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"Ergonomic Assessment and User-Centered Redesign of Traditional Corn Farming Tools: A Comprehensive Review of Biomechanical Health Risks, Socioeconomic Factors, and Technological Innovations in Smallholder Systems"

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Fonteyne (2023) explored the traditional milpa system of Mesoamerica, describing a suite of manual implements used in polyculture maize farming, such as hoes, dibblers, and hand knives. These tools, often crafted from wood, forged iron, or cane, were not just technical objects but cultural artifacts adapted to intercropped and uneven field conditions. Fonteyne emphasized that the material and design of these tools were shaped by local ecological contexts, creating ergonomic patterns that influenced posture and labor distribution. This foundational inventory of traditional implements serves as a reference for later ergonomic studies like Singh (2023) and Nerona (2023), which assess how these same tools affect body strain and movement efficiency during use.

Dhillon (2023) analyzed small-scale maize production systems and highlighted that manual tools—hoes, cutlasses, and seeders—remain dominant in low-resource farming communities. The study argued that tool selection is driven not only by technical efficiency but also by socio-economic constraints such as affordability, repairability, and the availability of local materials. Dhillon's findings reveal that economic accessibility determines ergonomic adoption, reinforcing Boakye's (2023) argument that technological interventions must align with farmers' socio-economic realities to achieve sustainable impact.

Araya et al. (2024) examined the integration of conservation agriculture (CA) practices in sub-Saharan Africa and discussed how traditional implements like hoes and cutlasses were adapted for reduced-tillage systems. The study concluded that tool geometry and material composition often limited CA effectiveness, as short handles and heavy blades encouraged poor posture and fatigue. These design constraints align with Negi (2025), who advocates ergonomic redesigns based on farmer anthropometry, and Singh (2023), who quantifies physiological impacts of tool use on operator performance.

The TAAT Maize Technology Catalogue (2021) documented both traditional and improved manual implements used in African maize production, including lightweight hoes and hand planters. The catalogue provides practical insights into ongoing innovations in tool materials, such as the use of light alloys and treated wood, to reduce strain and improve efficiency. TAAT's compilation forms a technical bridge between descriptive tool inventories like Fonteyne (2023) and the empirical ergonomics analyses of Singh (2023) and Thokchom (2024), both of which experimentally validate improved tool designs.

Nerona (2023) conducted an applied ergonomic study developing improved hand tools for small-scale maize farmers. The research focused on modifying handle length, grip curvature, and blade geometry to reduce musculoskeletal discomfort. Field trials showed notable improvements in user comfort and reduced fatigue during repetitive tasks. Nerona's practical findings operationalize the anthropometric recommendations of Negi (2025) and physiologic assessments of Singh (2023), demonstrating how ergonomic interventions can transform traditional tools without compromising cultural familiarity.

Sileshi (2025) emphasized the importance of local material sourcing and tool fabrication for sustainable agricultural development. Reviewing organic-input and localization practices, Sileshi concluded that farmer acceptance of new implements depends on whether tools can be built and maintained with available materials such as bamboo, timber, or scrap metal. This aligns with TAAT (2021) and Dhillon (2023), suggesting that the success of ergonomic innovations is tied to local production capacity and not just to functional design.

Boakye (2023) provided econometric evidence that the introduction of improved manual seeders and hand planters increases maize yields among smallholders in South Africa. However, Boakye cautioned that adoption is contingent upon tool cost and user familiarity, underscoring the socio-economic dimension of technology diffusion. His results complement the ergonomic findings of Singh (2023) and Nerona (2023), linking design and physiological improvements to measurable productivity gains.

Snapp (2022) analyzed how field variability—soil structure, slope, and microclimate—shapes tool effectiveness. The study found that in rough or uneven plots, traditional dibblers and hoes often outperform mechanical tools due to their adaptability and control. Snapp's conclusions explain the persistence of traditional implements despite ergonomic shortcomings and reinforce Araya's (2024) observation that environmental conditions must guide tool redesign.

Singh et al. (2023) carried out an ergonomic field evaluation of a manually operated maize planter, measuring physiological indicators such as heart rate and oxygen consumption. The results revealed that handle configuration and tool weight directly influence operator strain and efficiency. This study established empirical metrics that serve as design targets for ergonomic prototyping, connecting biomechanical outcomes to the human-centered redesigns of Nerona (2023) and Negi (2025).

Negi et al. (2025) advanced this discussion by collecting anthropometric data from hill-region farmers to establish specific handle diameters, grip tapers, and tool lengths suited to their body dimensions. Their quantitative recommendations provide a scientific foundation for redesigning traditional tools like sickles, forks, and khurpis. Negi's anthropometric framework extends Singh's (2023) physiological analyses and gives concrete specifications for future ergonomic prototypes.

Thokchom (2024) designed and tested a combined maize planter–vermicompost applicator optimized for terraced fields. The implement's lightweight metal frame and wooden handles addressed ergonomic and material-accessibility issues, ensuring local manufacturability. Thokchom's multifunctional approach links with TAAT (2021) and Boakye (2023), suggesting that integrated, cost-efficient designs enhance usability and adoption.

The "Manually Operated Maize Planter" study by Kumar et al. (2023) further examined the interaction between operator technique and tool geometry, offering detailed documentation of planter parts and materials. It bridges design-oriented studies (TAAT, Negi) with physiological analyses (Singh, Nerona), showing how ergonomic adjustments in handle positioning can enhance both comfort and seeding precision.

Chahal (2021) compared traditional and redesigned hand tools through field trials, posture scoring, and time-efficiency tests. Results showed that longer handles and contoured grips reduced workload and improved posture stability. These findings provide quantitative evidence supporting the later ergonomic refinements seen in Negi (2025) and Singh (2023).

Tiwari (2021) provided a detailed typology of hand-weeding tools such as crescent hoes, wheel hoes, and chisel weeders, assessing trade-offs between field capacity, energy use, and ease of maintenance. His analysis guides prototype selection in ergonomic redesign projects like that of Alcantara's corn-farming tools and complements Singh (2023) and Fonteyne (2023) by linking tool geometry with biomechanical performance.

Finally, Mantilla et al. (2025) explored how subjective comfort perceptions correlate with measurable grip pressure and handle dimensions. The findings highlight that psychological comfort is an essential ergonomic parameter, connecting human-centered usability (Nerona 2023) with the anthropometric principles outlined by Negi (2025). This integration underscores the holistic nature of ergonomic tool design for traditional agriculture.

Usage patterns and task analysis in smallholder corn production

Villaver et al. (2021) surveyed smallholder maize households in the Philippines and mapped out task division and frequency across the cropping season. Their data show that while some heavy tasks (land clearing, ploughing) are occasionally mechanized or animal-assisted, planting, weeding, crop care, and harvesting remain largely manual and are performed repeatedly throughout the season. The household division of labor implies that tools must be usable by different ages and genders, and that the most urgent ergonomic targets are the high-frequency tasks (planting and weeding) that create cumulative exposure.

The Philippine Yellow Corn Industry Roadmap of Department of Agriculture (2021) documents that planting and harvesting are labour-intensive operations for corn producers in the Philippines and that many smallholders cultivate plots under 1 ha where full mechanization is impractical. The roadmap highlights seasonal peak labor demands (planting and harvest windows) and suggests that low-cost, portable implements that save time during those peaks could increase adoption — a direct policy link to designing simple ergonomic tools that fit small-plot systems.

Asfaw (2024) reviewed constraints and opportunities in Ethiopian maize systems and emphasized that labor availability and task sequencing (land prep → planting → multiple weedings → fertiliser application → harvest) determine both productivity and tool choice. Because weed control often requires repeated passes, Asfaw argues that weeding tools that reduce bending and repetitive motion could deliver outsized benefits in labor-scarce seasons; this highlights the need to prioritize ergonomic redesign for high-frequency, high-exposure tasks.

Negewo's (2023) review of weed science in Ethiopian maize draws attention to the fact that weed pressure and the chosen control method (manual hoeing, mechanical weeding, herbicide) substantially change labor profiles: fields managed with manual weeding required many person-days across the season. The paper underscores that task frequency (how many times fields are hoed) is a crucial input for ergonomic evaluations, suggesting that prototypes should be tested for both short bursts of intense work and for long cumulative workloads across weeks.

Gachoki et al. (2023) used panel agronomic data in Ghana and Malawi to show that management choices (row planting, intercropping, fertilizer timing) directly affect labor allocation — for example, row planting often increases labor during planting (more precise placement) but reduces later weeding labor if paired with timely management. Their findings imply that tool interventions should be considered together with technique changes (e.g., supporting row planters with ergonomic handles to mitigate higher short-term labor demands).

Gong et al. (2024) developed machine-vision methods for detecting maize rows to support automated weed removal; while a technical paper, it has direct implications for human tasks by clarifying which parts of weeding farmers do manually (interrow vs intrarow). The work helps task analysis by identifying where human dexterity is most needed (near plants) and where mechanized or ergonomic tools could be most effective (open interrows). This distinction helps prioritize ergonomic redesign toward precise, plant-safe tools.

Mashaba-Munghemezulu, Chirima, and Munghemezulu (2021) examined the spatial and temporal patterns of smallholder maize farms using multi-temporal Sentinel-1 satellite data to support agricultural monitoring and sustainability efforts. Their research revealed that smallholder maize plots are often highly fragmented and vary widely in size and location, reflecting the heterogeneity of rural agricultural systems. Such fragmentation affects how farmers organize their fieldwork — planting, weeding, and harvesting occur in multiple small plots, increasing travel time and reducing operational efficiency. This spatial variability also contributes to inconsistent postures and repetitive start–stop motions during manual tasks. From an ergonomic standpoint, this implies that traditional tools must be lightweight, portable, and adaptable to small, irregular plots. For farmers in Alcantara, Cebu, similar field fragmentation may intensify fatigue and increase musculoskeletal strain, underscoring the need for user-centered design that accommodates small, discontinuous work areas.

Cecil et al. (2023) conducted a cross-country analysis across Zambia, Malawi, and other African regions to determine how much control smallholder maize farmers have over crop yields under varying management, environmental, and socioeconomic conditions. Using a process-based modeling approach combined with household-level data, the study found that yield variation is not only driven by weather and soil factors but also by human decision-making and labor allocation. Farmers' task planning — when to plant, weed, or apply fertilizer — directly influences yield outcomes, yet many are constrained by limited tools and labor availability. These findings emphasize that understanding task timing and workload distribution is critical for improving both productivity and farmer well-being. In the context of ergonomic tool design, such insights highlight the importance of aligning tool functionality with farmers' decision cycles and seasonal workload peaks, ensuring that implements reduce time pressure and physical burden during high-labor periods like planting and weeding.

Aysegül Tanin and Engindeniz (2024) analyzed the economic aspects of grain maize production in Türkiye, focusing on input costs, labor intensity, and profitability. Their study revealed that manual labor remains a dominant cost component in small-scale maize production, particularly during sowing and harvesting. Although mechanization could enhance efficiency, smallholders often rely on traditional tools due to financial constraints and small field sizes that are unsuitable for large machinery. The researchers concluded that the high dependence on manual labor requires targeted improvements in hand tools to enhance both productivity and worker comfort. For Alcantara's farmers, these economic findings reinforce the idea that ergonomic improvements can serve a dual purpose: reducing physical strain and lowering production costs through time efficiency. Designing affordable, user-centered tools adapted to local crop management practices could therefore have significant economic and ergonomic benefits for smallholder corn producers.

Biomechanical loads & musculoskeletal outcomes in farming

Teo (2021) used inertial measurement units (IMUs) combined with surface electromyography (sEMG) to quantify muscle activation and joint ranges during banana fresh-fruit-bunch harvesting. The paper demonstrated how repetitive overhead and asymmetric postures produce elevated trapezius and deltoid activations and linked specific motion patterns to likely sites of MSD (shoulder, neck). By providing a clear method for combining kinematics and EMG, Teo sets a methodological benchmark for later crop-specific biomechanical studies and underscores that measurable, task-specific muscle loads must inform ergonomic tool redesigns.

Building on the IMU+sEMG approach, Roggio et al. (2022) evaluated portable agricultural equipment and measured sEMG responses in young operators performing static and dynamic tasks. They found that different portable tools produced distinct muscle-activation signatures and fatigue trajectories, indicating that even small equipment changes (weight distribution, handle shape) materially alter biomechanical loads. Roggio's device-level insights naturally extend Teo's task-level mapping: once you know which muscles are overloaded in a task, you can test how design changes alter that overload in the field.

Poochada (2022) synthesized evidence on MSD prevalence among plantation agricultural workers and highlighted that prolonged repetitive postures, heavy lifting, and pushing/pulling are consistently associated with high MSD rates. Their review emphasized that prevalence data correlate with the objective EMG/IMU findings in Teo and Roggio — where muscle activation and posture studies predict the epidemiology seen in plantation cohorts — and pointed to the need for interventions targeting the most common high-load tasks (repeated stooping, overhead work, heavy carrying).

Akbar (2023) provided a regional systematic review of work-related musculoskeletal disorders among farmers in Southeast Asia, quantifying very high prevalences of low-back, shoulder, and knee pain. The work linked risk factors to task types (weeding, transplanting, carrying), reinforcing Poochada's global prevalence findings and signaling that local cultural and practice differences (tool use, load carriage methods) must be considered when interpreting biomechanical measures across sites.

Shivakumar (2024) produced a systematic review and meta-analysis of MSDs in agricultural workers in low- and middle-income countries and confirmed that low-back pain is the most frequently reported MSD (often >50% 12-month prevalence). Importantly, Shivakumar synthesised evidence connecting specific biomechanical exposures (stooping time, frequency of heavy lifts) to pain outcomes, offering quantitative effect sizes that bridge field biomechanics (Teo, Roggio) and population health (Akbar).

Jirapongsuwan et al. (2023) tested community ergonomic interventions (tool redesign and training) and evaluated their effectiveness at reducing WMSD symptoms in agricultural populations. Their randomized/controlled field trials showed reductions in self-reported pain and improvements in some functional outcomes following ergonomic tool changes — an intervention-level counterpart to the exposure-level studies, demonstrating that reducing measured muscle load and awkward posture can translate into meaningful health improvements.

Gao et al. (2022) investigated orchard worker fatigue using ECG and other physiological signals during harvesting tasks, finding objective markers of fatigue that correlated with task duration and postural demands. Gao's physiological-fatigue measures align with the EMG and kinematic patterns reported by Teo and Roggio, providing convergent biometric evidence (heart rate variability + EMG) that long work bouts and awkward postures produce both neuromuscular fatigue and systemic stress — important when designing prototypes to reduce not only local muscle load but cumulative physiological strain.

Kim (2024) measured upper- and lower-limb muscle activation across 19 "green-care" farming activities using sEMG and showed that activities requiring sustained arm elevation or repeated gripping produced the highest upper-limb %MVC values. Kim's mapping of activity → %MVC complements Teo's crop-specific work and is directly useful when selecting target tasks in Alcantara (e.g., planting vs harvesting) for which prototypes should be tested to lower %MVC in overburdened muscles.

Kumari (2023) examined push–pull tasks typical in agricultural settings using EMG and found that muscle activation increased with applied load and that beyond certain thresholds tasks become difficult or unsafe. Kumari's experimental load-response curves are invaluable because they provide pragmatic thresholds (force levels) for safe manual tool operation — data that tool designers can use to set weight/force targets for seeders, wheel-hoers, or push-type implements.

Le (2024) evaluated the biomechanical impact of arm-support exoskeletons (ASEs) in simulated agricultural tasks and reported reductions in shoulder and upper-back muscle activation but also noted trade-offs (changes in balance, increased load elsewhere). Le's exoskeleton work highlights technological solutions that can reduce measured muscle load (per Roggio, Kim) but also cautions that assistive tech must be assessed for whole-body biomechanical consequences, not just local muscle relief.

Wang (2023) analyzed how harvesting height influences biomechanical load and found that incorrect harvesting height increases trunk flexion and lumbar loading, substantially elevating low-back injury risk. This height-specific finding connects directly to Shivakumar and Akbar's low-back prevalence work by showing a clear, modifiable ergonomic parameter (harvest height) whose adjustment can reduce lumbar load in routine tasks.

Gao (2022) and Wang's height findings point toward prevention; Ellestad (2024) — while not agriculture-exclusive — quantified muscle activation during loaded-carry tasks and demonstrated that trunk and hip musculature engagement increases nonlinearly with carried load. Ellestad's biomechanics of loaded carriage maps directly onto common farm activities (water/bag carrying, produce transport) that the prevalence studies (Poochada, Akbar, Shivakumar) repeatedly identify as MSD risk factors, producing concrete load targets for interventions (limits, resting schedules).

Beseler (2023) used occupational injury surveillance data to explore the intersection of injury, MSD symptoms, and psychosocial stressors in agricultural workers. Their analysis showed that biomechanical risk is compounded by stress and that recovery outcomes worsen when biomechanical loads are coupled with poor psychosocial conditions. Beseler's findings expand the purely biomechanical picture (EMG, kinematics) by showing the multi-factorial nature of MSD outcomes — reminding designers that reducing biomechanical load is necessary but not sufficient for lasting health gains.

Rubin (2024) studied head-load carriage in smallholder populations and measured physiological and perceptual responses, showing that head loads (traditional carrying methods) significantly raise neck/trunk muscle activation and perceived exertion. Rubin provides culturally relevant load-carriage evidence that complements Ellestad's loaded-carry mechanics, and suggests that tool or load-carriage redesign (e.g., panniers, ergonomic baskets) could materially lower neck/trunk MSD burden in contexts like Alcantara.

Finally, a recent methodological advance by Alcan (2023) reviewed developments in surface EMG technology and signal processing — improvements that make field-based muscle-load assessment more reliable and portable. Alcan's methods review closes the loop: better field measurement (IMU + sEMG + ECG) — as used by Teo, Roggio, Kim, Gao — produces higher-quality exposure data that directly yields better-targeted ergonomic interventions and more defensible claims about reductions in biomechanical load and MSD risk.

Biomechanical analysis towards corn arming

Azmon (2021) evaluated maize seeding ergonomics by comparing the conventional hand-sowing method with a lightweight motorized maize seeder. Using observational posture scoring and simple physiological measures, the study showed the seeder increased work rate and reduced awkward stooping and squatting during sowing, implying lower cumulative biomechanical load on the lower back and knees. Azmon's device-level findings emphasize how modest mechanization can change the body-level exposure profiles that later studies quantify with EMG or IMUs; they therefore form a practical link to more instrumented human-biomechanics assessments and to design comparisons of seeders.

Chaudhary (2021) performed an ergonomic evaluation of a walking-type power-operated maize stalk harvester versus traditional manual cutting. The paper reported posture changes, reduced repetitive bending, and lower hand-tool forces when the walking harvester was used — but also flagged new intermittent loads (machine handling, carrying), shifting rather than eliminating biomechanical risk. Chaudhary's results complement Azmon's seeder study by showing that whether mechanization reduces or redistributes loads depends on implement design and task context, a theme echoed later in studies of implement–crop contact and stalk biomechanics.

López-Gómez (2024) designed and compared two maize seeder concepts (robot-compatible vs robust/simple designs) and evaluated their functional performance. Although primarily focused on machine performance, their QFD-driven design comparison considered operator interaction (handling, coupling, maintenance) as a design criterion, linking implement usability to operator biomechanical exposure. López-Gómez therefore acts as the bridge between device performance metrics and human ergonomic outcomes: a seeder that performs well but is awkward to handle can increase musculoskeletal load despite better agronomic placement.

DeKold (2023) examined sources of experimental error in in-field biomechanical phenotyping of maize stalks, demonstrating that small misplacements in load-cell height or device position can produce large errors in measured bending stiffness and strength. This methodological caution has direct design implications: if implement designers or ergonomists use stalk strength metrics to set tillage or cutting forces, they must rely on precise phenotyping protocols; otherwise, implement interaction with stalks (and resultant operator forces during cutting/harvesting) may be misestimated. DeKold's methodological work therefore underpins plant–implement biomechanical studies used to estimate operator loads.

Carter (2024) quantified the shear modulus and mechanical properties of maize stalk tissues, separating rind and pith contributions. By producing repeatable measures of stalk resistance to torsion and shear, Carter provides the crop-side biomechanical constants needed to model forces experienced by cutting tools and operators during harvesting. In combination with DeKold's error analysis, Carter's data enable more accurate simulations of tool–stalk interaction forces that are later felt by human operators and measured in ergonomics studies like Chaudhary's.

Tabaracci (2024) described a biomechanical phenotyping pipeline for stalk lodging (failure) traits, offering higher-throughput ways to measure stalk bending and failure. Tabaracci's pipeline ties stalk mechanical vulnerability to field operations: fragile stalks may require gentler handling or different cutting angles, and implement design must account for within-field variability in stalk strength — another reason why human biomechanical load can vary even for nominally identical tasks. Thus Tabaracci links plant variability to both implement design (López-Gómez) and operator exposure

Lohani & Rana (2024) investigated maize shelling ergonomics among women farmworkers and compared conventional, improved, and modified hand tools using OWAS, RULA, and physiological measures. They found the modified tool substantially reduced cardiovascular and musculoskeletal strain while increasing throughput. This human-centered, task-specific evidence complements the mechanistic plant/implement work (Carter, Tabaracci) by showing how small changes in hand-tool geometry and task sequence mitigate biomechanical load at the operator level. It also reinforces Azmon and Chaudhary's finding that redesigns can reduce cumulative exposure if they consider real workflow.

K. Wang (2021) reviewed combine-harvester losses for maize and discussed machine settings, rotor speeds, and cutting heights that influence crop damage and operator handling tasks. Although the paper emphasizes crop loss, its practical implication is biomechanical: machine settings that increase ear or stalk damage often require manual re-work (bending, stooping, lifting) and therefore greater operator biomechanical exposure post-harvest. Wang's review thereby connects large-scale mechanization choices to on-the-ground human loads that ergonomics studies record.

Devi (2024) developed a manually-operated maize planter-vermicompost applicator for narrow terraces and described ergonomic considerations (weight, handle length, materials) to improve farmer comfort during planting. Devi's prototype work is the practical counterpart to López-Gómez's design comparisons: it demonstrates how simple, low-cost implements can be optimized to reduce repetitive stooping and carrying loads in constrained terraces, highlighting that biomechanical benefits can be achieved with context-appropriate engineering.

Balbaa (2022) investigated maize morphological traits (height, stalk thickness) under stress and their relations to lodging and ease of harvest. Balbaa's agronomic-biomechanical perspective matters for operator load because shorter, more brittle stalks or those with atypical morphology change the required cutting forces and operator postures during harvest. This agronomic–biomechanical link means that ergonomic interventions must be integrated with crop management recommendations to fully reduce operator load.

Sun (2024) analyzed the impact of mechanization level on maize planting efficiency and costs; while economic in focus, the study reported ergonomic indicators such as reductions in person-hours and shifts in task composition when mechanization increases. Sun's work connects macro-level mechanization choices to micro-level biomechanical outcomes, showing that adoption of certain machines can greatly reduce cumulative manual exposure but may introduce localized handling loads — reinforcing Chaudhary and Wang's points about load redistribution.

DeKold (companion study / 2023 methodological) — closing the loop, a companion methodological note (see DeKold's broader 2023 work) underscores that integrating crop biomechanics (Carter, Tabaracci) with human ergonomics (Azmon, Lohani) requires cross-disciplinary measurement: synchronized data from stalk tests, implement force sensors, and operator sEMG/IMU produce the complete exposure picture. This methodological synthesis is crucial: without precise, aligned measurements you cannot credibly claim a prototype reduces true biomechanical load across the crop–implement–operator system.

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