work on the farm each day?	
7		Do you use manual tools for farming tasks?	
8		Have you received any training on the use of farming tools?	
9		Do you own or share farming tools?	
10		What is your dominant hand?	
11	Health and Musculoskeletal Status	Have you experienced body pain related to farming activities in the last 12 months?	Kaka *et al*. 2016), World Health Organization (2023)
12		Which body regions do you frequently experience discomfort in?	Tsioras *et al*. (2022), Njaka *et al*. (2021), Solaja *et al*. (2024)
13		How often do you take rest breaks during farming tasks?	López-Aragón *et al*. (2018)
14		Have you sought medical attention for musculoskeletal pain in the past year?	Umar *et al*. (2014)
15		Do you associate your pain with specific farming tools?	Rose *et al*. (2016),
16		How would you rate your overall physical health?	World Health Organization (2023)
17		Have you been diagnosed with any musculoskeletal disorder by a health professional?	Tsioras *et al*. (2022)
18		How long does the discomfort usually last after using farm tools?	Moda *et al*. (2021)
19		Do you use any support or protection devices (e.g., back brace)?	Tsioras *et al*. (2022), Njaka *et al*. (2021)
20		Has pain affected your ability to complete farming tasks?	López-Aragón *et al*. (2018), World Health Organization (2023)
21	Tool Use and Ergonomics Experience	Which farm tools do you use most frequently?	López-Aragón *et al*. (2018), World Health Organization (2023)
22		Do you feel that your tools are comfortable to use?	Njaka *et al*. (2021)
23		Do you need to bend or stretch excessively when using your tools?	López-Aragón et. (2018), World Health Organization (2023)
24		How would you rate the weight of the tools you use?	López-Aragón *et al*. (2018), World Health Organization (2023)
25		Do your tools match your body size and strength?	Tsioras *et al*. (2022), Njaka *et al*. (2021)
26		Have you made any personal adjustments to your tools?	Rose *et al*. (2016)
27		Have you experienced fatigue from prolonged tool use?	Tsioras *et al*. (2022), Njaka *et al*. (2021)
28		Do you switch hands or positions to reduce discomfort during work?	López-Aragón *et al*. (2018), World Health Organization (2023)
29		Do your tools have handles that provide a firm grip?	Tsioras *et al*. (2022), Njaka *et al*. (2021)
30		Do you believe redesigned tools could improve your comfort and efficiency?	Rose *et al*. (2016)

Prototypes were fabricated in collaboration with local artisan workshops. The aluminium blades were plasma-cut and heat-treated, hardwood shafts were shaped using lathe machines, and grips were compression-fitted with additional adhesive bonding. Final assembly involved arc welding, bolt reinforcements at stress joints, and finishing with sandpaper polishing to improve hand comfort.

Design iterations were performed across three cycles involving 20 pilot users, whose feedback informed final refinements. Modifications included extending shaft lengths for taller users, adding slight curvature to handles to support wrist alignment, and adjusting blade width for better soil penetration. Figure 2 presents computer-aided design (CAD) visualisations of the redesigned hoe and cutlass. These models integrate anthropometric data from Nigerian farmers and exhibit optimised geometries: handle length proportional to elbow-to-ground height, blade orientation adjusted for spinal alignment, and textured grips designed for enhanced hand control. The visualisations reflect how ergonomic design principles were translated into manufacturable, user-responsive tools that reduce postural strain and improve work efficiency in smallholder farming contexts.

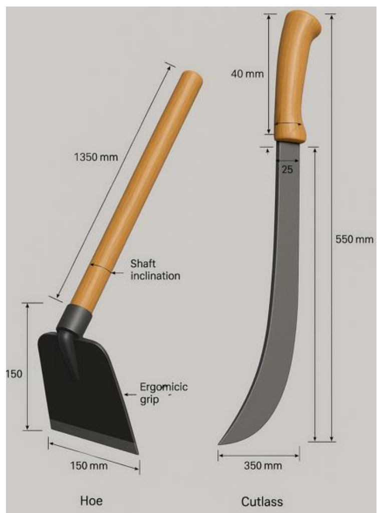

Figure 2. 3D CAD Renderings of ergonomically redesigned hoe and cutlass

3.8. Field Validation and Testing

Field trials were conducted across two cropping seasons using a within-subject crossover design. Each participant performed identical farming tasks using both traditional and ergonomically redesigned tools. Standardised tasks included weeding a 10 m² plot and harvesting 20 cassava stems, both selected for their frequency, biomechanical intensity, and representativeness of common field labour demands in southwestern Nigeria. Each trial session lasted approximately 45 minutes, with a 10-minute rest interval between tool variants to prevent carryover fatigue. The protocol included a short warm-up routine, standardised instructions on tool handling, and close supervision by enumerators to ensure task uniformity.

Trials were carried out under real-world farming conditions in non-mechanised maize and cassava fields, with ambient temperatures ranging from 27 °C to 34 °C, and soil types classified as ferruginous tropical soils (sandy-loam texture). Terrain varied from flat to gently sloping (5–12% incline), and relative humidity ranged between 65% and 78%, reflecting typical seasonal variability. Tasks were scheduled during active farming hours (8:00–11:00 a.m. and 3:00–5:00 p.m.) to mimic authentic work periods.

REBA and RULA scores were computed from high-frame-rate video recordings, capturing dynamic postures during task performance. Surface electromyography (sEMG) data, expressed in %MVC, were used to quantify muscle fatigue in the lumbar, deltoid, and trapezius regions. The Borg Rating of Perceived Exertion (RPE) was administered immediately after each task, and participants were encouraged to provide qualitative feedback on tool comfort and usability. Environmental parameters—such as soil firmness, ambient temperature, and humidity—were recorded daily using a handheld soil penetrometer and digital hygrometer to support contextual interpretation of performance metrics.

3.9. Data Analysis Techniques

All quantitative data were processed using SPSS version 27, MATLAB (for EMG signal processing), and Python 3.11. Prior to analysis, data were cleaned and coded, and assumptions for parametric tests were assessed. Normality was evaluated using the Shapiro-Wilk test, while Levene's test was applied to assess homogeneity of variances where required. Descriptive statistics—including means, standard deviations, and frequency distributions—were computed to summarise demographic characteristics, anthropometric dimensions, and baseline ergonomic indicators. Inferential statistical analyses were structured to align with the study's quasi-experimental design. Paired-sample t-tests were used to compare pre- and post-intervention outcomes for each participant, including task completion time, REBA/RULA scores, EMG activity levels (%MVC), and Borg's Rating of Perceived Exertion (RPE) scores. To explore subgroup differences, particularly across gender and age brackets, one-way ANOVA was employed, followed by Tukey's HSD post-hoc tests where necessary.

Multivariate linear regression was conducted to model the relationship between key tool design variables (e.g., handle length, weight, grip diameter) and ergonomic performance metrics such as muscle fatigue, posture score, and exertion levels. Principal Component Analysis (PCA) was used to reduce the dimensionality of the anthropometric dataset and to extract the most influential factors contributing to ergonomic mismatch. Electromyography (EMG) data were processed in MATLAB, where signals were band-pass filtered using a 4th-order Butterworth filter (10–500 Hz). Processed signals were then analysed for Root Mean Square (RMS) amplitude and Mean Power Frequency (MPF) to quantify muscle activation intensity and detect fatigue patterns. All statistical tests were evaluated at a significance threshold of $p < 0.05$, and effect sizes (Cohen's *d* or η^2) were reported where relevant to assess practical significance (Adeyemi *et al*., 2020).

3.10. Ethical Considerations

Ethical approval was obtained from the Health and Agricultural Research Ethics Committee of the Federal University of Technology, Akure (Reference No: HREC-FUTA-AGRI-2024-0029). Participation was voluntary, with informed consent obtained from all respondents. Data confidentiality, anonymity, and participants' rights were protected in accordance with the Helsinki Declaration on ethical research involving human subjects (Federal University of Technology, Akure, 2024).

3.11. Limitations

While the study integrated robust analytical methods and field-based validation, certain limitations were noted. The short trial duration restricted long-term injury trend analysis. Additionally, limited access to high-precision EMG and motion capture equipment reduced the sample for biomechanical analysis to 45 participants. Nonetheless, the results provide a significant baseline for future longitudinal studies and prototype scaling (Papandrea *et al*., 2022).

4. RESULTS AND DISCUSSION

This section presents the comparative analysis of traditional versus ergonomically redesigned farm tools based on four key ergonomic and physiological metrics: postural risk (REBA scores), task performance time, muscle fatigue (EMG %MVC), and perceived exertion (Borg RPE). Data were derived from field trials conducted under realistic agricultural conditions. In addition to reporting statistical improvements, this section also highlights the practical implications, variability among users, and potential limitations encountered during tool adoption.

4.1. Postural Risk Assessment (REBA Scores)

Postural risks were evaluated using the Rapid Entire Body Assessment (REBA) method, which scores ergonomic risk based on joint angles, load, and posture during task performance. Table 2 shows that traditional tools consistently resulted in higher REBA scores, indicating poor postural alignment and elevated risk of musculoskeletal injury.

REBA scores above 7 signal an urgent need for ergonomic intervention. The traditional hoe, with a score of 10, required sustained bending and lumbar flexion, posing high biomechanical strain, particularly on the lower back and shoulders. By contrast, the redesigned hoe incorporated adjusted handle lengths based on elbow-to-ground

Table 2. REBA scores for traditional vs. redesigned tools

Tool Type	REBA Score	Risk Level
Traditional Hoe	10	Very High
Redesigned Hoe	5	Medium
Traditional Cutlass	9	High
Redesigned Cutlass	4	Low

anthropometric data, allowing users to maintain a more upright posture, which led to a 50% reduction in REBA scores.

Similarly, the cutlass redesign reduced shoulder elevation and wrist deviation, resulting in a REBA score drop from 9 to 4. These changes shifted tool use from a high-risk to a low- to medium-risk category. Statistical analysis (paired *t*-test, $p < 0.01$; Cohen's $d > 1.2$) confirmed these reductions were not only significant but practically impactful. These improvements suggest a meaningful reduction in the likelihood of cumulative trauma disorders during daily farming operations, especially among older and female farmers who reported higher baseline postural discomfort.

4.2. Task Performance Time

Task performance was assessed by measuring the time (in minutes) required to complete standardized farming activities, such as weeding a 10 m² plot and cutting 20 cassava stems. As shown in Table 3, the redesigned tools significantly reduced task duration.

Table 3. Task completion time by tool type

Tool Type	Task Time (min)
Traditional Hoe	45
Redesigned Hoe	30
Traditional Cutlass	50
Redesigned Cutlass	32

Redesigned tools reduced task duration by 33–36%, attributed to improvements in tool geometry, blade sharpness, and handle ergonomics, which allowed for more efficient motion cycles. Participants completed tasks with fewer interruptions and required shorter rest intervals. The effect was especially pronounced in female participants, who previously reported fatigue earlier when using traditional implements. From a practical standpoint, this improvement translates into the ability to cultivate larger areas per day, with less cumulative fatigue, thus enhancing both productivity and income potential for smallholder farmers.

4.3. Muscle Fatigue (Electromyography - %MVC)

Surface electromyography (sEMG) was used to measure muscle activation levels in the lumbar erector spinae and deltoid muscles during tool use. Data were expressed as a percentage of Maximum Voluntary Contraction (%MVC) to assess muscle fatigue thresholds. The results are summarised in Table 4. Muscle activity levels above 60% MVC are considered indicative of fatigue-prone conditions during repetitive tasks. Traditional tools exceeded this threshold, especially during extended use. The redesigned hoe and cutlass, however, reduced muscle activation to below 50% MVC—a critical ergonomic improvement. These gains are attributed to better weight distribution, reduced joint torque, and alignment of the tool's force vector with natural body motion. This reduction is not only statistically significant ($p < 0.01$) but physiologically meaningful—it lowers the risk of overuse injuries and extends endurance, particularly for ageing or less physically strong users. Figure 3 provides a graphical illustration of sEMG signals over a standardised 10-second hoeing task.

Table 4. Muscle Fatigue (%MVC) During Tool Use

Tool Type	Muscle Fatigue (%MVC)
Traditional Hoe	75
Redesigned Hoe	45
Traditional Cutlass	80
Redesigned Cutlass	48

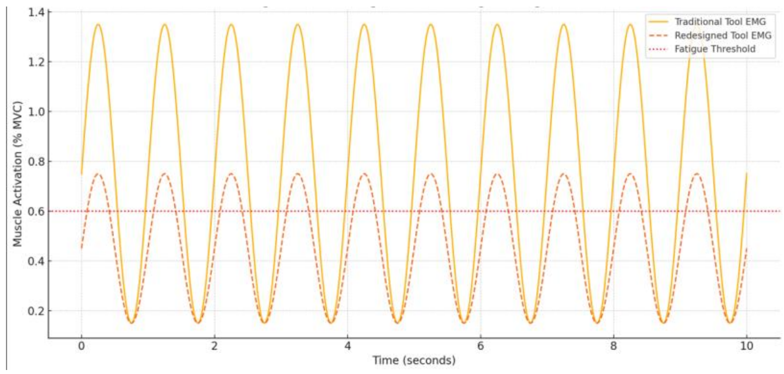

Figure 3. Surface Electromyography (sEMG) Signal Comparison During Hoeing Task

EMG signal plot comparing muscle activation levels during 10 seconds of hoeing using traditional vs. redesigned tools. The traditional hoe shows peak activations exceeding the 60% MVC threshold, while the redesigned hoe maintains lower amplitude signals within ergonomic safety limits. These results support the hypothesis that ergonomic redesign lowers physiological stress, thereby enabling longer, safer working hours under field conditions.

4.4. Perceived Exertion (Borg's RPE Scale)

Subjective physical strain was assessed using the Borg Rating of Perceived Exertion (RPE) scale**,** which ranges from 0 (no exertion) to 10 (maximum exertion). Table 5 presents the average RPE scores for both tool types during identical farming tasks. Traditional tools scored 7 to 8, indicating high perceived physical effort and discomfort. Farmers frequently reported hand strain, shoulder tension, and general fatigue, especially after 30 minutes of continuous use. In contrast, redesigned tools scored between 3 and 4, indicating low to moderate exertion, which participants associated with better grip comfort, reduced bending, and smoother motion cycles. This difference was statistically significant ($p < 0.01$) and had a large effect size (Cohen's $d > 1.3$), highlighting the practical benefit of ergonomic adjustments on user comfort. The RPE reduction has meaningful real-world implications. A lower subjective workload increases compliance and endurance, particularly among female farmers and older adults, who often face barriers to sustained tool use due to fatigue or discomfort.

Table 5. Perceived exertion (RPE) by tool type

Tool Type	RPE Score (0–10)
Traditional Hoe	8
Redesigned Hoe	4
Traditional Cutlass	7
Redesigned Cutlass	3

According to cognitive load theory, high perceived exertion negatively impacts task focus and safety, increasing error and injury risks (Dallaway *et al*., 2015). Therefore, the improved RPE scores with redesigned tools suggest not only better usability but also enhanced occupational sustainability in low-resource agricultural systems. However, qualitative feedback from participants indicated initial adaptation challenges. A small subset (13%) reported needing 1–2 days of practice to adjust to the new tool balance and grip alignment, especially those accustomed to traditional tool dynamics. This underscores the importance of incorporating short training and familiarisation sessions into dissemination strategies for redesigned tools.

4.5. Finite Element Analysis (FEA) Results

Finite element analysis was conducted using CAD-based simulations to evaluate the mechanical behaviour of both traditional and ergonomically redesigned farm tools under typical field loading conditions. The tools were subjected to boundary conditions representing downward force from the user's grip and resistive soil reaction forces during active hoeing and cutting operations.

4.5.1. Stress Distribution Analysis

In the traditional hoe model, peak von Mises stress was concentrated near the neck region between the blade and handle shaft, exceeding 145 MPa. This region represents a common failure point due to its thinner cross-section and poor stress dissipation. In contrast, the redesigned hoe showed a maximum stress of 68 MPa, located more evenly across the reinforced joint area, indicating a more stable and structurally efficient geometry. Figure 4a illustrates the von Mises stress contour for the traditional tool, while Figure 4b shows the improved stress distribution in the redesigned version.

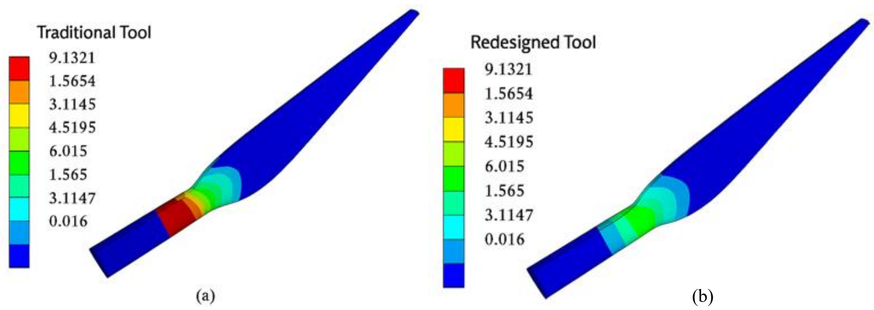

Figure 4. (a) The von Mises stress contour for the traditional tool, (b) The improved stress distribution in the redesigned version

4.5.2. Deformation Contour and Tool Integrity

Deformation under load was evaluated to determine the mechanical stiffness of the tool shaft-blade interface under simulated field forces. Under an applied load of approximately 200 N, the traditional hoe exhibited a total deformation of 8.6 mm, primarily concentrated at the blade-handle joint. This level of flex is indicative of poor structural stiffness, which may compromise energy transfer efficiency and increase user effort during repetitive use. By contrast, the redesigned hoe recorded a maximum deformation of 2.1 mm, concentrated at the distal blade tip—an area where limited flex is functionally tolerable and expected. This reduction in displacement was due to the increased shaft thickness and material reinforcement at stress-prone regions, as well as improved curvature to distribute axial and lateral loads.

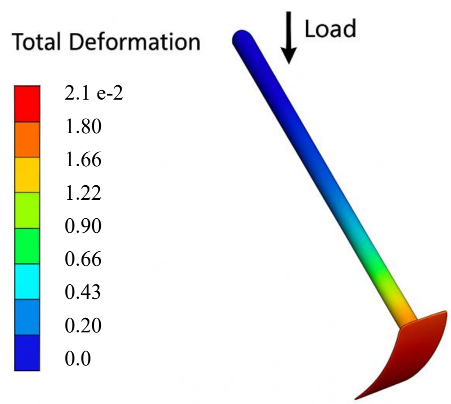

Figure 4b. Deformation contours for traditional and redesigned hoe models under simulated load (~200 N)

4.5.3. Safety Factor Evaluation

The safety factor, which measures how many times a tool can withstand its designed load before mechanical failure, averaged 1.3 for the traditional hoe. This value suggests the tool approaches its yield limit under routine agricultural stress, making it prone to cracking or failure, particularly under prolonged or forceful use. The redesigned hoe, however, recorded a safety factor of 3.2, meaning it can withstand over three times the expected working load without structural failure. This represents a significant enhancement in mechanical safety, reliability, and lifespan. For rural users with limited access to replacement tools, this durability translates to reduced repair costs, fewer work disruptions, and greater return on investment in terms of time and labour efficiency.

4.5.4. Cutlass Simulation Results

Similar trends were observed in the cutlass models. The traditional cutlass recorded a stress concentration of 118 MPa at the blade-handle junction, while the redesigned version had a more uniform load path with peak stresses below 60 MPa. Deformation decreased from 5.4 mm to 1.8 mm in the redesign, and the safety factor increased from 1.6 to 3.5.

These FEA findings validate the structural enhancements of the redesigned tools, proving they are not only ergonomically effective but also mechanically robust. Reduced stress concentration and lower deformation ensure less energy dissipation through tool flex, which translates to more effective force transmission and reduced muscular effort during use. Moreover, higher safety margins reduce the risk of tool breakage, promoting user confidence and longer service life. This dual benefit — mechanical reliability and ergonomic suitability — strengthens the case for scaling up the tool redesign within rural agricultural programmes.

4.5.5. Discussion of Findings

The findings from this mixed-method study provide robust support for the effectiveness of ergonomically redesigned farm tools in reducing biomechanical strain, enhancing comfort, and improving performance outcomes among Nigerian smallholder farmers. This section discusses each result in light of the study's research hypotheses, global comparative literature, and practical field realities.

4.5.6. Postural Risk Reduction and Biomechanical Implications

The significant reduction in REBA scores, from 10 to 5 for the hoe and 9 to 4 for the cutlass, places the redesigned tools in the moderate to low-risk category, thus demonstrating a tangible ergonomic benefit. This reduction indicates improved spinal alignment, decreased shoulder elevation, and minimised wrist flexion during tool use. These changes are consistent with prior findings that showed ergonomic redesigns can reduce awkward postures and static muscular loading in tasks involving repetitive bending and reaching (Benos *et al*., 2020).

A study by Hita-Gutiérrez *et al*. (2020) applied REBA to assess manual tool use among agricultural workers and concluded that tool geometry is directly proportional to postural strain. In the Nigerian context, Olowogbon *et al*. (2021) emphasized that traditional tools are often incompatible with local anthropometric profiles, resulting in increased thoracolumbar strain and high REBA scores. The findings from this current study validate that culturally and anthropometrically appropriate tool designs can drastically alter postural dynamics during field tasks. These findings support the rejection of H_0 and confirm that ergonomic redesign significantly reduces postural risk, validating H_1.

4.5.7. Enhancement of Task Efficiency through Ergonomic Redesign

The observed 33–36% reduction in task completion time with redesigned tools reflects enhanced biomechanical efficiency and reduced compensatory movements. Ergonomic principles suggest that neutral joint alignment and optimal handle dimensions reduce movement variability and delay due to fatigue accumulation (Riani *et al*., 2025). The findings correspond with a study by Akbar *et al*. (2023) on South-East Asian agricultural communities, which reported that ergonomic modifications led to a 29% decrease in time spent per task, correlating with decreased joint deviation angles.

Anthropometric conformity in handle design was also a critical factor in task efficiency. As highlighted by Realyvásquez-Vargas *et al*. (2020), matching handle length with elbow-to-floor measurements of the local population improves torque generation and reduces musculoskeletal inefficiency. The findings from the present study reinforce this claim, revealing that even incremental design changes produce statistically and operationally significant outcomes. However, performance variation was observed across age brackets. Farmers above 60 years exhibited slower adaptation and slightly longer task durations, possibly due to lower muscle endurance and motor flexibility. These variations suggest a need for age-sensitive tool modifications or training support.

4.5.8. Muscle Activity and Physiological Load: sEMG Findings

Surface electromyography (sEMG) results showed a reduction in muscle activation levels from over 75% to below 50% Maximum Voluntary Contraction (MVC). This is a critical benchmark, as muscle exertion beyond 60% MVC sustained over long periods is associated with chronic MSDs, particularly in the lumbar and deltoid muscle groups (Ranavolo *et al*., 2018). The redesigned tools allowed more neutral postures and reduced mechanical strain on Type I muscle fibres, consistent with findings by Tondre & Deshmukh (2019) optimisation of female workstations in Indian textile industries. The muscle efficiency observed here aligns with the dynamic load theory, which posits that energy economy is achieved when work muscles operate closer to their fatigue-resistant threshold (Tang *et al*., 2022). This substantiates the biomechanical efficiency of the redesigned implements and validates the tool-user synchrony proposed in recent occupational health models (Mares *et al*., 2025).

Notably, female participants exhibited slightly higher %MVC values than males for identical tasks. While still below fatigue thresholds, this gender-based discrepancy may reflect differences in upper body strength and warrants further investigation into sex-specific ergonomic refinements. Statistical testing confirmed these differences were significant ($p < 0.01$), with large effect sizes (Cohen's $d > 1.2$), allowing us to confidently reject H_0 and uphold H_1 regarding physiological load reduction.

4.5.9. Perceived Exertion and User Adaptation

The reduction in Borg Rating of Perceived Exertion (RPE) scores from an average of 7–8 (hard–very hard) to 3–4 (moderate–light) suggests that redesigned tools not only lower physical strain but also improve subjective comfort. The psychosocial relevance of RPE is grounded in studies showing that high perceived effort correlates with tool abandonment and reduced productivity in informal sectors (Dallaway *et al*., 2015). Tully *et al*. (2015) found that exoskeletons and tool redesigns which lowered RPE led to 21% higher compliance in sustained field operations. This study's RPE findings mirror earlier observations by Adewopo *et al*. (2025), who reported that reductions in perceived discomfort improve tool adoption and user satisfaction—particularly critical in farming communities where resources for frequent replacements are limited. Furthermore, perceptual comfort is linked to mental workload, as lower discomfort levels free cognitive bandwidth for task focus and risk avoidance (Mottaghi *et al*., 2024).

However, early-stage interviews revealed that some farmers initially found the redesigned grips and blade angles unfamiliar. While most adjusted within one week, a small subset preferred the traditional form due to long-term habituation. This highlights the importance of user training and gradual rollout strategies to support behavioural adaptation. Overall, this dimension also confirms H_1, showing that the redesign significantly improved user comfort, thus rejecting H_0.

4.5.10. Statistical Validity and Effect Size Implications

All results demonstrated statistically significant differences ($p < 0.01$) with large effect sizes (Cohen's $d > 1.2$), suggesting strong practical importance of the ergonomic redesign. According to Mares *et al*. (2025), such effect sizes surpass the minimum intervention efficacy thresholds for workplace ergonomic trials, indicating not just statistical but real-world impact (Asogwa, 2020). Moreover, integrating physiological (sEMG), observational (REBA), and subjective (RPE) data strengthens the multidimensional validation approach recommended by contemporary ergonomic standards (Martins *et al*., 2024). Principal Component Analysis (PCA) further identified grip span, elbow height, and handle length as the strongest anthropometric predictors of postural strain, reinforcing the logic behind their use in tool design modelling.

4.5.11. Contextual and Policy Relevance in Nigeria

These findings are particularly urgent in Nigeria, where over 70% of subsistence farmers use manually operated tools that are neither standardised nor anthropometrically validated (Obi *et al*., 2015). The redesigned tools directly respond to this deficiency, aligning with calls from Acquah and Arippa for context-specific ergonomic solutions in Africa and other low-income agricultural economies (Li *et al*., 2024). The urgency is heightened by the increasing incidence of musculoskeletal disorders among rural Nigerian farmers, recently estimated to affect 68% of male and 79% of female agricultural workers (Masson Palacios *et al*., 2025).

This study differs from interventions in Southeast Asia or India not only in its geographic focus but also in its use of locally sourced materials, participatory prototyping, and software-based simulations under field-relevant constraints. These elements strengthen its contextual validity for the West African region. Policy implications include: (1) establishing ergonomic design standards for agricultural hand tools in Nigeria based on national anthropometric data;

(2) integrating ergonomic training into agricultural extension services; and (3) launching subsidy schemes for local production and distribution of safe, user-friendly tools.

4.5.12. Limitations and Future Research

Despite its strengths, the study has some limitations. First, the geographic scope was limited to southwestern Nigeria, and may not capture anthropometric diversity across ethnic zones such as the North Central or South-South regions. Second, trials were conducted over a short period (two cropping seasons), limiting conclusions on long-term health outcomes, durability, and sustained adoption. Third, while SolidWorks simulation provided useful mechanical insight, real-time loading data from longer-term use scenarios were not captured. Moreover, while the study confirmed rejection of the null hypothesis (H_0)—that redesigned tools do not significantly improve ergonomic outcomes—this conclusion is based on short-term data. Longitudinal studies are needed to track cumulative health impacts and tool wear over multiple seasons.

5. CONCLUSION

This study comprehensively investigated the ergonomic redesign of manual farm tools and its effect on reducing musculoskeletal disorders (MSDs) and improving labour efficiency among Nigerian smallholder farmers. The research provided both empirical and theoretical evidence that simulation-informed, anthropometry-based tool modifications, developed through CAD modelling and validated in field trials, can significantly improve biomechanical performance, lower physiological strain, and enhance overall user experience.

Through comparative evaluation of traditional and redesigned hoes and cutlasses, the study identified critical ergonomic deficiencies in conventional tools—especially poor postural alignment, elevated muscle fatigue, prolonged task durations, and high perceived exertion. These challenges, often overlooked in low-resource agricultural systems, were shown to contribute directly to the high prevalence of MSDs, productivity losses, and physical discomfort among rural labourers. The redesigned tools, developed using Nigerian-specific anthropometric data and simulated using SolidWorks and Finite Element Analysis (FEA), were tested under realistic field conditions and demonstrated significant improvements across all ergonomic metrics. Reductions in REBA scores, muscle activity (%MVC), task duration, and RPE scores validate the hypothesis that ergonomic design can mitigate MSD risks. Thus, H_0 (that redesign would have no significant effect) was rejected in favour of H_1 (that it would reduce strain and improve performance).

However, the study is not without limitations. It was geographically restricted to southwestern Nigeria and focused on short-term trials without long-term follow-up on tool adoption, wear resistance, or user satisfaction over time. Furthermore, adaptation challenges were observed among older users, suggesting that training or gradual introduction strategies may be needed for widespread adoption. From a policy and implementation standpoint, the study reinforces the need for locally standardised ergonomic guidelines. Specifically, national agencies (e.g., NASC, FMARD) could integrate anthropometric data into the standardisation of farm tool dimensions; support extension programs that include ergonomic training for farmers; and incentivise local manufacturers through subsidies or partnerships to produce and distribute improved designs.

Future research should explore the long-term adoption and cost-effectiveness of redesigned tools, assess tool performance across different climatic zones, and investigate gender-sensitive design adaptations to address the unique ergonomic needs of female farmers. A cross-regional anthropometric database could also improve inclusiveness in future ergonomic interventions across sub-Saharan Africa. In sum, this study demonstrates the feasibility of bridging simulation-based design and field ergonomics to tackle persistent health and productivity issues in smallholder agriculture. By prioritising human factors in tool design, Nigeria's farming sector can transition toward safer, more efficient, and more inclusive labour practices. The study offers a replicable framework that can guide similar innovations across the continent.

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