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Ergonomic Evaluation and Optimization of Agricultural Machinery for Women Farmers

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Abstract

Women constitute a substantial share of the agricultural labor force in Africa, yet the tools and machinery available to them are mostly designed based on male anthropometric norms; this imposes avoidable musculoskeletal risk and drudgery. This study evaluated the ergonomic compatibility of four commonly used farm implements, a traditional hoe, a manually operated groundnut harvester, a knapsack sprayer, and a cassava frying/garri-processing station. It considered the anthropometric and postural needs of women farm operators, and tested a set of dimensional optimizations intended to reduce musculoskeletal risk. One hundred and fifty (150) women farm operators aged 20–55 years in south-western Nigeria were anthropometrically measured across sixteen body dimensions, and postural risk during machine operation was assessed using the Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) methods, complemented by the Standardized Nordic Musculoskeletal Questionnaire (NMQ) and an Overall Discomfort Rating (ODR, Borg CR-10 scale). Anthropometric analysis showed that there is a substantial mismatch between machine dimensions and the accommodating range of females; between 24% and 88% of operators fell outside the recommended fit envelope for individual interface parameters. Based on dimensional optimization of handle height, grip diameter, working height, and load distribution, mean REBA scores fell from 7.7 ± 1.0 to 4.4 ± 0.7, and mean RULA scores fell from 6.1 ± 0.9 to 3.8 ± 0.6 in a one-way ANOVA and paired t-test, $p < 0.00$. Musculoskeletal discomfort that had prevailed for 12 months fell across all nine body regions assessed by the NMQ. It was most notable in the lower back from 74% to 35%, shoulders from 69% to 31%, and wrists/hands from 61% to 22%. The results showed that the redesign of machine operator interfaces can measurably reduce musculoskeletal risk and drudgery among women farmers. The study proposes a replicable ergonomic optimization protocol for extension and manufacturing use.

Keywords: Ergonomics, Optimization, Women, Agricultural machinery

Kadın Çiftçiler İçin Tarım Makinelerinin Ergonomik Değerlendirmesi ve Optimizasyonu

Özet

Afrika'daki tarımsal iş gücünün önemli bir kısmını kadınlar oluşturmaktadır; ancak kadınların kullanımına sunulan alet ve makineler çoğunlukla erkeklere özgü antropometrik normlara göre tasarlanmıştır. Bu durum, önlenebilir kas-iskelet sistemi risklerine ve ağır, yıpratıcı bir çalışma ortamına yol açmaktadır. Bu çalışma; geleneksel çapa, manuel yer fıstığı hasat makinesi, sırt tipi ilaçlama pompası ve manyok işleme (garri üretimi) istasyonu olmak üzere, tarımda yaygın olarak kullanılan dört farklı ekipmanın ergonomik uyumluluğunu değerlendirmiştir. Çalışmada, kadın çiftçilerin antropometrik ve duruşsal gereksinimleri dikkate alınmış; kas-iskelet sistemi risklerini azaltmayı amaçlayan bir dizi boyutsal optimizasyon test edilmiştir. Nijerya'nın güneybatısında yaşayan, 20–55 yaş aralığındaki 150 kadın çiftçinin on altı farklı vücut ölçüsü alınmış; makine kullanımı sırasındaki duruşsal riskler, "Hızlı Üst Uzuv Değerlendirmesi" (RULA) ve "Hızlı Tüm Vücut Değerlendirmesi" (REBA) yöntemleriyle analiz edilmiştir. Bu değerlendirmeler, "Standart İskandinav Kas-İskelet Sistemi Anketi" (NMQ) ve "Genel Rahatsızlık Derecelendirme" (ODR, Borg CR-10 ölçeği) ile desteklenmiştir. Antropometrik analizler, makine boyutları ile kadınların vücut ölçüleri arasında ciddi bir uyumsuzluk olduğunu; operatörlerin %24 ila %88'inin, incelenen çeşitli arayüz parametreleri için önerilen uygunluk sınırlarının dışında kaldığını ortaya koymuştur. Tutma kolu yüksekliği, kavrama çapı, çalışma yüksekliği ve yük dağılımı gibi unsurlarda yapılan boyutsal optimizasyonlar sonucunda; ortalama REBA puanları 7,7 ± 1,0'dan 4,4 ± 0,7'ye, ortalama RULA puanları ise 6,1 ± 0,9'dan 3,8 ± 0,6'ya düşmüştür (tek yönlü ANOVA ve eşleştirilmiş t-testi, $p < 0,00$). NMQ ile değerlendirilen dokuz vücut bölgesinin tamamında, son 12 aydır hissedilen kas-iskelet sistemi rahatsızlıklarında azalma gözlemlenmiştir. Bu azalma özellikle bel bölgesinde %74'ten %35'e, omuzlarda %69'dan %31'e ve el bilekleri/ellerde %61'den %22'ye düşüşle kendini göstermiştir. Elde edilen sonuçlar, makine operatör arayüzlerinin yeniden tasarlanmasının, kadın çiftçilerde kas-iskelet sistemi risklerini ve çalışma yükünün ağırlığını ölçülebilir düzeyde azaltabileceğini kanıtlamıştır. Çalışma, tarımsal yayım hizmetlerinde ve imalat süreçlerinde uygulanabilecek, tekrarlanabilir bir ergonomik optimizasyon protokolü önermektedir.

Anahtar kelimeler: Ergonomi, Optimizasyon, Kadınlar, Tarım makineleri.

INTRODUCTION

Women are responsible for a large share of the labor that sustains smallholder agriculture in Africa; they often engage in land preparation, planting, weeding, harvesting, and post-harvest processing. Despite this central role, the design of agricultural hand tools and machinery is usually developed based on anthropometric and biomechanical data derived from male operators. This mismatch between operator body dimensions and machine interface dimensions causes awkward posture, elevated musculoskeletal loading, and drudgery in women.

Work related musculoskeletal disorders (WMSDs) are among the most reported health problems in farming populations across Asia and Africa. In recent times, systematic evidence has confirmed that the low back, shoulders, and neck are the region's most consistently affected among farmers in the wider Southeast Asia region (Akbar *et al.,* 2023).

Gender differences compound this risk; women farmers and farm workers have consistently reported significant high frequencies of musculoskeletal discomfort than their male counterparts. These include the neck, shoulders, and wrists/hands regions; a pattern attributed in part to smaller body dimensions, lower grip strength, and repetitive, monotonous work patterns relative to poorly fitted equipment (Lunner Kolstrup, 2012). The need to assess ergonomics risk in agriculture has moved toward anthropometric characterization and the observation of postural-risk tools; these include the Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA), and standardized self-reported discomfort instruments such as the Nordic Musculoskeletal Questionnaire (NMQ). This helps to quantify risk and evaluate the effect of design interventions (Das, 2023; Kaewdok *et al.,* 2021).

In Nigeria specifically, anthropometric surveys of agricultural workers in the south-east have confirmed that female workers differ significantly from male workers across most body dimensions, and that both groups differ from the international reference data typically used by equipment manufacturers, reinforcing the need for population- and gender-specific design data (Oduma and Oluka, 2017; Obi *et al*., 2015). Comparable findings from smallholder contexts elsewhere in sub-Saharan Africa show that female-specific anthropometric databases are largely absent, even though hand-tool and machine dimensions derived from Western or male-normed data are demonstrably a poor fit for African women farmers (Mugisa *et al.,* 2016).

Anthropometry and Machine Design for Women Farmers

Anthropometric mismatch between operator and machine is a foundational cause of awkward posture and excessive biomechanical loading. Surveys of Nigerian agricultural workers show female operators to be consistently smaller than male operators across most standing and reach dimensions, with exceptions in a small number of dimensions such as hip breadth (Oduma and Oluka, 2017). Elsewhere in the region, anthropometric measurement of 89 women smallholder farmers in Uganda found that body-dimension prediction models developed for Western women could not be reliably applied to sub-Saharan African women, and that even within the region, Bantu and Nilotic ethno linguistic groups differed meaningfully from one another, underlining the need for locally generated design data rather than imported reference tables (Mugisa *et al.,* 2016).

Postural Risk Assessment in Agricultural Work

RULA and REBA remain the most widely applied observational postural-risk tools in agricultural ergonomics because they require no specialized equipment and can be scored from photographs or video of the operator at work. Reviews from different farm tasks found out that RULA and REBA are more discriminating than the Ovako Working posture Assessment System (OWAS) for machinery-related tasks. However, OWAS can perform better in some manual field operations that support the use of more than one tool where feasible (Das, 2023). The use of a camera that is AI-assisted in 3D is an emerging refinement of this approach: a recent evaluation of shovels with long handles and pitchforks used by women farmers found that tools with moderate handle lift angles between 27–56°, lift heights at elbow height, and mass under 2 kg produced lower peak hip and shoulder flexion. They

also had better RULA/REBA outcomes than designs that have heavier and steeper angles (SARE Grant Management System, 2026).

Self-Reported Discomfort and Gendered Risk

The Nordic Musculoskeletal Questionnaire is the most used report instrument for musculoskeletal symptoms that are work-related. Its structured body region format is well suited to be used when farm operators are illiterate and where they are administered by trained enumerators (Kuorinka *et al.*, 1987). When applied to dairy farm populations, the instrument showed that female workers report musculoskeletal discomfort at higher rates than male colleagues in the neck, shoulders, and wrists/hands. This was because a larger share of that discomfort was repetitive (Fathallah, 2010).

Despite the available evidence, ergonomic evaluation is rarely built into the design of agricultural machinery for women in Nigeria. Only a few studies combined anthropometric measurement and postural risk assessment of a designed interface in a single evaluation. This study addresses that gap by (i) characterizing the anthropometric profile of a sample of women farm operators in south-western Nigeria, (ii) quantifying the ergonomic mismatch between existing machinery and this profile, (iii) assessing postural risk and self-reported discomfort during operation of four representative implements, and (iv) testing whether targeted dimensional optimization of the machine-operator interface reduces measured risk and discomfort.

MATERIALS AND METHODS

Study Area and Participants

The study was carried out with farm operators who are women and drawn from rural farming communities in south-western Nigeria. One hundred and fifty (150) women aged 20–55 years with a mean of 34.6 ± 8.9 years; each with a minimum of two years' active involvement in farm operations, were purposively and randomly selected across the sampled communities. They were selected based on these criteria: active engagement in at least one of the four target operations, absence of any musculoskeletal condition, and willingness to provide informed consent. Ethical clearance and consent at the level were obtained prior to data collection, and all measurements and observations were conducted with participant confidentiality maintained throughout.

Machinery and Tasks Evaluated

Four (4) implements of agricultural tasks majorly performed by women in the study area were selected for evaluation: (i) the use of a traditional hoe for manual tillage, (ii) a manual groundnut harvester, (iii) a knapsack sprayer used for pesticide/herbicide application, and (iv) a cassava frying/garri processing station. These implements were chosen to cover static/postural load, dynamic/repetitive load, and carried/asymmetric load; these represent the principal categories of physical exposure reported for women in smallholder agriculture.

Anthropometric Measurement

Sixteen body dimensions relevant to machine interface design which include: stature, eye height, shoulder height, elbow height, hip height, knuckle height, sitting height, popliteal height, shoulder breadth, hip breadth, elbow-to-elbow breadth, hand length, hand breadth, maximum power-grip diameter, forward grip reach, and body weight were measured for each participant using a calibrated anthropo-meter, stadio-meter, and digital weighing scale. It followed the standard anthropometric survey procedure. Means, standard deviation, and 5th, 50th, and 95th percentile values were computed for each dimension to define the female-accommodating design range used.

Postural Risk Assessment (RULA and REBA)

Each participant was observed and recorded while performing her habitual task with the relevant implement under normal field conditions. Postures were scored independently by two trained assessors with the Rapid Upper Limb Assessment (RULA) method (McAtamney and Corlett, 1993) and the Rapid

Entire Body Assessment (REBA) method (Hignett and McAtamney, 2000). The discrepancies that were greater than one action level were resolved by joint review of the recording.

Musculoskeletal Discomfort and Overall Discomfort Rating

Self-reported musculoskeletal discomfort was assessed with a Standardized Nordic Musculoskeletal Questionnaire (NMQ) (Kuorinka *et al*., 1987). The questionnaire was translated to Yoruba for ease of comprehension among the illiterates; it recorded discomforts that have prevailed for 12 months across nine body regions. These regions include: neck, shoulders, upper back, elbows, wrists/hands, lower back, hips/thighs, knees, and ankles/feet. Immediately after each observed task session, participants also rated their overall perceived exertion on the Borg CR-10 Overall Discomfort Rating (ODR) scale, ranging from 0 (no discomfort) to 10 (extremely severe discomfort).

Ergonomic Optimization Procedure

For each implement, the existing interface dimension most implicated in postural risk, such as handle height, grip diameter, strap span and carried load, working height, and handle length as shown in Table 2, was compared against the 5th–95th percentile female-accommodating range. A recommended dimension was selected within this range, which is generally close to the 50th percentile while allowing sufficient tolerance for both smaller and larger operators. This was implemented on a modified prototype for each implement. All 150 participants then repeated their task with the use of the optimized configuration. RULA, REBA, NMQ, and ODR data were recaptured under identical observation and interview protocols to allow a direct before/after comparison on the same operator sample.

Statistical Analysis

Descriptive statistics of mean, standard deviation, and percentiles were computed for all the anthropometric and ergonomic variables. A one-way analysis of variance (ANOVA) was used to test for differences in pre-optimization REBA scores for the four tasks. Paired-samples t-tests were used to compare RULA and REBA scores and overall discomfort ratings before and after ergonomic optimization within each task. Statistical significance was set at $p < 0.05$. All analyses were performed in Python (SciPy 1.x).

RESULTS

Anthropometric Characteristics of Women Farm Operators

Table 1 is a summary of the sixteen (16) body dimensions that were measured for the 150 women farm operators sampled. Mean stature was 1512.9 mm, with an SD = 62.1 mm and a 5th–95th percentile range of approximately 1411–1613 mm, while mean body weight was 58.2 kg (SD 8.5 kg). Standing elbow height, a key reference dimension for handle and working-surface height, averaged 950.3 mm (5th–95th percentile: approximately 872–1031 mm). The anthropometric profile obtained for this sample of south-western Nigerian women farm operators is consistent with, but not identical to, previously reported values for Nigerian and other sub-Saharan African female agricultural populations. This reinforces the conclusion that machine dimensions cannot safely be transferred across regions or sexes without local verification (Oduma and Oluka, 2017; Mugisa *et al.*, 2016).

Table 1. Anthropometric dimensions of sampled women farm operators

Body Dimension	Mean	SD	5th %ile	50th %ile	95th %ile
Stature (standing height)	1512.9	58.4	1419.9	1514.7	1612.9
Eye height (standing)	1414.1	59.3	1326.9	1418.2	1515.6
Shoulder height (standing)	1243.0	52.2	1157.8	1242.0	1327.7
Elbow height (standing)	950.3	46.6	876.0	948.2	1031.3
Hip height	823.6	41.3	757.1	823.6	892.4
Knuckle height (standing)	702.0	33.2	649.2	701.0	758.2
Sitting height	799.3	33.0	743.2	801.5	853.9

Popliteal height (sitting)	396.7	25.2	356.1	397.8	434.3
Shoulder breadth	378.4	21.2	347.0	378.4	414.5
Hip breadth (sitting)	372.5	27.8	328.8	373.0	420.0
Elbow-to-elbow breadth	392.3	27.2	350.9	390.5	436.8
Hand length	172.7	8.3	158.6	172.7	186.5
Hand breadth	73.9	5.9	64.0	73.7	83.7
Grip diameter (max power grip)	40.9	4.9	32.1	41.0	47.3
Forward grip reach	695.1	37.5	634.9	694.6	757.8
Body weight (kg)	58.2	8.3	45.3	58.7	70.8

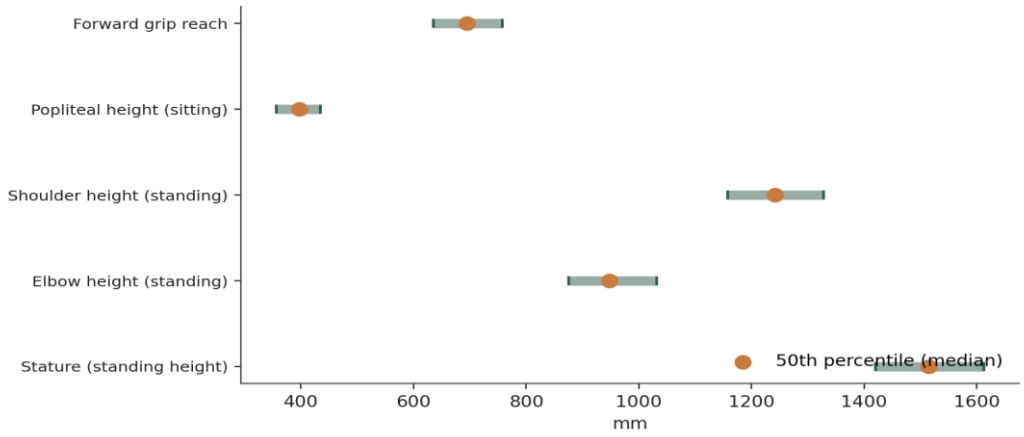

Figure 1. 5th–95th percentile range of selected anthropometric dimensions of the sampled women farm operators

Machines-Operator Interface Mismatch

Table 2 shows the comparison of existing dimensions of the machine against the accommodating range of female operators. The cassava frying/garri-processing station showed the largest mismatch, with an existing working (pan) height of 620 mm against a recommended elbow-height range of 760–955 mm, which leaves an estimated 88% of operators working below their optimal reach envelope and therefore in sustained forward-flexed trunk posture. The knapsack sprayer's full-load carried weight of 20 kg exceeded the recommended safe-carry range for 83% of operators, and its shoulder-strap span was too wide for 66% of the sample. From the level of mismatch documentation for the study, 88% of operators were outside the recommended fit envelope for a single interface parameter; this helps explain why the baseline REBA scores recorded here (mean 6.8–8.6 across implements) fall into the same high-risk range reported for other labor-intensive manual and semi-mechanized farm tasks in the literature (Das, 2023; Fathallah, 2010).

Table 2: Machine-operator interface mismatch

Machine	Interface Parameter	Existing	Recommended	Mismatched %
Manually operated groundnut harvester	Handle grip height (mm)	1050 mm	915 mm	71%
Manually operated groundnut harvester	Grip diameter (mm)	34 mm	36 mm	24%
Knapsack sprayer	Shoulder strap span (mm)	430 mm	372 mm	66%
Knapsack sprayer	Full load weight (kg)	20 kg	14 kg	83%

Cassava frying/garri processing pan station	Working (pan) height (mm)	620 mm	870 mm	88%
Cassava frying/garri processing pan station	Stirring paddle handle length (mm)	900 mm	1150 mm	79%
Traditional hoe (baseline)	Handle length (mm)	850 mm	1050 mm	74%

Postural Risk Assessment (RULA and REBA)

Table 3 presents mean RULA and REBA scores for each task before and after dimensional optimization. Before optimization, all four implements produced mean REBA scores in the high-risk band with score ≥ 7; cassava frying/garri station scored the highest with REBA 8.6 ± 0.8 and the knapsack sprayer lowest of the four with REBA 6.8 ± 0.7. After optimization, mean REBA scores fell into the medium-risk band (score 4–7) for all implements, and mean RULA scores fell below the action-level threshold of 4 for three of the four implements.

Table 3. Mean ± SD RULA and REBA scores per machine/task, before and after ergonomic optimization

Machine/Task	RULA (Before)	RULA (After)	REBA (Before)	REBA (After)
Traditional hoe (baseline)	6.4±0.6	4.2±0.5	8.1±0.9	4.8±0.6
Groundnut harvester	5.8±0.5	3.6±0.4	7.3±0.8	4.1±0.5
Knapsack sprayer	5.4±0.7	3.3±0.4	6.8±0.7	3.9±0.5
Cassava frying/ garri station	6.7±0.5	3.9±0.4	8.6±0.8	4.6±0.6

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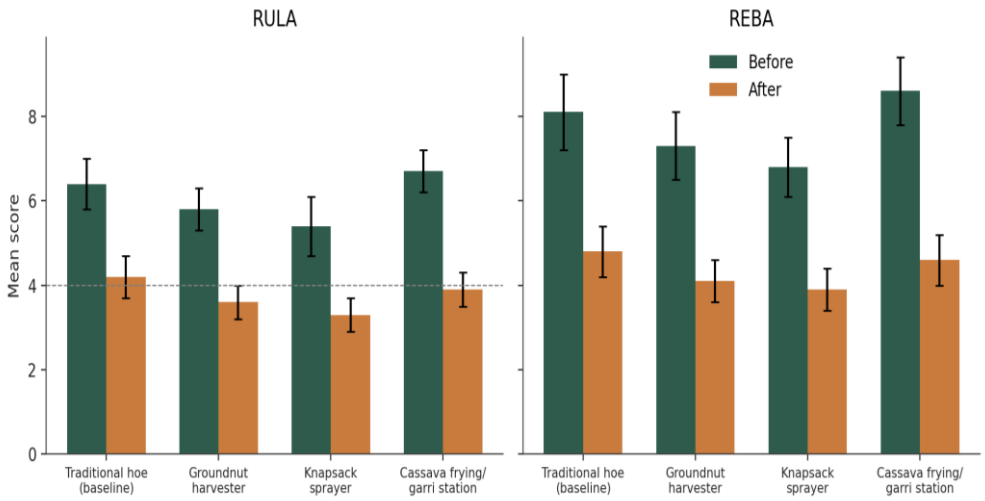

Figure 2. Mean RULA and REBA action scores per machine/task, before and after ergonomic optimization

A one-way ANOVA of pre-optimization REBA scores across the four (4) tasks showed a statistically significant difference of $F(3,116) = 32.01$, $p < 0.001$, which confirmed that postural risk varied by task; cassava frying/garri station and traditional hoe carried a significantly higher risk than the knapsack sprayer. A paired-samples t-test comparing pooled REBA scores before and after optimization for all machines showed a significant reduction at $t = 38.31$, $p < 0.001$, which indicates that the optimization of dimensions had a genuine improvement in postural risk not by chance.

Musculoskeletal Discomfort (NMQ)

Twelve-month musculoskeletal discomfort prevalence, reported with the use of NMQ, was highest at baseline in the lower back at 74%, shoulders at 69%, and wrists/hands at 61%. This pattern is consistent with continuous forward flexion during frying, repeated gripping during harvesting, and asymmetric carried load during spraying. After optimization, prevalence fell for all of the body regions assessed. Most remarkable was the lower back from 74% to 35%, a 39-percentage-point reduction, and the shoulders from 69% to 31%.

The pattern of discomfort by body region observed was concentrated in the lower back, shoulders, and wrists/hands; this mirrors findings from dairy farm populations, where female workers report significantly higher discomfort than male colleagues in precisely these regions, attributed to repetitive, monotonous work performed at a mismatched working height rather than to isolated heavy-lifting incidents (Lunner Kolstrup, 2012). This convergence from the different farming systems considered suggests that there is an underlying mechanism that is causing gendered ergonomic risk in agriculture.

Table 4. Twelve-month musculoskeletal discomfort prevalence (NMQ) among women farm operators, before and after ergonomic optimization

Body Region	Prevalence Before (%)	Prevalence After (%)
Neck	52	24
Shoulders	69	31
Upper back	58	26
Elbows	27	14
Wrists/Hands	61	22
Lower back	74	35
Hips/Thighs	33	18
Knees	41	22
Ankles/Feet	38	19

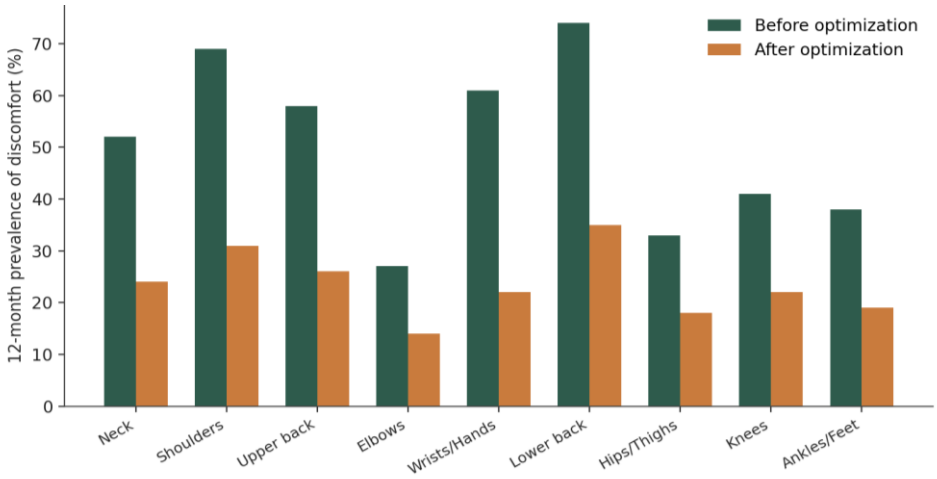

Figure 3. Musculoskeletal discomfort prevalence by body region (NMQ), before and after ergonomic optimization

Overall Discomfort Rating

Discomfort Rating (Borg CR-10) fell by 44–50% in all four (4) tasks after optimization, as shown in Table 5; with the largest relative reductions recorded for the knapsack sprayer and cassava frying/garri station, which had 50.0% each.

Table 5. Overall Discomfort Rating (Borg CR-10 scale, 0–10) before and after ergonomic optimization

Machine/Task	ODR Before	ODR After	% Reduction
Traditional hoe (baseline)	7.1	4.0	43.7
Groundnut harvester	6.6	3.4	48.5
Knapsack sprayer	6.2	3.1	50.0
Cassava frying/ garri station	7.6	3.8	50.0

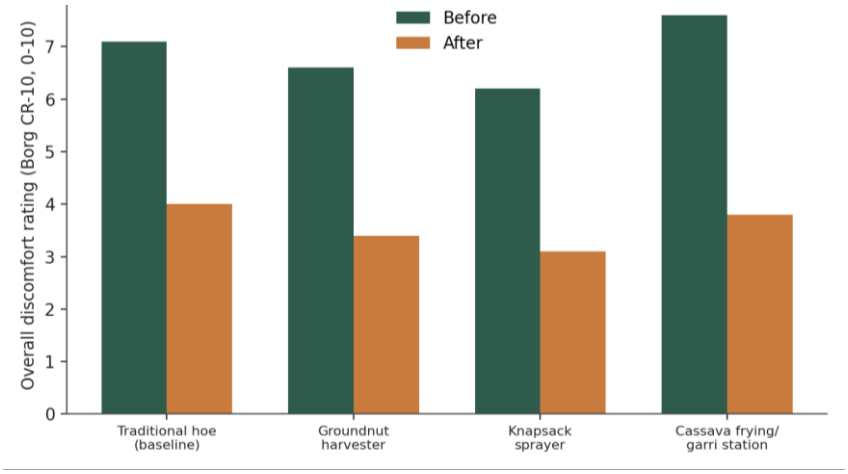

Figure 4. Overall Discomfort Rating (ODR) of women operators before and after ergonomic optimization of machine/tool interfaces.

CONCLUSION AND RECOMMENDATIONS

This study characterized the anthropometric profile of 150 women farm operators in south-western Nigeria, quantified the ergonomic mismatch between four commonly used farm implements and this profile, and demonstrated that dimensional optimization of the machine-operator interface which include handle height and grip diameter, working height, strap span, and carried load. It was observed that there were statistically significant reductions in both observed postural risk (RULA and REBA). Self-reported musculoskeletal discomfort (NMQ and ODR). Mean REBA scores fell from the high-risk to the medium-risk band across all four implements, and twelve-month discomfort prevalence fell across everybody region assessed, most substantially in the lower back, shoulders, and wrists/hands.

The study therefore recommends that: (i) agricultural machinery for women operators in Nigeria should be dimensioned to capture their anthropometric data, (ii) working height at fixed processing stations should be set at standing elbow height for the target user population, (iii) carried loads on backpack-type equipment such as knapsack sprayers be limited to within the safe-carry range.

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