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Original Article

Ergonomic design of fertilizer application equipment to enhance the health and safety of Thai coffee farmers

Rakpongsiri K[1], Lau AC[2], Duangkaew R[1]

[1]Department of Physical Therapy, Faculty of Allied Health Science, Thammasat University (Rangsit campus), Pathumtani, Thailand. [2]Department of Medical Engineering, Faculty of Engineering, Thammasat University (Rangsit Campus), PathumThani 12120, Thailand.

Corresponding author:
Kedsara Rakpongsiri,
Lecturer, Department of Physical Therapy, Faculty of Allied Health Science, Thammasat University (Rangsit campus), Pathumtani, Thailand.
E-mail: kesara.r@allied.tu.ac.th
Tel.: +660298692139
ORCID ID: https://orcid.org/0009-0004-3122-8208

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ABSTRACT

Introduction: Thai coffee farmers are prone to musculoskeletal disorders (MSDs) due to repetitive tasks, heavy lifting, and awkward postures. This study evaluated the impact of prototype fertilizing equipment on reducing ergonomic risks among farmers.

Methods: A quasi-experimental pre–post study assessed ergonomic risks in six body regions using the Rapid Entire Body Assessment (REBA) method. Data were collected during actual fertilizer application, both before and after one month of equipment use. The "worst" postures were captured via photos and videos over the course of this one month. Basic demographic information was recorded for 30 purposively selected coffee farmers aged 25–50 years in Ban Nam Ki, Nan Province.

Results: The results revealed a significant reduction in ergonomic risks, with total REBA scores dropping from 8.83 (SD = 1.14) before equipment use to 3.63 (SD = 0.47) after use ($p < 0.001$). Significant improvements occurred in the neck, trunk, legs, and upper arms (all $p < 0.001$), while the lower arm showed little change and the wrist slightly worsened. These changes may relate to equipment design or specific tasks. Overall, the proportion of high-risk postures decreased to 13.3% from 86.7% of low-risk postures, indicating substantial ergonomic safety gains.

Conclusion: The prototype fertilizing equipment proved effective in reducing overall ergonomic risks, as evidenced by improvements in REBA scores and a more even distribution of risk levels. Although wrist strain increased slightly, the overall reduction in risk highlights the positive impact on farmer health and safety. Future improvements to equipment design should focus on addressing wrist strain to further enhance ergonomic benefits.

Keywords: Coffee farming, ergonomics, fertilizing equipment, innovation, REBA, safety

Introduction

Coffee farmers in Thailand are particularly vulnerable to musculoskeletal disorders (MSDs), a significant long-term health concern, due to the physically demanding nature of their work.[1,2] Tasks such as pruning, harvesting, and fertilizing often require farmers to maintain awkward postures, perform repetitive motions, and lift heavy loads. These activities can lead to muscle pain, chronic conditions, and, in severe cases, disability. Poor health resulting from these strains can negatively impact productivity, making it harder for coffee growers to sustain their work.[1,2]

The global demand for coffee continues to rise, driven by a growing interest in high-quality, specialty coffee. Thailand is increasingly recognized as a significant player in this market. As coffee cultivation expands, it places additional strain on farmers who already face physical challenges, emphasizing the need for improvements in farming practices and equipment.[3] Thailand's coffee industry, particularly in northern regions such as Chiang, Chiang Rai and Nan, is seeing increased investment and export potential, with coffee becoming a key agricultural product contributing to the country's economy. As coffee production scales up to meet the demands of the global market, farmers are under more pressure to maintain high levels of productivity while managing the physical toll of their work. Given this expanding industry, addressing farmers' physical health is critical not only for individual well-being but also for the long-term sustainability of the coffee sector. The increased reliance on manual labor in coffee farming highlights the urgent need for ergonomic solutions that can reduce strain, prevent injuries, and improve overall work efficiency. Ergonomic interventions can help mitigate the risks associated with tasks such as fertilizing, which remains one of the most physically demanding activities on the farm.[4,5,6,7] Among these tasks, fertilizer application stands out as one of the most physically taxing, often performed manually without specialized tools. The lifting of heavy fertilizer sacks and the repetitive motion of spreading fertilizer pellets exacerbate the risk of injury. (Figure1)

Figure 1: Coffee farmers manually apply fertilizer by carrying and spreading pellets, a labor-intensive process.

Therefore, the engineering design of fertilizer application equipment incorporating ergonomic knowledge is crucial for reducing physical strain, safeguarding the health of Thai coffee farmers, and ultimately enhancing productivity. The developed fertilizer application tool was tested with coffee farmers in northern Thailand. The tool's effectiveness in improving ergonomics was assessed using the Rapid Entire Body Assessment (REBA) method, a well-established ergonomic assessment tool.[8,9] REBA helps identify and mitigate MSD risks by evaluating factors such as body posture, force exertion, and the interaction between the worker and equipment.[10,11] This study highlights improvements in new fertilizer application equipment that integrate ergonomic principles, compared with manual application methods, providing a healthier approach for Thai coffee farmers.

Methods

A quasi-experimental pre–post design was used to evaluate an ergonomically designed fertilizer applicator intended to reduce strain associated with manual methods.[12] The prototype weighed 11 kilograms and could carry up to 20 kilograms of fertilizer for males and 14 kilograms for females, remaining within legal limits.[13] By enabling fertilizer to be carried on the back and dispensed automatically, the device reduced bending and twisting, as shown in Figure 2. Ergonomic risk was assessed using the Rapid Entire Body Assessment (REBA), a validated tool for estimating the risk of musculoskeletal disorders. The study took place in the Ban Nam Ki community, Nan Province, northern Thailand, during the 2023 agricultural season. Ethical approval was granted by the Human Research Ethics Committee of Thammasat University (COA No. 095/2566), and written informed consent was obtained from all participants. Eligible farmers were aged 25–50 years with at least one year of experience, while those with musculoskeletal disorders, chronic illness, major surgery, or conditions impairing function were excluded. Thirty participants who met these criteria were recruited, providing a feasible sample for paired

comparisons. Data were analyzed using IBM SPSS Statistics version 29.0, with descriptive statistics applied and paired t-tests performed to compare REBA scores. Statistical significance was set at $p < 0.05$, with 95% confidence intervals calculated.

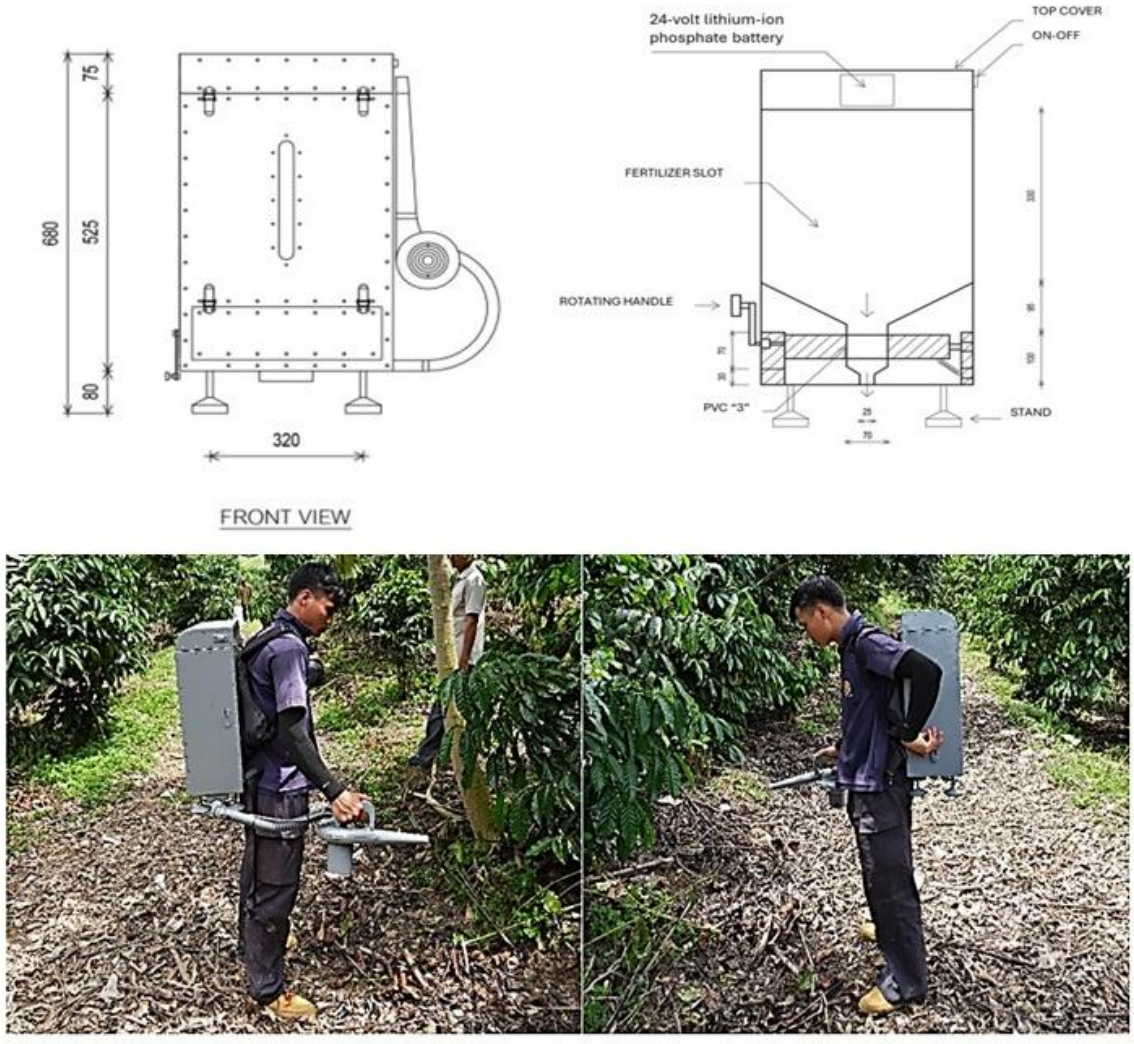

Figure 2: An ergonomic fertilizer applicator prototype simplifies application and reduces farmer strain, proven in field tests

The REBA assessment was followed by the procedure below.

1. Observe the worker performing the job task and identify the "worst" or most demanding postures. Capture these postures using photos or videos.

2. Assess the position of the worker's body segments, including the neck, trunk, legs, upper arms, lower arms, and wrists. Use the REBA scoring tables to assign a score to each body region.

3. Consider additional factors such as force exerted, load/weight handling, and activity type, and add the corresponding scores.

4. Calculate the final REBA score by summing the scores for each body region and the scores for the additional factors. The REBA score ranges from 1 to 15, with higher scores indicating a higher risk of MSDs.

Use the REBA action level guidelines to determine the urgency of implementing ergonomic improvements.

The REBA assessment worksheet (Figure 3) assesses the position of the neck, trunk, legs,

arms, and wrist. REBA divides the body into two sections: Section A (analysis of the neck, trunk, and legs) and Section B (analysis of the arms and wrists). The assessment process involved selecting the posture to assess, typically the most demanding or "worst" posture. Subsequently, each body section was evaluated by assigning scores based on the position and movement of each body part using the provided scoring tables. Furthermore, the assessment considers force/load by adding points based on the amount of force exerted and the weight handled. It also evaluates coupling by adding points based on the interaction between the worker and the task or equipment. Finally, the assessment considers work movements and activities by adding points based on the type and frequency of movements and activities. The final REBA score was calculated by combining the scores for each body part, force/load, coupling, and work movements and activities. As assessed by the Rapid Entire Body Assessment (REBA), the final scores (Table 1) indicate the level of ergonomic risk, ranging from very low (1) to very high (11+), with scores of 8 or higher denoting high risk and necessitating immediate corrective actions.

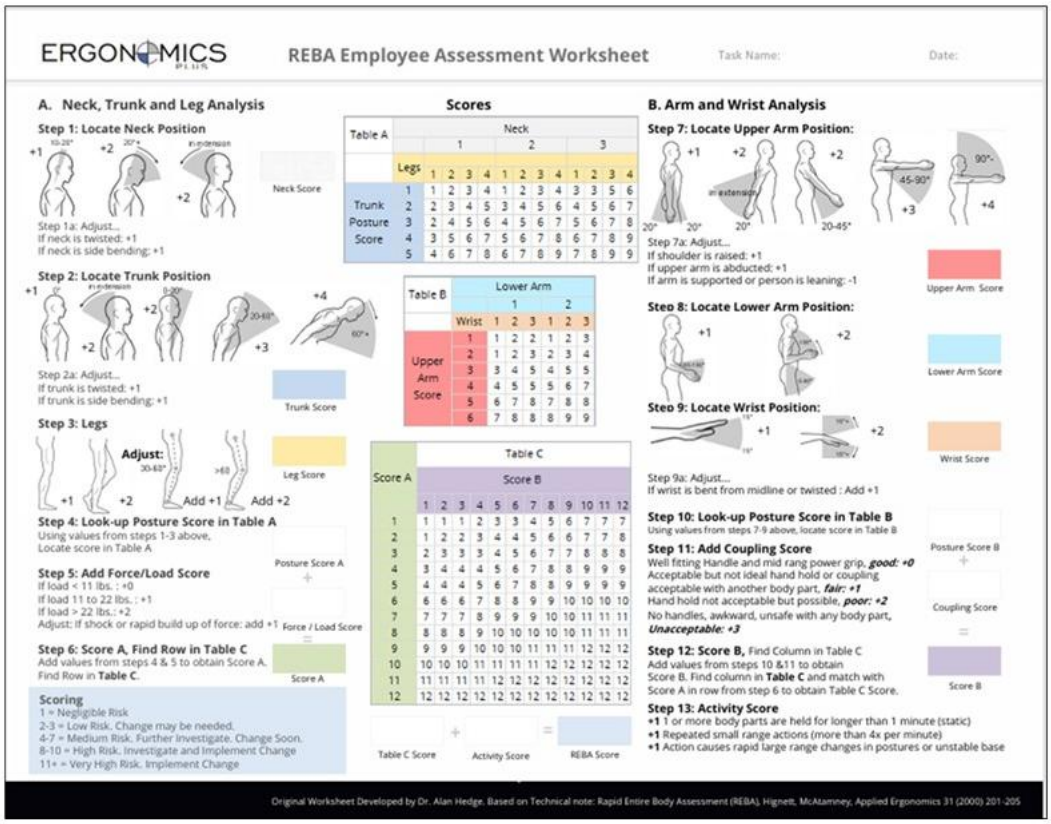

Figure 3: REBA assessment worksheet

Table 1: The Final REBA Scores

REBA Score	Ergonomic Risk Level
> 11	The risk is very high and must be improved immediately.
8 – 10	The risk is high and should be analyzed further and improved immediately.
4 -7	The risk is moderate and should be further analyzed and improved.
2 - 3	The risk is low and still needs to be improved.
1	The risk is very low.

Results

The results of the REBA risk evaluation (Table 2) compared ergonomic risks before and after the use of the fertilizer applicator among 30 farmers, demonstrating significant improvements across several body regions following one month of equipment use.

The mean score for neck related risk decreased from 2.06 (SD = 0.44) before using the equipment to 1.10 (SD = 0.30) after use, indicating a reduction in risk with a t-value of 9.52 and a highly significant p-value of <0.001, suggesting a meaningful decrease in neck strain.

The mean score for trunk-related risk decreased from 3.67 (SD = 0.60) to 2.00 (SD = 0.26), with a t-value of 12.04 and a p-value of <0.001. This substantial reduction suggests that the equipment significantly reduces the ergonomic risk for the trunk.

The risk for the legs dropped from 1.98 (SD = 0.82) to 1.03 (SD = 0.18), with a t-value of 6.16 and p-value <0.001. This indicates a significant improvement in leg posture and strain after using the equipment.

The mean risk for the upper arm went from 2.40 (SD = 0.38) to 1.50 (SD = 0.13), with a t-value of 11.64 and a p-value <0.001, showing significant improvement in upper arm posture.

The mean score for the lower arm remained almost unchanged, with a slight decrease from 1.76 (SD = 0.31) to 1.70 (SD = 0.24). The t-value of 0.85 and p-value of 0.403 suggest no significant change for the lower arm.

The wrist risk score increased from 1.31 (SD = 0.42) to 1.78 (SD = 0.31), with a t-value of -4.87 and p-value <0.001, indicating a slight increase in wrist strain after using the equipment.

The total ergonomics risk score drastically decreased from 8.83 (SD = 1.14) to 3.63 (SD = 0.47), with a t-value of 22.54 and a p-value of <0.001, indicating an overall reduction in ergonomic risk.

The use of fertilizer assistance equipment led to significant improvements in reducing ergonomic risk for the neck, trunk, legs, and upper arms, except the lower arm and wrist. However, the total risk score demonstrates that the equipment effectively lowers the overall ergonomic risk for farmers.

Table 2: Ergonomics risk assessment before and after using fertilizer assistance equipment (n=30 farmers) for one month.

Risk assessment using the REBA method	Before use		After use		t	Mean Diff.	p-value (95% CI)
	$\bar{x}$	S.D.	$\bar{x}$	S.D.			
Neck	2.06	0.44	1.10	0.30	9.52	0.97	<0.001* (0.75-1.17)
Trunk	3.67	0.60	2.00	0.26	12.04	1.67	<0.001* (1.38-1.94)
Legs	1.98	0.82	1.03	0.18	6.16	0.84	<0.001* (0.63-1.26)
Upper arm	2.40	0.38	1.50	0.13	11.64	0.90	<0.001* (0.74-1.05)
Lower arm	1.76	0.31	1.70	0.24	0.85	0.68	0.403 (-0.09-0.23)
Wrist	1.31	0.42	1.78	0.31	-4.87	0.46	<0.001* (0.66-0.27)
Total Score	**8.83**	**1.14**	**3.63**	**0.47**	**22.54**	**5.20**	**<0.001* (4.72-5.67)**

* At the significance level of 0.05

Table 3: Results of the ergonomics risk assessment before and after using the prototype fertilizing equipment (n=30 farmers)

Risk level	Score	Before	After
		Number	Number
The risk is very high and must be improved immediately.	>11	1 (3.3%)	0 (0.0%)
The risk is high and should be analyzed further and improved immediately.	8-10	26 (86.7%)	0 (0.0%)
The risk is moderate and should be further analyzed and improved.	4-7	3 (10.0%)	4 (13.3%)
The risk is low, but improvements still need to be made.	2-3	0 (0.0%)	26 (86.7%)
The risk is minimal.	1	0 (0.0%)	0 (0/0%)

The distribution of risk levels before and after using the prototype fertilizing equipment. The categories include very high, high, moderate, low, and minimal risk, based on the total REBA score (Table 3). Before Equipment Use, one farmer (3.3%) was at very high risk. The majority of farmers (26, 86.7%) were at high risk (8-10). Three farmers (10%) were at moderate risk. No farmers were at low or very low risk (1). After Equipment Use: No farmers were at very high risk. No farmers were at high risk. Four farmers (13.3%) were at moderate risk. Most farmers 26 (86.7%) were at low risk. No farmers were at a very low risk. Equipment use significantly reduced farmer risk, eliminating high and very high-risk categories and shifting the majority into the low-risk category.

Discussion

The findings of this study provide important insights into the ergonomic benefits of the prototype fertilizing equipment for Thai coffee farmers. The substantial reduction in ergonomic risk, especially in the neck, trunk, legs, and upper arms, demonstrates the effectiveness of the tool in alleviating physical strain associated with manual fertilizer application. The REBA assessment scores clearly indicate that the equipment significantly reduced the risk of musculoskeletal disorders (MSDs) for farmers in these areas, highlighting the positive impact on their overall health and safety.[8] The dramatic drop in the total risk score from 8.83 to 3.63 further substantiates the equipment's role in improving ergonomic conditions.

However, the study also reveals that some areas of the body, particularly the lower arm and wrist, did not benefit as much from the equipment design. The minimal reduction in the lower arm's risk and the slight increase in wrist strain suggest that these areas might require further design improvements. One possible reason for the rise in wrist discomfort could be the equipment's handling mechanism or the repetitive nature of the wrist movements required during fertilizer application.[14] Addressing this issue in future designs will be crucial for ensuring that the tool provides comprehensive ergonomic benefits. The shift in the risk level distribution is another significant outcome of the study. Before using the equipment, a large proportion of farmers were categorized in the high-risk group, indicating the severity of ergonomic concerns. Post-use, however, most farmers were reclassified into the low-risk category, showcasing the effectiveness of the equipment in reducing overall physical strain.[15] This change is a clear indication that the ergonomic intervention not only improves farmers' health but also has the potential to enhance their productivity and long-term work sustainability.[16]

Given that coffee farming in northern Thailand is physically demanding, especially tasks like fertilizing, the importance of ergonomic equipment cannot be overstated. The positive results from this study suggest that integrating ergonomic principles into the design of farming equipment can lead to substantial improvements in the health and safety of farmers. As coffee farming continues to grow in Thailand, ensuring that workers have access to tools that reduce

physical strain will be essential in supporting both the health of individual farmers and the broader sustainability of the coffee industry.[17] Furthermore, the study underscores the need for continuous monitoring and iteration in the design process. While the prototype was successful in reducing the risks in many body areas, future equipment modifications should focus on improving wrist ergonomics to avoid the slight increase in strain observed.[18] This iterative approach, informed by feedback and further studies, will allow for the development of even more effective tools in the future. The positive effects observed in this study may encourage further exploration into integrating ergonomic equipment into other physically demanding agricultural tasks. Moreover, the use of REBA as a standardized method for assessing ergonomic risks provides a reliable framework that can be adapted for other farming activities, ensuring that ergonomic concerns are addressed systematically.[19-21]

Conclusion

This study highlights the significant benefits of ergonomic farming equipment in improving the health, safety, and productivity of Thai coffee farmers. The prototype fertilizing equipment demonstrated significant effectiveness in reducing ergonomic risks for farmers, as evidenced by improvements in REBA scores and the distribution of risk levels. While there was an increase in wrist strain, the overall reduction in risk highlights the positive impact of the equipment on farmer health and safety. Future improvements in the equipment design could further address issues related to wrist strain and ensure even greater ergonomic benefits.

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