Design, Development, and Validation of Ergonomic Farming Tools to Enhance Safety and Efficiency

1.0 Introduction

Farming is one of the most labor-intensive and hazardous work, demanding significant physical effort and posing risks of musculoskeletal disorders (MSDs) and occupational injuries. While technological advancements are transforming farming practices globally, most tools and equipment still lack ergonomic and technological designs tailored to the diverse physical requirements of the agricultural workforce, particularly women farmers (Singh S. , Work Load of Farm Women in Livestock Activities and Their Musculoskeletal Disorders' Symptoms, 2017; Kolstrup, 2012). The physical demands of repetitive tasks such as digging, shoveling, and bending exacerbate these risks, contributing to significant health challenges, lost productivity, and economic burdens (Davis & Kotowski, 2007; Rosecrance, Rodgers, & Merlino, 2006).

Historically, farming tools, including shovels, pitchforks, and tillers, were designed for average male users, neglecting the anatomical and physiological differences of women who are in average shorter and have less strength (Verma & Chaudhary, 2021). This ergonomic mismatch has led to increased risks of injury and discomfort among women farmers, who often represent a significant proportion of the agricultural workforce in small-scale and family farming operations (Madinei & Nussbaum, 2023). These challenges underscore the importance of integrating ergonomic principles and advanced technologies into the design and evaluation of farming tools and equipment.

Emerging technologies, such as electric tillers, auxiliary handles, and autonomous systems, present transformative opportunities to enhance safety and efficiency in agriculture. Electric tillers, for instance, offer reduced vibration and quieter operation compared to traditional gas-powered models but often lack ergonomic adjustability tailored to women's physical characteristics (Naeini, Karuppiah, Tamrin, & Dalal, 2014; Madinei & Nussbaum, 2023). Similarly, auxiliary handles have shown promise in reducing trunk flexion and wrist deviation during repetitive tasks like shoveling and raking, but their designs often prioritize universal applicability over task-specific functionality and user-specific needs (Mohammed-Thariq, Ravi-Hansika, & Mohammed-Irfeey, 2022; Koopman , Kingma, Faber, De Looze, & Van Dieen, 2019).

2.0 Literature Review: Ergonomic Farming Tools for Women Farmers

Despite the significant presence of women in agriculture, most farming tools remain poorly adapted to their physiological and ergonomic needs. Existing studies highlight the prevalence of musculoskeletal disorders (MSDs) due to prolonged exposure to repetitive movements, heavy loads, and tools that fail to accommodate women's anthropometric differences (Banibrata, 2013; Madinei & Nussbaum, 2023). While some research has explored ergonomic interventions, these studies often focus on general agricultural ergonomics rather than gender-specific modifications (Singh & Arora, 2010). Universal ergonomic interventions have been applied in various agricultural contexts to improve tool usability and reduce injury risk. Previous studies have assessed general improvements in agricultural tools such as anti-vibration handles, lightweight tool design, and adjustable features to accommodate a broad range of users. For example, (Thota, Kim, Freivalds, & Kim, 2022) developed an attachable anti-vibration handle that reduced hand-arm vibration exposure across different farming tools. Similarly, Freivalds (1986) explored tool handle modifications that improved grip efficiency, reducing wrist and shoulder strain across various farming implements (Freivalds, 1986b).

While universal ergonomic interventions have improved the usability of farming tools, they often fail to address the specific needs of women farmers, who differ from their male counterparts in stature, upper body strength, and biomechanical movement. Studies confirm that most agricultural tools are designed for the average male user, requiring higher force exertion from women, leading to inefficient work postures and increased fatigue and injury risks (Singh & Arora, 2010). A study on female rice farmers found that 99% reported musculoskeletal discomfort, with 94% experiencing chronic lower back pain due to excessive bending and tool mismatch (Banibrata, 2013). Women’s lower upper-body strength and shorter stature make handling long, heavy, or oversized tools particularly challenging (Madinei & Nussbaum, 2023). Traditional hand tools, such as shovels, pitchforks, and hoes, do not accommodate women’s average grip span, height, and strength levels, leading to excessive energy expenditure and muscle fatigue (Koopman , Kingma, Faber, De Looze, & Van Dieen, 2019).

One major research gap is that gender-specific ergonomics is largely ignored in farming tool designs. Most agricultural tools have been developed based on male anthropometry, failing to consider women's stature, grip strength, and biomechanics (Madinei & Nussbaum, 2023). The limited adjustability in tool designs further exacerbates the problem, as auxiliary handles and ergonomic modifications exist but often lack the necessary height, angle, and rotational adjustability, leading to inefficiencies and new ergonomic risks (Koopman , Kingma, Faber, De Looze, & Van Dieen, 2019). Additionally, current ergonomic studies rely on observational assessments, lacking real-time AI-driven motion analysis for precise posture and muscle strain evaluation (Eskandari, Ghezelbash, Shirazi-Adl, Arjmand, & Lariviere, 2024).

In terms of power tools, previous research has focused on improving tillers by incorporating ergonomic refinements such as adjustable handles, vibration-dampening technology, and smart automation features. Mahajan compared gas-powered and electric tillers, highlighting that gas-powered tillers generate high-vibration exposure, contributing to hand-arm vibration syndrome. Prolonged exposure to vibrating farm tools leads to chronic back pain and grip strength loss, affecting long-term health outcomes for farm operators (Naeini, Karuppiah, Tamrin, & Dalal, 2014). While electric tillers offer ergonomic advantages such as lower vibration, lighter weight, and reduced noise levels, many designs still lack adjustability for different users. Poorly designed electric tillers suffer from stability issues, requiring ergonomic refinements such as adjustable handles to optimize usability (Mahajan, et al., 2024).

One approach to addressing these challenges has been the introduction of auxiliary handles, which provide a secondary grip point, allowing users to maintain a more upright posture while reducing wrist and back strain. Studies on auxiliary handle designs have shown that they can significantly reduce musculoskeletal strain by improving grip control and reducing awkward postures. (Mohammed-Thariq, Ravi-Hansika, & Mohammed-Irfeey, 2022), found that auxiliary handles improve tool control and reduce wrist strain, making them beneficial for prolonged tool use. However, trade-offs in elbow strain require optimized placement for task-specific use (Davis & Kotowski, 2007). Despite their benefits, most commercial auxiliary handles are designed for universal applications, limiting their effectiveness for women farmers. Another critical research gap lies in biomechanical and mechanical validation. Few studies quantify mechanical advantages, torque, and stress distribution in tool designs, leading to limited scientific validation of ergonomic improvements (Beer, Johnston, DeWolf, & Mazurek, Mechanics of Materials, 8th Edition, 2020). Without biomechanical assessments, many ergonomic modifications lack empirical backing, making it difficult to determine their actual benefits in reducing strain and improving efficiency.

This study fills these gaps by systematically designing, developing, and evaluating ergonomic farming tools tailored specifically for women farmers. Unlike previous research that applies universal ergonomic principles, this study directly addresses the needs of women farmers by evaluating the ergonomic impact of standard versus redesigned farming tools including shovels, pitchforks, gas tillers, and electric tillers using motion tracking and biomechanical modeling. The development and testing of ergonomic auxiliary handles with adjustable grip angles and height settings aim to improve usability for diverse anthropometric profiles. Additionally, by comparing gas-powered versus electric tillers with a focus on vibration exposure, user control, and fatigue levels in women farmers, this research provides quantitative data on how modified tools improve posture, reduce musculoskeletal load, and enhance safety.

2.1 Goal

This study aims to develop and validate ergonomic farming tools to improve work safety and improve efficiency for women farmers. The detailed objectives are as follows:

2.1.1 Objectives

Objective 1: Assess ergonomic challenges in shovels, pitchforks, auxiliary handles, and electric tillers using AI-powered ergonomic analysis and validated assessment tools.

Objective 2: Quantify physical strain, vibration, and postural risks associated with farming tasks, analyzing the impact of tool design factors including handle height, lift angles, and grip effort.

Objective 3: Design and develop improved ergonomic solutions, including adjustable auxiliary handles and enhanced electric auger tillers with ergonomic handles, motor-wheel adjustments, and automation features.

Objective 4: Evaluate redesigned tools through field trials with women farmers, collecting physiological and ergonomic data to validate improvements and refine designs.

Objective 5: Promote the adoption of ergonomic tools by sharing findings through workshops, publications, and partnerships with manufacturers to ensure scalability and accessibility for women farmers.

3.0 Methodology

Identifying Ergonomic Challenges in Farming Tools: To identify ergonomic challenges associated with commonly used farming tools, this study will utilize motion tracking, biomechanical analysis, and ergonomic risk assessment tools including the Rapid Upper Limb Assessment (RULA) and the Rapid Entire Body Assessment (REBA). These methods have been widely applied in ergonomic studies to assess postural risks in manual labor-intensive tasks (Davis

& Kotowski, 2007; McAtamney, & Corlett, 1993). AI-powered motion tracking software, including TuMeke and Inseer Ergonomics, will be used to analyze joint angles, muscle strain, and repetitive motion patterns among women farmers, following similar methodologies adopted in previous agricultural ergonomics research (Madinei & Nussbaum, 2023).

Additionally, validated ergonomic tools including the Ovako Working Posture Analysis System (OWAS) will be applied to assess work-related musculoskeletal disorder (MSD) risks, as successfully used in studies evaluating ergonomics in rice farming (Banibrata, 2013). Anthropometric measurements will be collected to compare tool dimensions with user body proportions, following the approaches of (Singh & Arora, 2010), who assessed mismatches between tool designs and female anthropometry in agricultural tasks. The findings from this assessment will inform the design modifications required to enhance tool usability and reduce strain.

Measuring Physical Strain, Vibration, and Postural Risks in Farming Tasks: Quantifying the physical strain and ergonomic inefficiencies of existing farming tools requires a combination of biomechanical, physiological, and vibration exposure assessments. Studies such as those by (Eskandari, Ghezelbash, Shirazi-Adl, Arjmand, & Lariviere, 2024)) have successfully used wearable sensors and motion capture systems to measure postural load in agricultural workers. Joint angle measurements, captured through high-speed video analysis, will be used to assess musculoskeletal strain in the hip, shoulder, elbow, and wrist, as applied in previous tool evaluation studies (Koopman et al., 2019).

Hand-arm vibration exposure (HAV) and whole-body vibration (WBV) assessments will be conducted using tri-axial accelerometers to monitor vibration levels of gas and electric tillers, following ISO 5349-1 standards, as seen in previous studies on power tools in agriculture (Brensinger, 2020). Electromyography (EMG) sensors will be used to measure muscle fatigue and force exertion while handling different tools, applying methodologies used in evaluating ergonomic risks in tiller operation (Naeini, Karuppiah, Tamrin, & Dalal, 2014). Grip strength will be analyzed using a digital dynamometer, considering the variations in handle diameter and grip force requirements, a factor often overlooked in agricultural tool design (Mohammed-Thariq, Ravi-Hansika, & Mohammed-Irfeey, 2022). These assessments will help determine the ergonomic inefficiencies in tool design and provide data to guide improvements.

Designing and Developing Ergonomic Solutions for Farming Tools: Building on the findings of Objectives 1 and 2, ergonomic modifications will be implemented using a user-centered design (UCD) approach, incorporating anthropometric data, biomechanical analysis, and iterative prototyping. The development process will leverage Computer-Aided Design (CAD) software, including SolidWorks, to model adjustable auxiliary handles and ergonomic electric tiller enhancements, a technique successfully applied in designing optimized agricultural hand tools (Freivalds, 1986a; Jirapongsuwan, et al., 2023)

Prototypes of adjustable auxiliary handles will be fabricated using 3D printing technology, following the iterative design methods used in previous ergonomic tool development (Eskandari, Ghezelbash, Shirazi-Adl, Arjmand, & Lariviere, 2024). These handles will feature adjustable grip angles, height settings, and rotational flexibility to reduce strain on the wrist, elbow, and lower back, optimizing force distribution as recommended in previous auxiliary handle research (Koopman , Kingma, Faber, De Looze, & Van Dieen, 2019).

For electric tillers, the motor-wheel adjustments will focus on integrating height-adjustable handles and smart vibration-dampening mechanisms to improve user control and reduce HAV exposure. Auger-based rotary tiller modifications will be validated against existing tine-based tillers, following methodologies from previous studies evaluating alternative soil tillage systems (Madinei & Nussbaum, 2023). To improve usability, automation features such as gyroscopic sensors for balance control and real-time IoT-based monitoring of vibration and battery levels will be integrated, drawing inspiration from recent research on smart agricultural tools (Mahajan, et al., 2024). The prototypes will undergo stress testing and mechanical validation using torque and flexural stress analysis (Beer, Johnston, DeWolf, & Mazurek, 2020), ensuring safety and durability before field trials.

Field Trials and Validation of Ergonomic Tool Prototypes: The study focuses on enhancing farming safety and efficiency by evaluating three electric tiller prototypes: the Tine Electric Tiller (RYOBI 40V HP Brushless Rear Tine Tiller 16-inch and 18-inch Rear Tine Tiller) and the Auger Electric Tiller (a patented rotary tiller system developed by Dr. Aaron M. Yoder of Green Heron Tools). The three tillers will be evaluated for their ability to reduce physical strain, and musculoskeletal strain (MSD) and improve usability for women farmers, focusing on vibration and noise exposure, postural strain, and usability improvements. then integrate adjustable handle inclinations, smart automation features, and motor-wheel adjustments to enhance comfort and efficiency into the auger prototype.

Mechanical metrics will involve measuring load weights with a digital scale to ensure consistency across trials. The torque generated by the tools at various lift and rotation angles will be calculated using standardized formulas (Beer, Johnston, DeWolf, & Mazurek, Mechanics of Materials 8th Edition, 2020; Hibbeler, 2016). For lift torque:

180° Rotation:

$$T = F.r \quad (1)$$

45° Rotation:

$$Tlift = F \cdot r \cdot cos(\theta lift) \quad (2)$$

and for combined torque:

$$Tcombined = F \cdot r \cdot cos(\theta lift) \cdot sin(\theta rotation) \quad (3)$$

Where T_{lift} is Torque due to lift angle, F is the applied force, r is the distance from the auxiliary handle to the fulcrum, and θ_{lift} (16°, 32°, 48°) and $\theta_{rotation}$ represent the lift and rotation angles, respectively.

Stress analysis will further evaluate the mechanical performance of the prototypes. Flexural stress (σ) will be calculated using the formula (Budynas & Nisbett, 2015):

$$\sigma = M \cdot \frac{c}{I} \quad (4)$$

where M is the bending moment (F.L), c is the distance from the neutral axis, and I is the moment of inertia for a handle diameter (circular section).

$$I = \frac{\pi d4}{64} \quad (5)$$

The redesigned tools will be tested in real-world agricultural environments using a participatory ergonomic evaluation framework. Field trials will be conducted with a diverse group of women farmers, mirroring the task-based evaluation approach used in previous studies assessing ergonomic farming tools (Madinei & Nussbaum, 2023; Singh & Arora, 2010). Participants will perform repetitive agricultural tasks, including digging, lifting, tilling, and raking, using both conventional and redesigned tools. Joint motion and postural risks will be assessed using AI-based pose estimation software (output example shown in Fig.1), replicating methods successfully applied in ergonomic intervention studies for agricultural hand tools.

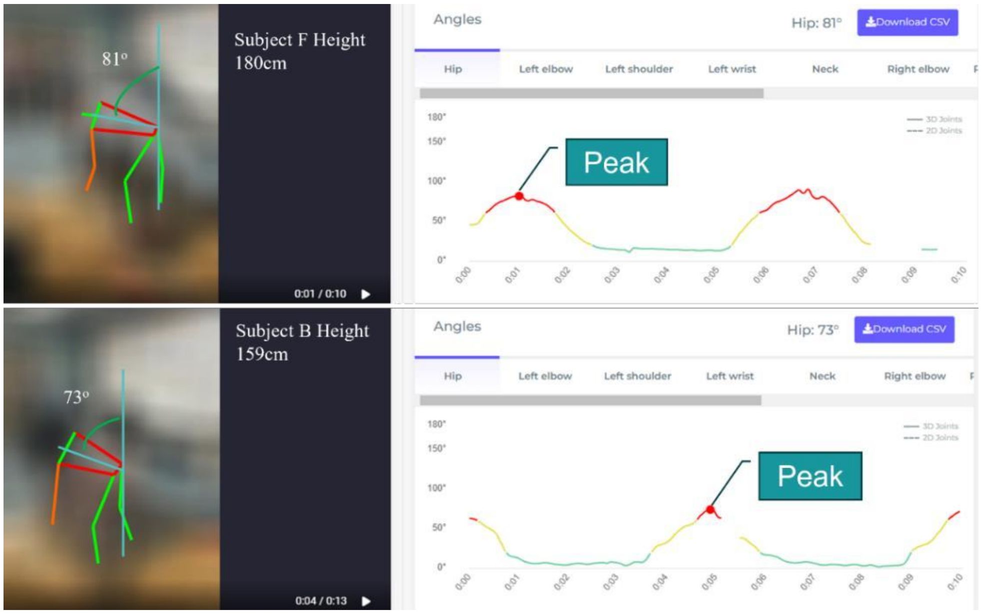

Fig. 1 Comparison of Hip Angles for Subject A (Top) and Subject B (Bottom) during the use of pitchfork 6. Subject A exhibits a greater maximum hip flexion angle (81°) compared to Subject B (73°), indicating more strain on the hip joint for this subject.

Physiological strain indicators including heart rate, oxygen uptake, and energy expenditure will be measured using wearable biometric sensors, applying methodologies used in evaluating workload reduction in mechanized farming (Banibrata, 2013). Participants perceived exertion levels will be recorded using the Borg Rating of Perceived Exertion (RPE) scale, a widely used metric in ergonomic tool assessments (Borg G. , 2016). User feedback will be collected through structured interviews and usability questionnaires, ensuring that the modified tools align with task-specific needs and comfort preferences, a critical factor in ergonomic tool adoption (Mohammed-Thariq, Ravi-Hansika, & Mohammed-Irfeey, 2022). Statistical analysis, including two-way ANOVA, will be performed to compare differences in joint angles, vibration exposure, and fatigue levels between the conventional and ergonomic tool designs.

Dissemination and Adoption of Ergonomic Farming Tools: To maximize real-world impact, findings from this study will be disseminated through multiple channels to reach researchers, policymakers, agricultural extension officers, and manufacturers. Knowledge-sharing activities will include farmer workshops, Academic publications, interactive training sessions, and instructional videos demonstrating the benefits and usage of ergonomic farming tools. Similar dissemination methods have proven successful in increasing technology adoption in rural agriculture. Fig. 2 The Flowchart represents a systematic methodology for evaluating the ergonomic performance of agricultural tools.

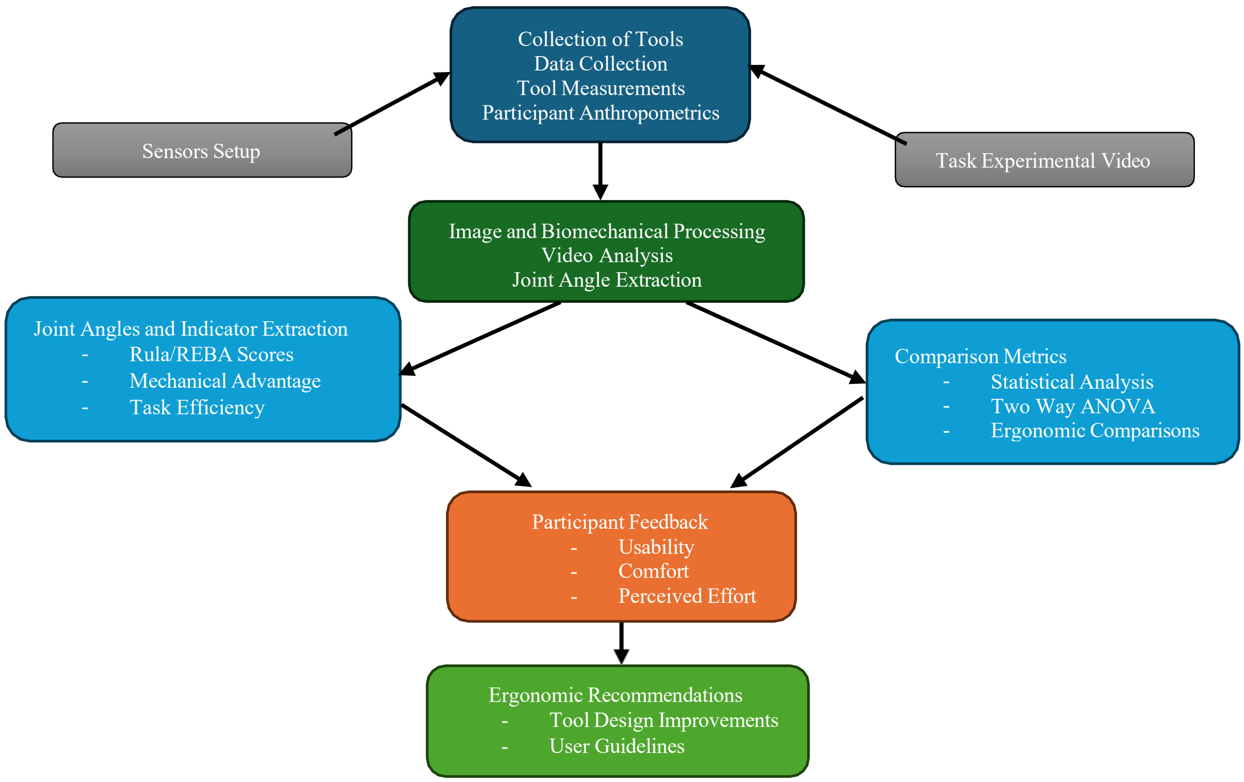

Fig. 2 Summary of Ergonomic Evaluation Process

4.0 Preliminary Work and Current Progress

The research has made significant advancements, with Study 1, Study 2, and Study 3 completed, while field experiments for the developed ergonomic auxiliary handle (Study 3) are yet to be carried out. Additionally, Study 4 is currently in the planning phase, focusing on the evaluation of power tillers both gas and electric tillers.

4.1 Study 1: Ergonomic Evaluation of Scoop Shovels and Pitchforks (Completed)

This study began with a detailed physical measurement and evaluation of farming hand tools, including shovels and pitchforks, to identify ergonomic inefficiencies. The tools were analyzed based on weight, handle length, handle lift height, and handle lift angles, Fig. 3 defines and illustrates some of the parameters. These tools were used to systematically evaluate ergonomic performance across the experimental conditions, using anthropometric comparisons to determine mismatches with women farmers' biomechanics. AI-driven motion tracking and biomechanical modeling assessed joint angles and physical strain during agricultural tasks.

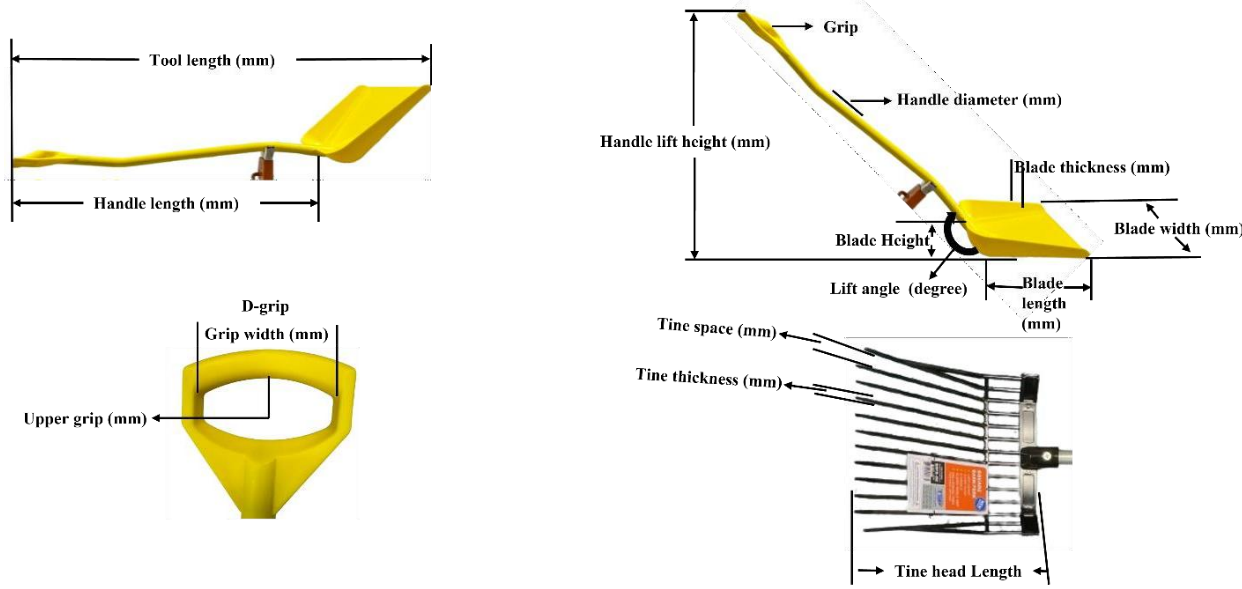

Fig. 3 Definition of part of the tool parameters for Shovel and Pitchfork. Selected parameters are important to indicate the ergonomic impact.

Findings revealed excessive hip flexion angles (54° ± 7.2°) and wrist deviations, leading to fatigue and discomfort. Additionally, mechanical advantage analysis showed that ergonomic modifications improved force efficiency by up to 14%, justifying the need for improved tool designs. These measurements were supplemented with detailed observations of tool interaction, focusing on comfort, usability, and perceived effort. Effort arm (E.a) and resistance arm (R.a) lengths were measured to analyze the leverage provided by each tool. The mechanical advantage (M.A.) of the tools was calculated using the formula:

$$M.A = E.a/R.a \qquad (6)$$

where: M.A. = Mechanical advantage, E.a = Effort arm, R.a = Resistance arm.

This analysis provided insights into the efficiency of each tool design in reducing user effort during repetitive tasks, illustrated in Fig. 4, where the agricultural shovel is represented as a third-class lever.

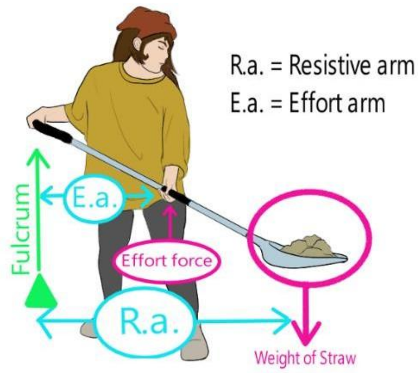

Fig. 4 Illustration of mechanical advantage analysis of a shovel. The weight of the straw was used as a load

4.2 Study 2: Ergonomic Effects of Auxiliary Handles on Hand Tools (Completed)

Building upon Study 1, this phase assessed commercially available auxiliary handles to determine their effectiveness in reducing musculoskeletal strain. Controlled experiments at the MU Equine Teaching Facility tested two auxiliary handles on shovels and pitchforks, the EAHA (RAH! Handle), designed to promote an upright posture and reduce trunk bending, and the EAHB (BackEZ Ergonomic Handle), aimed at minimizing wrist and shoulder stress while facilitating a natural arm position Fig. 5 while Fig. 6 shows A side-by-side comparison of three postures using a conventional shovel, a shovel with the RAH! Handle, and a shovel with the BackEZ Handle highlighting the changes in hip flexion, wrist angles, and posture improvements.

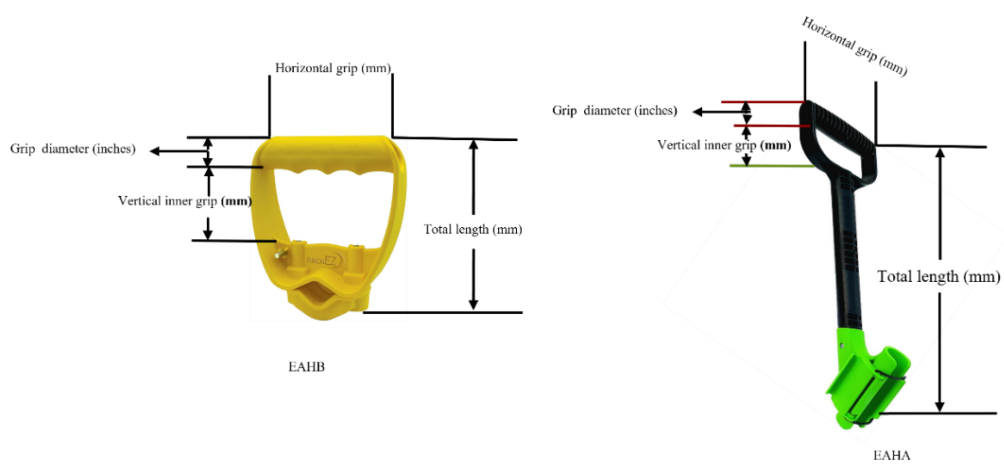

Fig. 5 Two auxiliary handles used in this study: EAHB (BackEZ handle) and EAHA (RAH! handle).

Anthropometric data, including height, elbow rest height, grip strength, and BMI, were recorded prior to the experiment (Table 1).

Table 1. Subjects' characteristics (n = 8)

Variables	Mean ± S. D	MAX	MIN
Subject Height (cm)	161.9 ± 5.05	168	153
Age (Years)	20.8 ± 1.39	22	18
Elbow rest height, Standing (cm)	100.2 ± 4.29	109	96.5
Hand height, standing (cm)	63.0 ± 2.75	66	58
Handbreadth (cm)	7.51 ± 0.22	7.87	7.14
Subject Weight (kg)	60.96 ± 7.15	74	51
Forearm-Forearm Breadth(ft)	1.41 ± 0.12	1.7	1.3
Shoulder height (cm)	135.4 ± 4.75	143	128
Average Left Grip Strength (kg)	26.1 ± 6.73	36	14
Average Right Grip Strength (kg)	28.50 ± 7.17	38	20
BMI (Body Mass Indexes)	23.5 ± 3.17	29	18.8

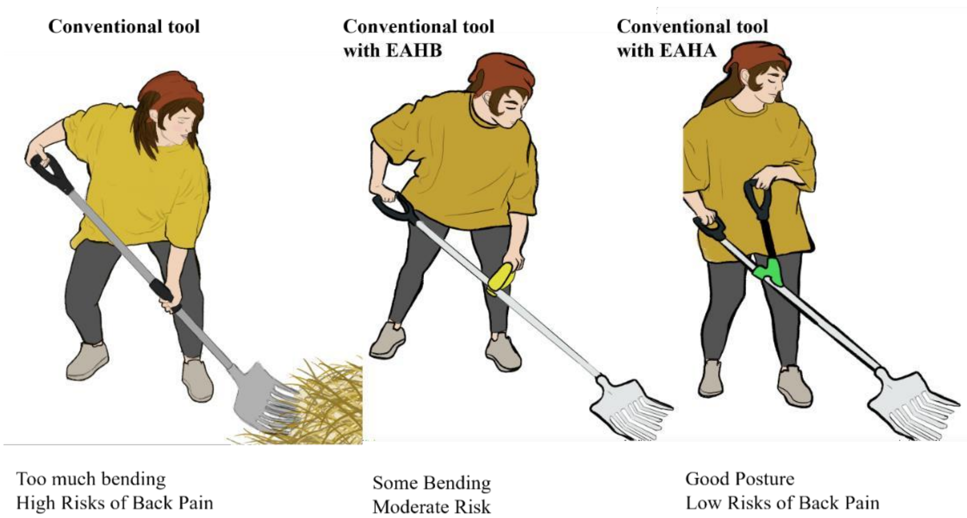

Fig. 6 Comparison of postures: User 1 (left) with a conventional tool shows high back pain risk; User 2 (center) with an EAHB handle shows moderate risk; User 3 (right) with an EAHA handle shows good posture and low back pain risk.

4.2.1 Qualitative Feedback and Observations

Participants provided qualitative feedback after each task through structured questionnaires. Feedback focused on perceived comfort, control, and physical exertion associated with each tool. The Borg CR-20 scale Table 2 was used to quantify participants' perceived exertion levels, integrating sensations of fatigue and stress into a single score. This feedback was critical for identifying user preferences and challenges, enabling iterative refinements of the auxiliary handle designs.

Table 2. Rating of Perceived Exertion (RPE) Scale and Descriptions

Rating of Perceived Exertion (RPE)	Description
6	No exertion, sitting and resting
7	Very, very light
8	Very, very light
9	Very light
10	Very light
11	Fairly light
12	Somewhat hard
13	Somewhat hard
14	Somewhat hard
15	Hard
16	Very hard
17	Very hard
18	Very, very hard
19	Extremely hard
20	Maximum Exertion (Borg, 1998)

The energy expenditure and physiological cost of these tasks were calculated using the formula provided by Varghese et al. (1994) (Kulkarni & Khakare, 2021; Varghese, Saha, & Atreya, 1994)

$$Energy\ expenditure\ (kJ \cdot min^{-1}) = 0.159 \times Average\ working\ heart\ rate\ (bpm^{-1}) - 8.72 \quad (7)$$

$$Cardiac\ Cost\ of\ Work = (Average\ Working\ Heart\ Rate - Average\ Resting\ Heart\ Rate) \times Duration\ of\ work \quad (8)$$

4.2.2 Data Analysis

The data were analyzed using statistical methods to identify significant differences in ergonomic and physiological outcomes between conventional and auxiliary-modified tools. One-way ANOVA was used to compare mean effort angles and physiological indicators across tasks and tool types. To pinpoint specific differences, post-hoc comparisons were conducted using Tukey's Honest Significant Difference (HSD) test. All statistical analyses were conducted using R version 4.3.1, with a significance level set at $p<0.05$.

Results indicated that auxiliary handles significantly reduced hip flexion (from 60° to 44°) and lowered overall back strain. However, the study also found that elbow effort angles increased, suggesting that while auxiliary handles improve posture, further refinements were needed to optimize usability and reduce upper limb strain.

4.3 Study 3: Development of Ergonomic Auxiliary Handles (Completed, Awaiting Field Testing)

Using insights from Studies 1 and 2, two novel ergonomic auxiliary handle prototypes were designed and fabricated. Prototype 1 featured a 180° rotational handle with height adjustability, in two increments of 20 mm (0.79 inches), providing a total adjustability of 40 mm (1.58 inches). This flexibility ensures that the tool can be tailored to users of varying heights and arm lengths. An integrated D-Grip handle with a Natural Inward Curvature (NIC) design further enhances grip comfort, minimizes wrist flexion, and aligns the wrist naturally Fig. 7 and Fig. 8 Additionally, the auxiliary handle has 3 versions with lift angles of 16°, 32°, and 48° respectively.

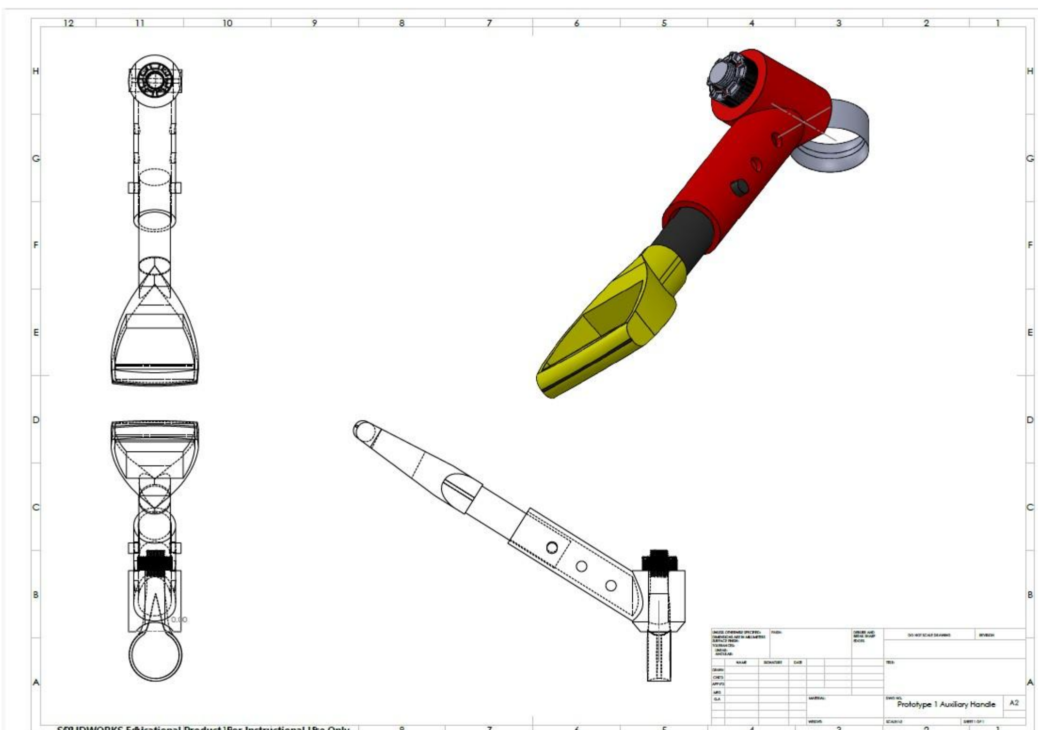

Fig. 7 Prototype 1: Auxiliary handle with 180° rotational clamps and adjustable height. This design will enable full rotational flexibility, promoting natural wrist alignment and might reduce strain during farming tasks.

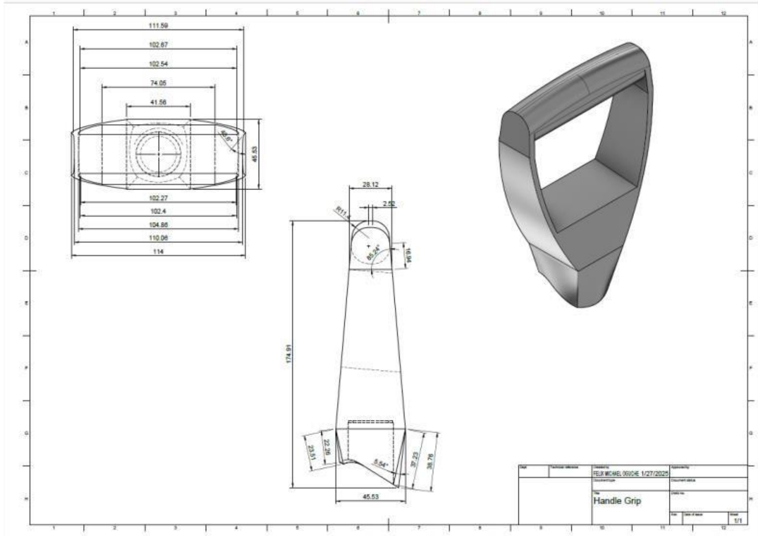

Fig. 8 Integrated D-Grip handle with Natural Inward Curvature (NIC) design. This ergonomic feature enhances grip comfort, minimizes wrist flexion, and allows for natural wrist alignment.

Prototype 2 incorporated a 45° lateral rotation design for better force distribution. rotational handle support with adjustable height, the handle height is adjustable in two increments of 20 mm (0.79 inches), providing a total adjustability of 40 mm (1.58 inches). This design enables dynamic wrist positioning, particularly for lateral wrist movements during repetitive tasks like shoveling and raking. The adjustable height increments mirror those of Prototype 1, ensuring compatibility with diverse anthropometric profiles. Like Prototype 1, it includes an integrated D-Grip handle. with the NIC design to improve wrist alignment and reduce strain Fig.9.

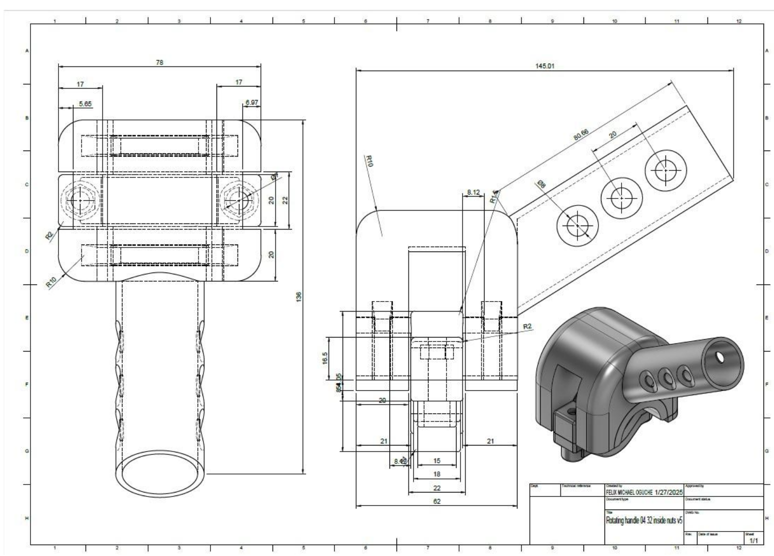

Fig. 9 Prototype 2: Auxiliary handle with 45° rotational support and adjustable height. This design allows for dynamic wrist positioning, reducing strain during lateral movements in farming tasks.

4.3.1 Prototypes 3 and 4:

Designed for straight-handled tools, both to be attached to the top handle to provide an additional grip point. It features a front-curved handle grip and a back-curved handle grip respectfully, the adjustable clamp mechanism accommodates tool handles of varying diameters, ensuring versatility across different tools Fig.10 Field testing with women farmers is yet to be conducted to validate real-world usability and effectiveness.

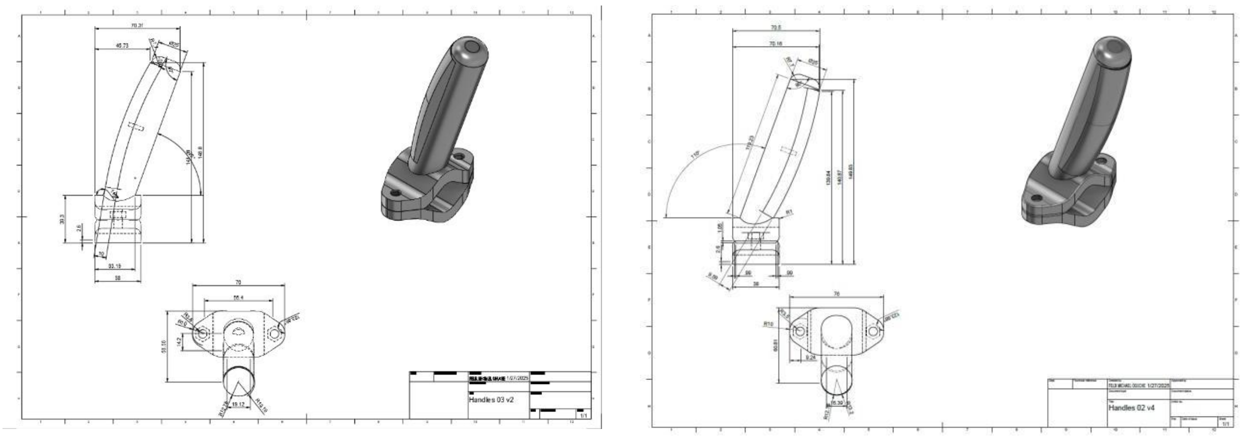

Fig. 10 Prototypes 3 and 4: Adjustable Auxiliary Handle attached to a straight-handled tool. This design provides an additional grip point, and an adjustable clamp mechanism accommodates tool handles of varying diameters.

4.4 Study 4: Ergonomic Electric Tiller Evaluation and Development (Development and Field-Testing Phase)

The auger system includes visual and auditory warnings, followed by a safe shutdown to protect the hardware. Additionally, programmable automation, powered by an Arduino Nano microcontroller, will enable task-specific customizations including depth and angle adjustments. Real-time feedback on vibration, sound, and operational metrics will further enhance usability and allow farmers to make informed decisions during tool operation Fig. 11 and Fig. 12.

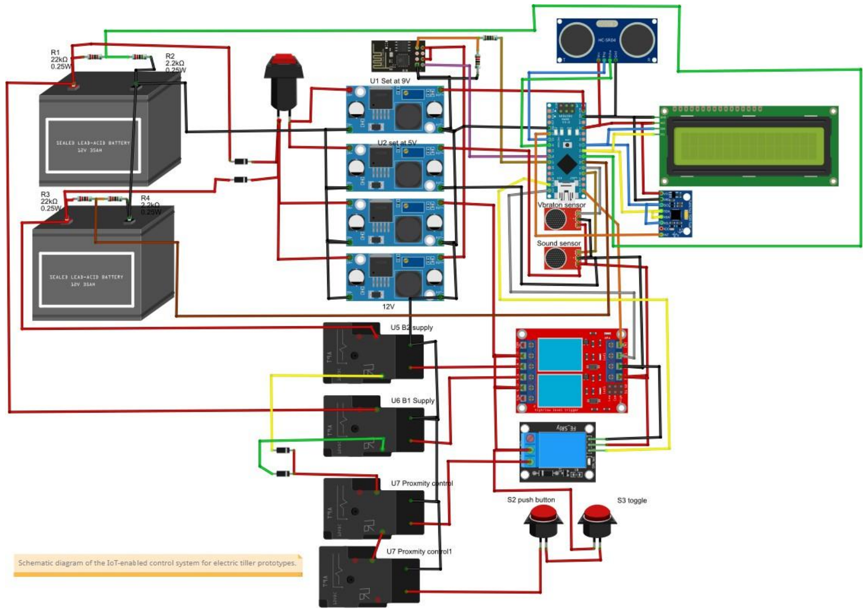

Fig.11 Schematic diagram of the IoT-enabled control system for electric tiller prototypes. This system integrates sensors, dual-battery management, and automation for monitoring and enhancing performance during agricultural tasks.

Fig. 12 The Auger Electric Tiller, with improvement. It features real-time feedback on vibration, sound, and operational metrics, along with visual and auditory warnings followed by a safe shutdown mechanism to enhance usability and safety for farmers.

5.0 Manuscripts/Abstracts Submitted

Manuscript Title: Quantitative Assessment of Farming Hand Tools: Camera-Based Analysis of Postural and Mechanical Parameters for Reducing Physical Strain in Women Farmer

Manuscript Title: Ergonomic Effects of Auxiliary Handles of Hand Farming Tools on Women

Abstract Title: *Design and Fabrication of Ergonomic Auxiliary Handles for Agricultural Tools*

- **Conference:** ASABE Annual International Meeting 2025

Abstract Title: *Development and Optimization of an Upgraded Walk-Behind Electric Tiller for Enhanced Farming Efficiency and Safety*

- **Conference:** International Society for Agricultural Safety and Health (ISASH) 2025

5.1 Conferences Attended and Presentations

- **ASABE Annual International Meeting (2024) – Oral Presentation Title:** *Ergonomic Evaluation of Scoop Shovels and Pitchforks: Impact on Women in Agriculture*
- **ISASH Conference (2024) – Oral / Poster Presentation Title:** *Ergonomic Benefits of Auxiliary Handles on Scoop Shovels and Pitchforks for Women Farmers*
- **Midwest Agricultural Engineering Conference (2023) – Poster Presentation Title**: *Optimizing Tool Ergonomics for Farmers: Development of Adjustable Auxiliary Handles for Reduced Strain*

5.2 Engagements

- **Focus group meeting 2023**: *Engage with the stakeholders, facilitate surveys, and showcase our farm safety project.*
- **Show-Me Farm Safety exhibit at the Missouri State Fair in Sedalia (Trade fair 2024) and 2024 Agribusiness Summit and Expo at The Exchange at Wall Street Cattle Company in Lebanon, Missouri:** *Engage with the public, facilitate surveys, and showcase our farm safety project. Throughout the event, we interacted with attendees, raising awareness about farm safety and gathering valuable feedback through surveys.*

5.3 Grant Proposal Summary

- Improving Farming Safety and Efficiency by Adopting Electric Tillers (Submitted to Heartland Center for Occupational Health and Safety February 2025)

- Developing Ergonomic Auxiliary Handles for Hand Farming Tools to Reduce Musculoskeletal Disorders (To be submitted to GPCAH Pilot Grants in May 2025)

5.4 Educational Materials Under Review

Several educational materials aimed at promoting ergonomic awareness among women farmers are currently under review. These include a flyer (Ergonomics in Hand Tools: Shovels and Pitchforks for Women Farmers), a booklet (Ergonomics in Hand Tools for Women Farmers), and a trifold brochure (Ergonomic Safety in Hand Tools: Using Shovels and Pitchforks the Right Way). Additionally, three educational videos - Introduction and Benefits of Ergonomic Tools, Choosing and Using Ergonomic Tools, and Auxiliary Handles and Proper Posture for Injury Prevention, are in the review process. A dedicated website, FarmTechForHer, has also been developed and is under review to provide accessible resources, research updates, and practical guidance on ergonomic tool use.

6.0 Next Steps

- Conduct field testing for the ergonomic auxiliary handle prototypes in real-world farming environments.
- Finalize experimental protocols for Study 4.
- Perform large-scale validation of ergonomic modifications, collecting biomechanical, physiological, and user experience data.
- Disseminate findings through academic publications, workshops, educational material, video, website, and industry collaborations to promote adoption.

7.0 Expected Results

This research is expected to reduce musculoskeletal strain and improve work efficiency for women farmers through ergonomic tool design. AI-powered assessments will identify high-risk postures and quantify exposure duration, informing targeted interventions. Improved tools with optimized handle height and grip size are anticipated to lower physiological strain, energy expenditure, and perceived exertion. Adjustable handles and lightweight designs should enhance usability, leading to increased adoption. Field trials will validate these improvements, demonstrating efficiency gains and positive user feedback. Additionally, workshops and publications will raise awareness, while collaboration with manufacturers will support large-scale production and long-term accessibility of ergonomic farming tools.

8.0 Timeline

Table 3: Timeline of the Research Dissertation

From	To	Research Activity
Year 1		
August 2023	December 2023	Baseline data collection for **Study 1** (ergonomic evaluation of farming tools); ergonomic assessment for **Study 2** (auxiliary handles).
January 2024	June 2024	Field trials for **Study 2** (auxiliary handle prototypes); prototype design and initial development for **Study 3** (electric tiller).
July 2024	October 2024	Data analysis and tool refinements for **Study 1**, **Study 2**, and **Study 3**; assessment of ergonomic outcomes and user feedback.
November 2024	December 2024	**Study 4**: Ergonomic of electric tiller prototypes with adjustable handles, inclination angles, and motor improvements.

From	To	Research Activity
Year 2		
January 2025	February 2025	Integration of smart sensors and automation features into electric tiller prototypes for **Study 3** and **Study 4**; initial field validation.
March 2025	May 2025	Comprehensive analysis of ergonomic, vibration, noise, and physiological data for all studies (1–4).
June 2025	August 2025	Dissemination of findings for **Study 2** (auxiliary handles), **Study 3** (electric tillers), and **Study 4** (advanced tiller prototypes); application for further funding.
September 2025	October 2025	Extended field trials for **Study 3** and **Study 4**; validation of tools under real-world conditions.
November 2025	December 2025	Refinement and scaling of prototypes for **Study 2**, **Study 3**, and **Study 4**; publication of findings in journals and industry reports.
Year 3		
January 2026	February 2026	Final field trials for all tools, including auxiliary handles and electric tillers; ergonomic and safety data analysis.
March 2026	April 2026	Preparation of dissertation chapters and manuscripts for publication covering **Studies 1–4**.
May 2026	June 2026	Dissertation defense and dissemination of findings through workshops, conferences, and collaborative outreach.

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